Interference effects in short-term memory for timbre

Gary E. Starr3) and Mark A. Pitt
Ohio State University, Columbus, Ohio 43210

(Received 3 May 1996; accepted for publication 13 March 1997)

Four experiments investigated memory for timbre using the interpolated-tone paradigm [Deutsch, Science 168, 1604–1605 (1970)], in which participants discriminate pairs of tones (standard and comparison) separated by intervening (interpolated) tones. Interpolated tones varied from the standard tone in spectral similarity (within-dimensional variation), fundamental frequency (cross-dimensional variation), and repetition frequency. While the latter two variables had negligible effects on timbre memory, interference with timbre memory increased with the spectral similarity of the interpolated tones to the standard tone. The findings closely parallel those found for pitch memory, and suggest that memory interference depends on perceptual similarity in both cases. © 1997 Acoustical Society of America. [S0001-4966(97)02507-1]

PACS numbers: 43.66.Jh, 43.66.Hg [JWH]

INTRODUCTION

An aim of research in auditory information processing is to understand how sound objects (e.g., speech, car horns, piano tones) are perceived and remembered. One experimental approach to investigating this issue has been to study how listeners perceive, both individually and in combinations, the auditory dimensions that make up sounds, such as pitch, timbre, and loudness (Melara and Marks, 1990a, 1990b; Pitt and Crowder, 1992). This paper continues in this tradition, focusing on memory for timbre and pitch.

Research on memory for pitch and timbre has examined whether memory for one dimension is affected by the other and how memory representations change over time (Krumhansl and Iverson, 1992; Melara and Marks, 1990a, 1990b; Pitt and Crowder, 1992). For example, Crowder (1989) had participants make speeded same/different pitch judgments to two tones separated by 500 ms. The judgments were faster and more accurate when the tones were played on the same instrument (i.e., had the same timbre) than when played on different instruments, suggesting timbre variation interfered with the memory for pitch. Melara and Marks (1990a, 1990b; Krumhansl and Iverson, 1992; Pitt, 1994) replicated and extended this cross-dimensional interference effect using a speeded classification paradigm (Garner, 1974). They also found the reverse effect: Pitch variation disrupted memory for timbre.

Cross-dimensional interference disappears, however, when memory for the standard tone is probed later in time. Using a same/different discrimination task, Deutsch (1970, 1982 for a review) and Semal and Demany (1991, 1993) obtained this result in experiments designed to elucidate the characteristics of pitch memory. A condition in which a five-second silent interval separated the standard and comparison tones provided a baseline measure of discrimination. Of interest was discrimination in other conditions, in which six tones were presented during the 5-s interval. These interpolated tones varied in pitch and timbre similarity to the standard tone.

For example, Semal and Demany (1991, experiment 1) had listeners discriminate the pitch of sine waves while interpolated tones were either close or far from the standard tone in pitch, timbre, or both dimensions. Timbre was varied by changing the harmonic complexity of the tones. Interpolated tones close in timbre were also sine waves, while tones far in timbre consisted of the first eight harmonics of a tone. Pitch was manipulated by varying the frequency range within which the interpolated tones could be selected. Interpolated tones close in pitch varied by no more than two semitones; tones far in pitch were at least two octaves different from the standard.

The primary finding was that pitch memory was disrupted by variation in the pitch of the interpolated tones (i.e., same-dimension interference), but not variation in timbre (cross-dimension interference). Relative to the baseline, discrimination was disrupted twice as much by interpolated tones close in pitch than tones far in pitch (error rates were 39% and 19%, respectively). Memory interference changed little when timbre varied, with error rates in the close and far timbre conditions not being reliably different (26% and 33%, respectively). Semal and Demany (1993) replicated this minimal effect of cross-dimensional interference in pitch memory with the dimension of loudness.

What emerges from these studies is that the representations of pitch and timbre are susceptible to cross-dimensional information when first encoded. Within 5 s cross-dimensional influences diminish to the point where intradimensional similarity is the primary source of interference. It appears as though dimensional representations solidify with time and, in so doing, lose their susceptibility to interference from other dimensions.

