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Absolute pitch is disrupted by a memory illusion[a)]

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ABSTRACT:
An experiment is reported, showing that short-term memory for pitch in absolute pitch (AP) possessors, while substantially more accurate than in AP nonpossessors, is also subject to illusory conjunctions of pitch and time and so can be distorted or enhanced by a single tone embedded in a sequence of six other tones. Both AP possessors and AP nonpossessors performed a short-term memory task. A test tone was presented, then a sequence of six intervening tones, and then a probe tone. The test and probe tones either were identical in pitch or differed by a semitone. The AP nonpossessors judged whether the test and probe tones were the same or different, and the AP possessors identified the test and probe tones by name. In some conditions, a tone of identical pitch to the probe tone or an octave removed from this tone was included in the intervening sequence. In both the AP possessors and AP nonpossessors, this illusion-producing tone increased judgments that the test and probe tones were identical. These results accord with a model of the system underlying short-term memory for pitch proposed earlier and show that this system is bidimensional in nature, involving both pitch height and pitch class.
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I. INTRODUCTION

Absolute pitch (AP)—otherwise known as perfect pitch—is defined as the ability to name or produce a musical note of a given pitch in the absence of a reference note [see Deutsch (2013) for a review]. This ability is very rare in North America and Europe, where its prevalence has been estimated as less than one in 10 000 (Bachem, 1955; Takeuchi and Hulse, 1993), while its prevalence among speakers of tone language such as Mandarin is considerably higher (Deutsch *et al.*, 2006; Deutsch *et al.*, 2009; Deutsch *et al.*, 2013). In general, the ability holds in face of variations in the acoustic characteristics of the notes to be identified, such as their prevalence in the classical repertoire, octave range, and instrument timbre, though these factors do influence performance by AP possessors to some extent (Bahr *et al.*, 2005; Miyazaki, 1989; Ward and Burns, 1982; Takeuchi and Hulse, 1993; Lee and Lee, 2010; Vanzella and Schellenberg, 2010; Deutsch *et al.*, 2013; Van Hedger *et al.*, 2015b). Exposure to detuned music can also influence AP judgments (Van Hedger *et al.*, 2018). In addition, such judgments can alter with advancing age (Vernon, 1977; Ward, 1999; Monsaignon, 2001) and with certain medications (Yoshikawa and Abe, 2003; Braun and Chaloupka, 2005).

The present study explored errors in pitch identification by AP possessors from a new perspective, showing that presenting a single tone in a sequence of only six other tones can produce note naming errors. The study was derived from one first published by Deutsch (1970a, 1972) and involves a memory illusion. In the earlier study, listeners were presented with a test tone, which was followed by four intervening tones, then by a pause, and then by a probe tone. The test and probe tones either were identical in pitch or differed by a semitone. The listeners were asked to ignore the intervening tones and to judge whether the test and probe tones were the same or different in pitch. It was found that when the test and probe tones differed, inserting in the intervening sequence a tone of identical pitch to the probe tone caused a substantial increase in errors. In other words, the critical intervening tone produced an increased tendency to judge that the test and probe tones were identical in pitch. It was concluded that in making same-different judgments, listeners recognized correctly that a tone of identical pitch to the probe tone had earlier occurred but were unable to locate its position in the sequence reliably and so assumed incorrectly that it had been the test tone. This conclusion was reinforced by the additional finding that when the test and probe tones were identical and the critical intervening tone was also identical, there was a dramatic increase in "same" judgments and so a dramatic reduction in errors (Deutsch, 1970a, 1972, 1975a,b).

On the basis of these findings, a model for the representation of pitch in short-term memory was proposed (Deutsch, 1972). On this model, memory for the pitch of a

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tone is laid down simultaneously on both a pitch continuum and a temporal continuum, resulting in a three-dimensional bell-shaped distribution such as shown in Fig. 1. It was further proposed that as time proceeds, this memory distribution spreads in both directions, particularly along the temporal continuum. Then, depending on whether the test and probe tone pitches are the same or different, this spread can lead either to errors of misrecognition or to enhanced recognition performance.