The latter claim is based primarily on evidence from pitch memory research. If these findings are indicative of general principles of auditory memory, then similar results should be found with other dimensions of sound. The purpose of the present study was to test this proposal by investigating short-term memory for timbre. We used the same
interpolated-tone paradigm as previous research (Deutsch, 1970, 1972, 1973). Participants discriminated tones that differed in timbre, and interpolated sequences varied in pitch and timbre similarity to the standard tone.

If timbre memory is similar to pitch memory, more interference should be found when the timbres of the interpolated tones are similar to the timbre of the standard tone than when they are not. Also, changes in the pitch of the interpolated tones should not interfere with timbre memory. Such an outcome would indicate that timbre is represented independently of pitch.

I. EXPERIMENT 1: TIMBRE INFLUENCES ON TIMBRE MEMORY

The aim of the first experiment was to determine if timbre similarity affects short-term memory for timbre. Four testing conditions were created. In the baseline condition, 5 s of silence occurred between the standard and comparison tones. In the three interpolated conditions, tones varying in timbre distance from the standard tone were presented during the 5-s retention interval. The only difference between the interpolated tones in the three conditions was the timbre distance of the tones to the standard tone.

A second aim of experiment 1 was to determine if musical training interacts with similarity effects in timbre memory. Past work on memory for timbre and pitch (Beal, 1985; Pechmann and Mohr, 1990; Pitt, 1994) found that musically untrained listeners show larger interference effects than trained listeners. Similar differences could be found with the current paradigm. This idea was explored by running the experiment with two groups of listeners. Untrained listeners were expected to show poorer discrimination in the interpolated conditions than the trained listeners.

A. Method

1. Participants

Thirty untrained listeners, with an average of 4 months playing a musical instrument, were recruited from the introductory psychology pool at Ohio State University. Twenty-five musicians were recruited from the same population; training on their primary instrument averaged 8 years. All participants reported normal hearing.

Discrimination accuracy in the baseline condition had to be at least 88% correct for a participant’s data to be included in the analysis. The criterion was set a priori and in keeping with past work (Deutsch, 1970; Semal and Demany, 1991, 1993). This inclusion criterion was used because the aim of the project was to assess how interpolated tones disrupt memory. If participants cannot discriminate timbre in the absence of interpolated tones, the cause of poor and similar discrimination across conditions is difficult to interpret (see also footnote 1).

Fifteen nonmusicians and eleven musicians passed the inclusion criterion. While this qualification rate (47%) may seem low, it is higher than that reported by Semal and Demany (1991, 38% in experiment 1) using the same paradigm.

2. Materials and apparatus

Timbre was manipulated by making incremental changes in the harmonic composition of a tone (i.e., spectral envelope). The complex tones comprised three immediately adjacent, equal-amplitude harmonics and their common fundamental frequency (f1). The fundamental frequency is the lowest perceived frequency component in a tone, and was always present in the eight timbres. Variation occurred only in the three contiguous harmonics, which moved as a group one harmonic step at a time farther in frequency from the fundamental (e.g., timbre 1 = f1 + f2 + f3 + f4; timbre 2 = f1 + f3 + f4 + f5, etc.). A total of eight timbres were digitally synthesized (using in-house software) in this manner, and are depicted in Fig. 1. These timbres sounded hollow, with perceived “sharpness” increasing from timbre 1 to timbre 8.

Timbre was varied using this method because the acoustics could be precisely and easily controlled while at the same time we were able to achieve a sufficiently wide range of variation in timbre. In addition, the procedure has been used successfully in related work (Semal and Demany, 1991; Singh, 1987). Although it is of minimal relevance to the question of immediate interest (timbre memory), one minor
drawback of using this method was that it does not permit conclusions to be drawn about which aspect of spectral envelope was responsible for any observed effects of timbre variation on timbre memory. This is because two acoustic characteristics of spectral envelope, centroid (average) frequency and frequency bandwidth, covaried across the timbres, being the smallest for timbre 1 and largest for timbre 8. Because the covariation does not compromise conclusions drawn about the question of interest (timbre memory), we felt the benefits of using the method outweighed the minor cost.