We first consider what happens according to the model when the test and probe tones differ in pitch, and a tone of identical pitch to the probe tone is included in the intervening sequence. Here, due to the spread of the memory distribution along the temporal continuum, the model predicts that listeners recognize correctly that a tone of the same pitch as the probe tone had occurred but are uncertain when it occurred and so sometimes conclude erroneously that it had been the test tone. So when judgments involve evaluating both the test and the probe tones, AP nonpossesssors would be more likely to judge the test and probe tones as identical in pitch, and AP possessors would be more likely to misname the test tone as the same as the probe tone. These predictions are tested in the present study.

Also, according to the model, the spread of a memory distribution along a temporal continuum should lead to a higher proportion of correct judgments when the test and probe tones are identical in pitch and a tone of this pitch is included in the intervening sequence: When a test tone is presented, followed later by a tone of identical pitch, the distributions for these two tones would overlap along the temporal continuum. The overlapping portions of these distributions would sum, leading to a stronger memory trace for the pitch of the test tone. So when judgments involve evaluating both the test and the probe tones, AP nonpossessors would produce fewer errors in this condition, and AP possessors would be more likely to name the test tone correctly. These predictions are also tested in the present study.

In the study of Deutsch (1970a, 1972), listeners were not selected for AP possession, so most, if not all, would have been unable to assign verbal labels to pitches and so could only make same-different judgments concerning the test and probe tones. In consequence, it could not be determined with certainty whether the erroneous judgments that the test and probe tones were the same in pitch were due to misremembering the pitch of the test tone (as predicted from the model) or to misperceiving the pitch of the probe tone. The present study resolved this issue in the case of AP possessors by asking them to identify the test and probe tones by name.

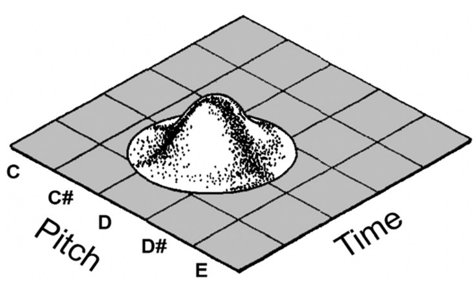

FIG. 1. Model representing the pitch of a tone in memory. Adapted from Deutsch (1972).

The stimulus patterns employed in the present experiment were similar to those of Deutsch (1970a, 1972), except that the test and probe tones were separated by a sequence of six (rather than four) intervening tones. Beyond examining the effects of inserting in the intervening sequence a tone of identical pitch to the probe tone, we explored the possibility that these effects would exhibit octave generalization. Deutsch (1973) obtained octave generalization for other interference effects in this basic paradigm, indicating that immediate memory for pitch is bidimensional in nature, including both tone height and pitch class. We therefore included a set of conditions in which a tone whose pitch was exactly an octave above that of the probe tone—and so of the same pitch class—was inserted in the intervening sequence.

We tested two groups of participants, one consisting of AP nonpossessors and the other of AP possessors, and the groups were balanced for age and for age of onset and duration of musical training. The AP nonpossessors judged for each sequence whether the test and probe tones were the same or different in pitch, by writing "same" or "different." The AP possessors instead wrote down the names of the test and probe tones after listening to each sequence.

II. METHOD

A. Procedure

The experiment consisted of two sessions, which were spaced a week apart. During the first session, the participants first filled out a consent form and were given a brief audiometry, which confirmed that they had normal hearing. They were then given an AP screening test using piano tones, followed by an AP test using sine waves. Following this, they participated in a brief preliminary experiment without feedback, to familiarize them with the procedure in the main experiment. Finally, they filled out a questionnaire describing their musical and linguistic backgrounds. The second session consisted of the main experiment.

B. Participants

Candidates for the experiment were recruited by word of mouth and by advertisement. All candidates were administered the screening test for possession of AP described below, and 12 AP possessors were recruited on the basis of scoring at least 85% on this test. These were six males and six females; average age 24.17 years (range 18–34 years), average age of onset of musical training 4.17 years (range 3–6 years), and average years of formal musical training 16.67 years (range 9–30 years). Sixteen candidates who failed to meet the AP screening criterion, most of whom denied having AP, were also recruited. These were seven males and nine females; average age 25.38 years (range 19–32 years), average age of onset of musical training

4.75 years (range 2–7 years), and average years of formal musical training 17.31 (range 6–27 years). The participants were current or recent university students with no known history of anatomical or neurological deficits and with normal hearing as determined by pure tone audiometry (250–8000 Hz). Six of the AP possessors spoke a tone or pitch accent language (Cantonese, Mandarin, Japanese, Korean), and two of the AP nonpossessors spoke a tone language (Mandarin, Taiwanese). The participants were paid for their services and gave written informed consent. All procedures were approved by the University of California San Diego Institutional Review Board (IRB).

C. Apparatus and stimuli

The participants were individually tested in a quiet room. All stimuli were presented from a MacBook Pro using Sennheiser HD 25 SP II headphones. Piano tone stimuli were generated on a Kurzweil K2000 synthesizer, which was tuned to the standard $A_4 = 440$ Hz. Sine wave stimuli were generated on an iMac computer, using the software Pd.

D. Preliminary investigations

1. Screening test for AP

Candidates for participation were presented with a set of 36 piano tones that spanned the three-octave range from C_3 (131 Hz) to B_5 (988 Hz), and they indicated the name of each tone in writing. To minimize the use of relative pitch as a cue, all intervals between successively presented tones were larger than an octave. The tones were 500 ms in duration and were presented in three blocks of 12, with 4.25-s intervals between onsets of tones within a block and 1-min rest periods between blocks. The test blocks were preceded by a practice block of four tones. No feedback was provided, either during the practice block or during the test blocks. Analysis of the responses showed that the average score of the AP possessors was 97.9% [standard deviation (SD) = 4.45], and the average score of the AP nonpossessors was 7.46% (SD = 5.53).

2. Sine wave test for AP

The sine wave test for AP was designed as the screening test, except that the tones were sine waves and were presented in a different pseudo-random order. As with the screening test, all intervals between successively presented tones were larger than an octave. Analysis of the responses showed that the average score of the AP possessors was 83.8% (SD = 10.8), and that of the AP nonpossessors was 9.20% (SD = 4.83). This test was not used to screen the participants, but it confirmed the high level of performance in the AP possessors and the low level of performance in the AP nonpossessors.

3. Practice experiment

The practice experiment was undertaken to familiarize the participants with the stimulus parameters to be employed in the main experiment, and the responses were not analyzed. The stimuli were arranged in three blocks of trials. The first block consisted of six trials, and the second and third block each consisted of 12 trials. No sequence contained a tone that was of the same pitch as the test or probe tone or that was an octave removed from either of these tones. Other than this, the stimulus parameters were as in the main experiment. No feedback was provided, and both the AP possessors and AP nonpossessors responded at the end of each trial by writing "same" or "different" on a score sheet.

4. Main experiment

The stimuli in the main experiment consisted of one block of six practice trials, followed by six blocks of 12 trials each. No feedback was provided.

On each trial, a sequence of tones was presented. This consisted of a test tone, which was followed by six intervening tones, then by a pause, and then by a probe tone. The participants were asked to listen to the test tone, to ignore the six intervening tones if they wished, and to listen to the probe tone. The AP nonpossessors, having heard the full sequence, judged whether the test and probe tones were the same or different in pitch and indicated their judgments by writing "same" or "different" on a score sheet. The AP possessors, having heard the full sequence, wrote down the names of the test and probe tones (as C, C#, D, and so on) on a score sheet.