The eight timbres were synthesized at 37 fundamental frequencies (A2–A5, 110–880 Hz, in semitone steps), producing a pool of 296 tones. The duration of all tones was 300 ms, with onset and offset rise/fall times of 5 ms. All tones were judged to be of equal loudness by the first author and two listeners trained in psychoacoustic experimentation, and digitized onto computer hard-disk at the sampling rate of 10 kHz (low-pass filtered at 4.8 kHz) with a precision of 12 bits.

Stimulus presentation and response collection were controlled by a microcomputer. Participants sat in individual sound-attenuated booths and listened to stimuli through AKG K240 studio headphones (binaural presentation) at a comfortable listening level. A white-on-black computer monitor was located 24 in. in front of each participant.

**a. Timbre similarity rating experiment.** A rating experiment was conducted to validate our intuition that the eight timbres varying in spectral envelope were sufficiently discriminable for the purposes of our experiment. This experiment was a necessary precondition for proceeding with Experiment 1. Ten listeners were presented a pair of tones, separated from each other by 500 ms, and then rated the similarity of their timbres on a seven-point scale (1 = most similar; 7 = least similar). All possible pairs were presented 2–3 times in a single randomized list. Results showed that timbres were rated as more different as spectral similarity decreased. Similarity ratings correlated strongly with the number of steps between timbres ($r = -0.64$, $p < 0.001$). The mean similarity rating was 1.1 when timbres differed by one step, 2.1 when they differed by three steps, and 3.5 when they differed by six steps. Thus, these stimuli satisfy the timbre-similarity requirements of the experiment.

3. **Experimental conditions and design**

The baseline condition, in which there was 5 s of silence between standard and comparison tones, was always run first to assess participants’ ability to discriminate timbre. Three interpolated tone conditions were created that spanned most of the range of spectral variation in the preceding similarity rating experiment. In each, a single timbre was presented six times.

In the one-step condition, the interpolated timbre was one timbral step from the standard tone. In the four-step and six-step conditions, the interpolated timbre differed from the standard tone by four and six steps, respectively. Discrimination was expected to improve with increasing timbre distance between the standard and interpolated tones.

The fundamental frequencies of the standard and comparison tones were either 311 or 349 Hz, but always remained constant in a trial. In “same” trials, the identical stimulus was presented as standard and comparison. In “different” trials, the standard and comparison tones differed from each other by three timbre steps (e.g., standard = timbre 2, comparison = timbre 5, see Fig. 1).

There were 24 same and 24 different trials in each condition. Four of the timbres (timbres 2, 3, 7, and 8) were used as the standard tone in the one-step and four-step conditions (half of the time at each frequency). Because the set of timbres was limited to seven, only timbres 2 and 8 could serve as standard tones in the six-step condition, reducing the set of possible standard and interpolated tone pairings by half. It is unlikely that this imbalance across conditions might affect discrimination because trial presentation was randomized (not blocked, see below) across interpolated conditions. Moreover, this problem was corrected in subsequent experiments, and the pattern of data did not change.

In “different” trials, direction of movement along the timbre continuum was counterbalanced across trials, with as many upward progressions (e.g., standard = timbre 2, comparison = timbre 5) as downward progressions (e.g., standard = timbre 5, comparison = timbre 2). The standard and comparison tones did not vary from each other in pitch. Because the set of timbres was limited to seven, there were only two possible standard/comparison pairs (timbres 2 and 5, and 8 and 5, respectively) in the six-step condition. Again, this imbalance was corrected in subsequent experiments.

4. **Procedure**

The experiment had two phases. In phase one (baseline condition), participants, who were tested in groups of four or fewer, were told that they would hear two tones separated by 5 s of silence, and were to determine if the tones were the same or different. They were to make a “same” response if the two tones were identical, and a “different” response if there was any difference between the tones. Responses were collected using two buttons on a four-button response board, one labeled “same,” the other labeled “different.” Participants used the left index finger to press the “same” button, the right index finger to press the “different” button. Feedback on the accuracy of responses was not provided.

Each trial started with the word “READY” printed on the computer screen in front of each listener. The phrase “are the TONES the same or different” was then printed on the screen, and 500 ms later the first tone was played. Five seconds later the second tone was presented, at which time participants responded. The next trial began once a response was collected or 3 s had elapsed. Prior to the baseline session, participants were given 12 practice baseline trials. All trials of the baseline condition were presented in a randomized list. The baseline session lasted approximately 10 min.

Phase two (interpolated conditions) was the same as phase one with the following exceptions. Participants were told that the 5-s interval would be filled with a sequence of tones. They were explicitly instructed to ignore the interpolated tones. Three hundred milliseconds of silence separated the standard tone from the first interpolated tone and the six interpolated tones from each other. There were 1400 ms of silence between the last interpolated tone and the comparison
tone. This extended silent interval demarcated the interpolated sequence from the comparison tone. After the last interpolated tone, the phrase “get ready to respond” was printed on the screen to alert participants that the comparison tone was about to be presented. The comparison tone was then played and participants had to respond. All interpolated trials were presented in a randomized list. Two short breaks were provided. Phase two lasted approximately 35 min.

B. Results and discussion

Figure 2 shows the mean proportion correct for the four conditions. The clear bars show results for the musically trained group and the shaded bars show results for the untrained group. Error bars represent the standard error of the mean.

As can be seen in the graph, accuracy was nearly identical for musicians and nonmusicians across all conditions. The largest difference between means was in the one-step condition (2%). No statistical comparisons between musicians and nonmusicians approached significance.

For both groups, accuracy steadily increased as timbre distance between the standard and repeating interpolated tones increased. An interpolated timbre that was one step removed from the standard tone resulted in a 13% drop in accuracy from the baseline. This drop was reduced to 7% in the four-step condition, and interference disappeared completely in the six-step condition.5

Based on the lack of difference between musically trained and untrained listeners, data in each of the four conditions were averaged across groups and submitted to a one-way analysis of variance, which yielded a reliable main effect \( F(3,75) = 31.6, p < 0.001 \). Paired comparisons revealed that all differences between conditions, with the exception of the baseline condition and the six-step condition, were statistically reliable \( (p < 0.05) \).

The pattern of results is strikingly similar to that found with pitch (Semal Demany, 1991; see Deutsch, 1986 for similar results with tone duration). With respect to same-dimension interference, memory for both dimensions appears to be similar.

II. EXPERIMENT 2: CROSS-DIMENSIONAL INTERFERENCE IN TIMBRE MEMORY

Having demonstrated a timbre similarity effect, we turned to the question of cross-dimensional (i.e., pitch) interference in timbre memory. In experiment 1 pitch distance was held constant. In experiment 2, timbre distance and pitch distance were varied across six interpolated conditions. There were three pitch distances: same, close, and far. At each pitch distance there were two timbre distances: one-step and five-step. A timbre similarity effect should be found at each of the three pitch distances, with discrimination better in the five-step than one-step conditions.

How discrimination changes across pitch distance will reveal the nature of pitch influences. If timbre memory is affected more by tones similar in pitch, than accuracy should be lower in the close pitch conditions than the far pitch conditions. Whether it is uniformly lower at the two timbre distances will depend on whether timbre and pitch interference interact.

On the other hand, similar timbre discrimination across pitch distances would suggest timbre memory is not disrupted by pitch information.

A. Method

1. Participants

Twenty-four participants, unselected as to musical experience, were recruited from the same population as in experiment 1. Sixteen scored above the inclusion criterion. Participants had an average of 1.6 years of training on a single musical instrument. None had participated in the previous experiment.