The experiment consisted of 72 trials, 36 in which the test and probe tones were identical, and 36 in which they differed. There were six conditions, and these are illustrated in Fig. 2. In conditions S-, S2, and SO2, the test and probe tones were identical in pitch. In condition S-, the intervening tones were chosen at random from a three-octave range, subject to the constraints described below. In condition S2, a tone of identical pitch to the test/probe tone was inserted in the second serial position intervening sequence. In condition SO2, a tone that was exactly an octave above the test/probe tone was inserted in the second serial position of the intervening sequence. In conditions D-, D2, and DO2, the test and probe tones differed by a semitone, either up or down. In condition D-, the intervening tones were chosen at random from a three-octave range, subject to the constraints described below. In condition D2, a tone of identical pitch to the probe tone was inserted in the second serial position of the intervening sequence. In condition DO2, a tone that was exactly an octave above the probe tone was inserted in the second serial position of the intervening sequence.

All sequences contained six intervening tones. These were taken from the equal-tempered scale ($A_4 = 440$ Hz) and varied in semitone steps in the three-octave range from C_3 (131 Hz) to B_5 (988 Hz). Subject to the constraints imposed by the conditions, the intervening tones were chosen at random and ordered at random, except that no tone of the same pitch as the test or probe tone, or that was a semitone removed from the test tone, or that was displaced by an

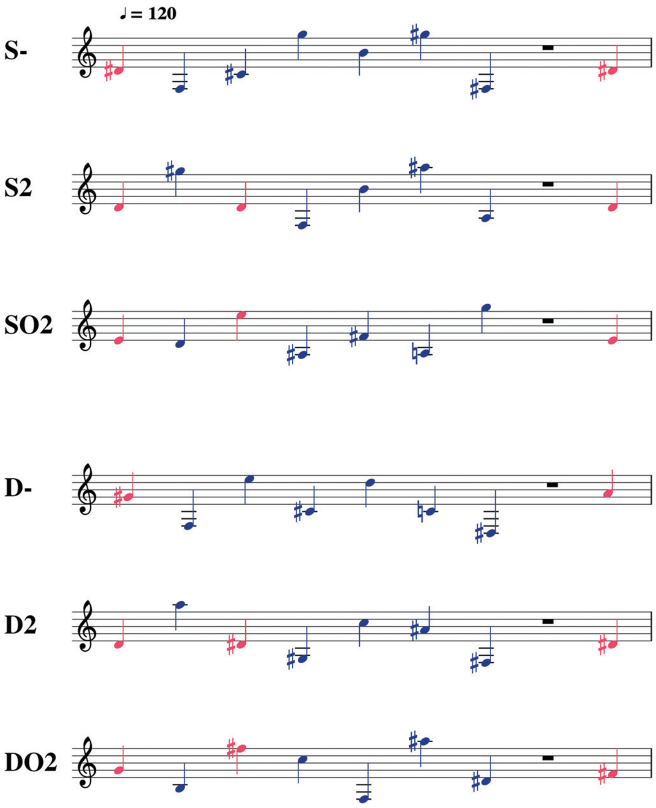

FIG. 2. Examples of sequences in the different conditions of the experiment. In conditions S-, S2, and SO2, the test and probe tones were identical in pitch. In condition S2, a tone of the same pitch as the test tone was included in the intervening sequence. In condition SO2, a tone whose pitch was exactly an octave above that of the test tone was so included. In conditions D-, D2, and DO2, the test and probe tones differed in pitch by a semitone. In condition D2, a tone of the same pitch as the probe tone was included in the intervening sequence. In condition DO2, a tone whose pitch was exactly an octave above that of the probe tone was so included.

octave from any of these tones was included in the intervening sequence.

In each of conditions S-, S2, and SO2, the test and probe tones were identical in pitch, and the 12 tones in the octave from C_4 (262 Hz) to B_4 (494 Hz) were each presented once. These were C; C#; D; D#; E; F; F#; G; G#; A; A#; B.