2. Materials and design

The experiment was identical to experiment 1 in all respects except for the experimental design. In addition to the baseline condition, there were six interpolated conditions, which were created by crossing two levels of timbre distance (one-step and five-step) with three levels of pitch distance (same, close, and far). A five-step timbre distance was used so that the same four tones could serve as a standard in all conditions, rectifying the inconsistency across timbre distances in experiment 1. In the same-pitch conditions, pitch remained constant across all tones. In the close-pitch conditions, pitches of the interpolated tones were one semitone above or below the pitch of the standard tone. In the far-pitch condition, pitches of the interpolated tones were one octave plus one semitone above or below the pitch of the standard. As in experiment 1, the pitch and timbre of the interpolated tones remained constant within a trial.

B. Results and discussion

The results are shown in Fig. 3. Discrimination in the interpolated conditions dropped by an average of 16% from baseline \( F(6,90) = 15.0, p < 0.001 \). A two-way ANOVA with pitch distance and timbre distance as variables yielded a main effect of timbre distance \( F(1,15) = 16.35, p < 0.001 \), a main effect of pitch distance \( F(2,30) = 4.91, p < 0.05 \), and no significant interaction \( F(2,30) = 0.52, p < 0.56 \).
Post hoc analyses indicated that at each pitch distance, discrimination in the one-step condition was significantly lower than in the five-step condition. Additionally, accuracy in the same-pitch condition was significantly higher than in the close-pitch condition. The close-pitch and far-pitch conditions did not differ reliably, nor did the same-pitch and far-pitch conditions.

The timbre similarity effect found in experiment 1 was replicated here, regardless of pitch distance. That there was a significant difference in accuracy between the five-step condition and the baseline condition, when one was not found between the six-step and baseline conditions of experiment 1, is not surprising. The five-step timbres are slightly closer perceptually than six-step timbres. If interference increases as perceptual similarity increases, then accuracy should be lower in the five-step condition compared to the six-step condition. However, based on this explanation, accuracy should have been lower in the four-step condition of experiment 1 than in the five-step condition of the present experiment, which was not the case. At present we have no explanation for this outcome and believe it is due to sampling variability.

Pitch interference effects were minimal overall, and they differed minimally as a function of timbre distance. In the five-step conditions, the effects of pitch distance were nonexistent, with accuracy being virtually identical in the close-pitch and far-pitch conditions. In the one-step conditions, there was a weak effect of pitch distance, with accuracy being 4% higher in the far-pitch than the close-pitch condition, but this difference did not approach significance \( F(1,188) = 4.56, p = 0.03 \), suggesting that the results of experiment 1 and 2 do not reflect memory for pitch (i.e., fundamental frequency).

The aim of the final two experiments was to elucidate further the cause of interference in memory for timbre. The experiments focused on two variables in the interpolated sequence. Experiment 3 examined whether a single interpolated tone produces similar amounts of disruption as six presentations of that tone. Experiment 4 explored whether a single change in timbre within the interpolated sequence causes additional memory disruption.

III. EXPERIMENT 3: ADDITIVE TIMBRE INTERFERENCE EFFECTS

One question raised by the results of experiments 1 and 2 is whether there are additive interference effects from presenting the interpolated timbre six times, or whether a single presentation of that tone is sufficient to produce the demonstrated similarity effect. One study that did manipulate the number of interpolated tones found small additive effects (Massaro, 1970). In his experiment 1, participants discriminated pitches when there were one or two interpolated tones. Accuracy was 4% higher when a single interpolated tone was presented instead of two.

The purpose of experiment 3 was to determine if additive interference effects could be found for timbre memory. The experimental design was identical to experiment 1 except that a single interpolated tone was presented between the standard and comparison tones.

A. Method

1. Participants

Twenty-eight participants were recruited from the same population as experiment 1. Twenty-one scored above the inclusion criterion. None participated in the previous experiments. Musical training averaged 1.21 years.

2. Experimental design

The single interpolated tone occurred at the same time in a trial as the first interpolated tone in experiment 1. There was a 4300 ms ISI between the interpolated tone and the comparison tone.
B. Results and discussion

Mean accuracy is plotted in Fig. 4. A timbre similarity effect is evident in the figure. Interpolated timbres more similar to the standard produced more interference than those less similar to the standard. The effects were highly reliable in a one-way ANOVA [F(3,60) = 20.4, p < 0.0001]. All comparisons between conditions were also significant, except that between the one-step and four-step conditions.

To determine whether one interpolated tone produced the same pattern of interference as six, a 2 × 3 (Experiment × Interpolated Condition) ANOVA was performed on the data from experiments 1 and 3. The data were first normalized for variation in baseline discrimination across experiments by subtracting (for each listener) accuracy in each of the three interpolated conditions from baseline. These difference scores (small scores represent high accuracy, large scores low accuracy) were then submitted to the analysis. There was a reliable main effect of experiment [F(1,45) = 8.48, p < 0.006], with the surprising result that one interpolated tone produced more interference than six. The main effect of condition reached significance [F(2,90) = 31.46, p < 0.001], while the interaction of experiment with interpolated condition was marginally significant [F(2,90) = 3.01, p < 0.06].

One outcome that differs slightly from what was found in experiment 1 is the lack of an increase in accuracy between the one-step and four-step conditions. Comparison of the means (normalized relative to baseline performance) with their counterparts in experiment 1 revealed that accuracy in the one-step condition was slightly higher (1%, a smaller difference score) in the present experiment and accuracy in the four-step condition was 5% lower (a larger difference score). The variation could be due to the presentation of just a single interpolated tone. However, given that the variation is small and not consistent across interpolated conditions, we conclude for the time being that it is due to sampling variability.

At present, two possible explanations present themselves for why one interpolated tone produced more interference than six. First, differences in baseline discrimination across experiments may might account for why larger effects were found with one interpolated tone. Accuracy in the baseline condition of experiment 3 was 5% greater than that in experiment 1 (Figs. 2 and 4), whereas accuracy in the interpolated conditions differed minimally across conditions. The other explanation is that auditory grouping principles (Bregman, 1990) are responsible for the differences in discrimination. When an interpolated tone was presented six times, those tones might have grouped with each other, and apart from the standard tone, thereby disrupting memory for the standard tone only minimally. However, when only one interpolated tone was presented, it might have grouped with the standard tone and formed a single stream, causing more interference than when that same interpolated tone grouped with the other five interpolated tones (Bregman and Rudnicky, 1975; Jones et al., 1987).

Although multiple presentations of the same interpolated timbre yielded no additive interference effects in timbre memory, additive effects might be found if timbre itself varied during the interpolated sequence. Massaro (1970; see also Deutsch, 1974), who found additive effects in pitch memory, used interpolated tones that differed in pitch. Although the cause of the memory decrement he found could have been due to the addition of a second interpolated tone rather than to a change in pitch of the second tone, the results of the current experiment suggest the former explanation is unlikely. The final experiment tested for additive interference when the interpolated tones changed in timbre.

IV. EXPERIMENT 4: ADDITIVE INTERFERENCE DUE TO TIMBRE VARIATION

Timbre variation within the interpolated sequence was limited to a single change, which occurred in the second interpolated tone. Timbre was held constant in tones 2–6. If interpolated tones beyond the first position do not disrupt memory for the standard, then the pattern of results should be predictable from knowing only the timbre distance between the first interpolated tone and the standard. In this case, the results should mirror those in experiment 1. On the other hand, if the second interpolated tone affects memory when its timbre differs from the first, then discrimination should differ compared to the case in which the first tone is simply repeated.

How discrimination differs was also investigated. One likely possibility is that interference caused by the second tone depends on the timbre distance between it and the standard, much like disruption caused by the first interpolated tone. Memory interference should decrease as timbre distance from the standard increases. If this effect held irrespective of the timbre distance between the first interpolated tone and the standard, interference effects would be additive across interpolated tones.