In each of conditions D-, D2, and DO2, the test and probe tones differed by a semitone, and the 12 tones from C_4 (262 Hz) to B_4 (494 Hz) were each presented once as a test tone and once as a probe tone. In each of these conditions, there were six sequences in which the probe tone was a semitone higher than the test tone; these test/probe tone combinations were C-C#; D-D#; E-F; F#-G, G#-A; A#-B. There were also six sequences in which the probe tone was a semitone lower than the test tone; these test/probe tone combinations were C#-C; D#-D; F-E; G-F#; A-G#; B-A#.

All tones were sine waves with 5-ms rise/fall times and were 200 ms in duration. They were presented via headphones at a level of approximately 70 dB sound pressure level (SPL). The inter-stimulus interval between the test tone and the first intervening tone was 300 ms, as were the intervals between all intervening tones. The pause between the last intervening tone and the probe tone was 2 s.

The trials were presented in six blocks of 12, with trials in the different conditions presented in random order. There were 12 trials within a block; these were separated by 10-s pauses during which the subjects recorded their judgments. The blocks were separated by 1-min pauses. Before the experiment began, a practice block of six trials was presented.

III. RESULTS

The overall error rates are shown in Figs. 3 and 4. For conditions where the test and probe tones were identical, a 2×3 mixed analysis of variance (ANOVA) was performed, with AP possession (AP, NAP) and condition (S-, S2, SO2) as factors. There was a significant effect of AP possession, $F(1, 26) = 7.26$, $p = 0.012$, $\eta_p^2 = 0.22$. There was a significant effect of condition, $F(2, 52) = 13.7$, $p < 0.001$, $\eta_p^2 = 0.34$. The interaction between AP possession and condition was nonsignificant, $F(2, 52) = 1.39$, $p = 0.26$. In planned comparisons, the AP possessors made significantly fewer errors than the AP nonpossessors in each condition separately: for S-, $t(26) = -2.50$, $p = 0.02$; for S2, $t(26) = -2.49$, $p = 0.02$; for SO2, $t(26) = -1.94$, $p = 0.06$ (two-tailed for all comparisons).

For conditions where the test and probe tones differed, a 2×3 mixed ANOVA was performed, with AP possession (AP, NAP) and condition (D-, D2, DO2) as factors. There was a significant effect of AP possession, $F(1, 26) = 23.5$, $p < 0.001$, $\eta_p^2 = 0.47$. There was a significant effect of condition, $F(2, 52) = 17.9$, $p < 0.001$, $\eta_p^2 = 0.41$. The AP possession $\times$ condition interaction was also significant, $F(2, 52) = 6.61$, $p = 0.003$, $\eta_p^2 = 0.20$. The AP possessors made significantly fewer errors than nonpossessors in each condition taken separately: For D-, $t(26) = -1.88$, $p = 0.07$; for D2, $t(26) = -4.43$, $p < 0.001$; for DO2, $t(26) = -4.62$, $p < 0.001$ (two-tailed for all comparisons).

Planned comparisons on the different conditions were carried out, in which performance was compared for the AP possessors and AP nonpossessors separately. For the AP

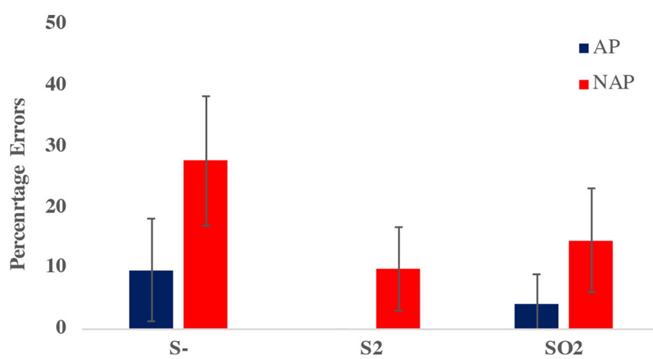

FIG. 3. (Color online) Percentage errors in the conditions in which the test and probe tones were identical in pitch. In condition S2, a tone of the same pitch was included in the intervening sequence. In condition SO2, a tone whose pitch was an octave higher was so included. In condition S-, no critical tone was included in the intervening sequence. All AP possessors performed perfectly (no errors) in the S2 condition. Error bars represent ±2 standard errors.