A. Method

1. Participants

Participants were from the same population as in past experiments. None had participated in any of the previous experiments, and all reported normal hearing. Thirty-four of forty-three met the inclusion criterion.
2. Experimental design

The baseline condition was identical to that in experiment 1. Four interpolated conditions were created, two no-change and two change. The no-change conditions were identical to the same-pitch conditions in experiment 2. The condition names were changed from one-step and five-step to one-one and five-five to convey the manipulations more clearly. Each word in the condition name denotes the timbre distance from the standard to the first and second interpolated tones, respectively.

The one-step and five-step intervals were also used in the change conditions. In the one-five condition, the first interpolated tone was one timbre step from the standard tone (e.g., standard=timbre 1, interpolated tone=timbre 2) and the next five interpolated tones were five timbre steps from the standard (e.g., timbre 6). In the five-one condition, this ordering was reversed, with the first interpolated tone five timbre steps from the standard (e.g., standard=timbre 1, interpolated tone=timbre 6), and the remaining five interpolated tones one timbre step from the standard (e.g., timbre 2).

The baseline condition was presented first, followed by the four interpolated conditions, which were presented together in one randomized list. The experiment was identical to Experiment 1 in all other respects.

B. Results and discussion

The results are graphed in Fig. 5. The by-now familiar timbre similarity effect is evident in the baseline and no-change conditions. Accuracy dropped 15% from baseline in the one-one condition and 7% in the five-five condition. All statistical comparisons between these conditions were reliable.

If the second interpolated tone had no effect on timbre memory, then the pattern of means in the no-change conditions should also be found in the change conditions. It is not. Instead, accuracy is slightly better in the one-five than five-one conditions. When each is compared with its no-change counterpart (same first timbre), an interesting outcome emerges. Accuracy in the one-five condition improved by 5% over that in the one-one condition. Accuracy in the five-one condition decreased by 6% compared with the five-five condition. The interaction across these conditions was reliable in a two-way ANOVA \( F(1,33) = 16.99, \ p<0.001 \), with timbre distance of the first tone (one-step and five-step) and timbre distance of the second tone (one-step and five-step) serving as variables. Accuracy in the five-one and one-five conditions did not differ reliably.

One interpretation of these results is that interference in the change conditions was an average of the effects of interpolated tones 1 and 2. Note that the means in both change conditions lie half-way between the no-change means. When the one-step timbre followed the five-step timbre, more interference was obtained than when the five-step was repeated, but not as much as that found in the one-one condition. When the five-step timbre followed the one-step timbre, a partial release from interference was found. Deutsch and Feroe (1975) found a similar release from interference in memory for pitch. Discrimination accuracy increased by approximately 8% when the fourth interpolated tone shared a specific pitch relationship with the second interpolated tone.

The present results clearly show that interpolated timbres beyond the first can affect memory for the standard. The form of the influence, disruption or release from interference, depends on the within-dimension similarity relationship among the interpolated tones and the standard. Net interference over tones appears to be an average of the effects observed when the tones are presented individually in the initial position of the interpolated sequence.

V. GENERAL DISCUSSION

Although a sizable amount of research has explored the acoustic and perceptual dimensions that define timbre (see Handel, 1989 for a review), relatively little work has been directed at identifying the characteristics of timbre memory per se. The current study sought to correct this state of affairs. Three characteristics of timbre memory were identified.

1. Timbre memory is disrupted by irrelevant within-dimension variation. In eight conditions across the four experiments, interference increased as timbre distance decreased between the interpolated and standard tones. The range of dimensional variation within which interference occurs is limited for timbre, just as it is for pitch. Interference in timbre memory is found when the interpolated tones were fewer than six timbre steps from the standard. Interference in pitch memory is found when the interpolated tones were within \( \frac{6}{7} \) of a whole tone (Deutsch, 1972) from the standard. Although the pitch and timbre scales are not directly comparable, the evidence does suggest that interference is caused by stimuli only within a certain proximity to the standard.

2. Timbre memory is disrupted minimally by irrelevant pitch variation. Interference in timbre memory changed when pitch distance varied between standard and interpolated tones (experiment 2).