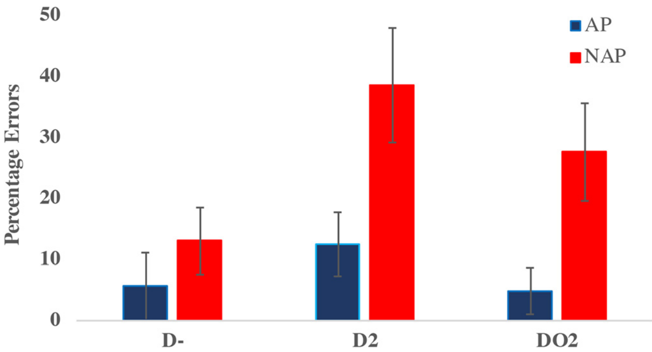

FIG. 4. (Color online) Percentage errors in which the test and probe tones differed in pitch by a semitone. In condition D2, a tone of the same pitch as the probe tone was included in the intervening sequence. In condition DO2, a tone whose pitch was exactly an octave above that of the probe tone was so included. In condition D-, no critical tone was included in the intervening sequence. Error bars represent ±2 standard errors.

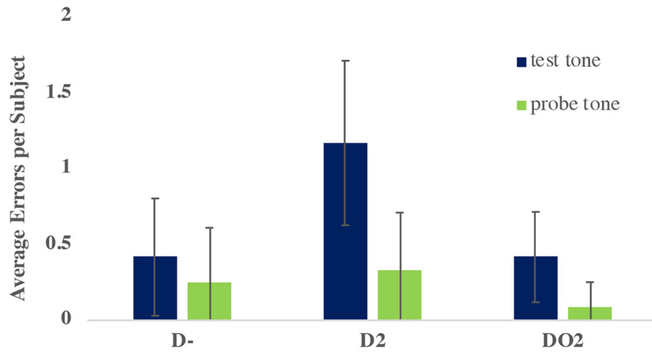

FIG. 5. (Color online) Naming errors of the test and probe tones by AP possessors, in the conditions where the test and probe tones differed in pitch. The blue bars show errors in which the test tone was erroneously given the same name as the probe tone. The green bars show errors in which the probe tone was erroneously given the same name as the test tone. Error bars represent ±2 standard errors.

nonpossessors, the error rate was significantly higher in condition D2 than in condition D-, $t(15) = 5.80$, $p < 0.001$; it was significantly higher in condition DO2 than in condition D-, $t(15) = 3.31$, $p = 0.005$; and it was significantly higher in condition D2 than in condition DO2, $t(15) = 2.64$, $p = 0.02$ (all two-tailed). The error rate was significantly lower in condition S2 than in condition S-, $t(15) = 4.76$, $p < 0.001$; it was significantly lower in condition SO2 than in condition S-, $t(15) = -3.65$, $p = 0.002$; and it was lower as a nonsignificant trend in condition S2 than in condition SO2, $t(15) = -1.29$, $p = 0.22$ (all two-tailed).

For the AP possessors, the error rate was significantly higher in condition D2 than in condition D-, $t(11) = 2.59$, $p = 0.03$; it was significantly higher in condition D2 than in condition DO2, $t(11) = 3.19$, $p = 0.009$; and the difference between conditions D- and DO2 was nonsignificant, $t(11) = 0.29$, $p = 0.78$ (all two-tailed). The error rate was significantly lower in condition S2 than in condition S-, $t(11) = -2.31$, $p = 0.04$; it was lower as a trend in condition S2 than in condition SO2, $t(11) = -1.73$, $p = 0.11$; and it was lower as a trend in condition SO2 than in condition S-, $t(11) = -1.23$, $p = 0.24$ (all two-tailed).