3. Interference effects in timbre memory can be additive, but they depend on the composition of the interpolated sequence, emerging only when timbre varies. A single interpolated tone caused more interference than six repetitions of that tone (experiments 1 and 3). By simply
changing the timbre of the second interpolated tone, interference changed (experiment 4). How it changed (increased or decreased) depended on the timbre distance between the interpolated tones and the standard.

A similar additive interference effect has been found in suffix effect experiments using two suffixes (Crowder and Morton, 1969; Morton et al., 1971). In a typical suffix effect experiment, participants hear a short list of items (e.g., eight) that must be recalled serially immediately after list presentation. An additional item, the suffix, is presented at the end of the list. Participants are often told to ignore the suffix or use it as a recall cue. Typical results are that inclusion of the suffix reduces recall of the last list item (Crowder and Morton, 1969). Presentation of a second suffix acoustically identical to the first leads to no additional drop in recall of the last item (Crowder, 1978; LeCompte and Watkins, 1995; Watkins and Sechler, 1989). However, when the second suffix is acoustically different from the first, recall drops. For example, LeCompte and Watkins (1995, experiment 1) found that recall of the last item was 8% better when two suffixes were presented in the same voice as the recall list than when the second of the two suffixes was in a different voice.

These findings are equivalent to what was found in the present study: Changes in the timbre of interpolated tones, not their repetition frequency, caused interference. The similarity of the results between the suffix-effect experiments and the present study suggest that findings using both tasks reflect the operation of the same process in auditory memory.

We began by noting similarities in how pitch and timbre are encoded during perception. Combined with the results of pitch memory experiments (e.g., Semal and Demany, 1991, 1993), our use of the procedure compared with its implementation by Deutsch (1970) and Semal and Demany (1991). For example, timbre of the interpolated tones was held constant. The results of pilot work, in which a range of other types of timbres was used, prompted these changes. Contact the authors for these data.

A pilot experiment was conducted to identify an appropriate timbre distance for “different” trials. A distance needed to be found for which the timbres were different enough to be discriminated, yet similar enough to avoid ceiling effects. A three-step distance was chosen because accuracy scores and qualification rates in experiments identical to the baseline condition were similar to those reported by Semal and Demany (1991) in a comparable condition.

Detailed analyses of the close-timbre rating data revealed that timbres 1 and 2 were rated significantly less similar than all other adjacent pairs. Mean rating was 3.2, with the rating for the next highest pair being 2.2. (Mean rating for all pairs except timbre1–timbre2 was 1.8.) This marked difference prompted us to use timbre 1 only as an interpolated tone, not as a standard or comparison tone. Therefore, only seven of the eight close timbres served as standard and comparison tones.

A signal detection analysis was performed on the data to measure accuracy without the potentially contaminating effects of response bias. For each participant, d-primes, adjusted for data collected in the same/different paradigm (MacMillan and Creelman, 1991) was computed for each of the four conditions. In the baseline, one-step, four-step, and six-step conditions, mean d-primes were 1.97, 1.07, 1.73, and 1.91, respectively. As is evident, the results of the sensitivity analysis parallel those obtained using percent correct: Accuracy increased as timbre distance between the standard and interpolated tones increased. A similar outcome was found between the accuracy measures when the sensitivity analysis was applied to the other experiments.


ACKNOWLEDGMENTS

Some of the data reported here were presented at the 127th and the 131st meetings of the Acoustical Society of America. We thank Bruno Repp and an anonymous reviewer for helpful comments. Address correspondence to Gary Starr, Department of Psychology, Wingate University, Campus Box 5005, Wingate, NC, 28174.

1Accuracy for the nonqualified participants averaged approximately 65% correct in all the interpolated conditions and 81% correct in the baseline condition. Other than the decrease in accuracy in the interpolated conditions compared to baseline, no differences were found between the interpolated conditions, making interpretations of interference effects difficult.

2Readers familiar with the Deutsch paradigm will notice simplifications in our use of the procedure compared with its implementation by Deutsch (1970) and Semal and Demany (1991). For example, timbre of the interpolated tones was held constant. The results of pilot work, in which a range of