A critical question addressed in this study concerned the increase in erroneous judgments when the test and probe tones differed in pitch and a tone of identical pitch to the probe tone was included in the intervening sequence. Did the subjects misremember the pitch of the test tone as identical to the probe tone (as predicted from the model), or did they instead misperceive the probe tone as identical to the test tone? This question was answered for the AP possessors by having them name the test and probe tones and then comparing the naming errors.

The results are shown in Fig. 5. A 2 (test, probe) × 3 (D-, D2, DO2) repeated measures ANOVA showed that, overall, more errors resulted from misnaming the test tone as identical to the probe tone than from misnaming the probe tone as identical to the test tone, $F(1, 11) = 7.18$, $p = 0.021$, $\eta_p^2 = 0.40$. There was also a significant main effect of condition, $F(2, 22) = 1.72$, $p = 0.005$, $\eta_p^2 = 0.38$, and a marginally significant interaction between these factors, $F(2, 22) = 2.86$, $p = 0.079$, $\eta_p^2 = 0.21$.

Taking the different conditions separately, there were significantly more errors due to misnaming the test tone as identical to the probe tone than to misnaming the probe tone as identical to the test tone in condition D2, $t(11) = 2.42$, $p = 0.03$, and in condition DO2, $t(11) = 2.35$, $p = 0.04$; however, mislabeling errors of the test and probe tones did not differ significantly in condition D-, $t(11) = 1.00$, $p = 0.34$ (all two-tailed).

To further compare the error patterns in each condition separately, a difference score was computed for each subject (incorrect judgments due to misnaming the test tone as identical to the probe tone minus misnaming the probe tone as identical to the test tone) in each condition. These difference scores were marginally higher for condition D2 than for condition D-, $t(11) = 1.88$, $p = 0.09$; they were higher as a trend for condition D2 than for condition DO2, $t(11) = 1.59$, $p = 0.14$; and they were not significantly different for condition DO2 than for condition D-, $t(11) = 1.00$, $p = 0.34$ (all two-tailed).

IV. DISCUSSION

The present study replicated and extended the findings of Deutsch (1970a; 1972) and resolved ambiguities of interpretation, at least for the AP possessors. When the test and probe tones differed in pitch, inserting in the intervening sequence a tone of identical pitch to the probe tone produced a substantial increase in erroneous judgments that the test and probe tone pitches were identical; further, the AP possessors misnamed the test tone as identical to the probe tone significantly more often than they misnamed the probe tone as identical to the test tone. When the test and probe tones were identical in pitch, inserting a tone of this pitch in the intervening sequence produced a substantial increase in correct judgments by AP nonpossessors; further, the AP possessors more often named the test and probe tones correctly. These findings are as predicted from the model of pitch memory proposed by Deutsch (1972) described in the Introduction.

The present findings therefore resulted from illusory conjunctions involving *what* tones were presented and *when* they occurred. Other studies have demonstrated *what-where* illusory conjunctions; these are responsible for the octave illusion (Deutsch, 1974, 1981; Deutsch and Roll, 1976), the scale illusion (Deutsch, 1975c), the glissando illusion (Deutsch *et al.*, 2007), the precedence effect (Wallach *et al.*, 1949), and the Haas effect (Haas, 1951). In addition, illusory conjunctions of pitch and timbre have been demonstrated (Hall *et al.*, 2000), as have illusory conjunctions of pitch and duration (Thompson *et al.*, 2001).

Further interesting findings were produced in the conditions in which a tone whose pitch was exactly an octave above that of the probe tone was inserted in the intervening sequence. When the test and probe tones differed in pitch, inserting a tone of the same pitch class as the probe tone resulted in a significant increase in erroneous judgments that the test and probe tones were identical. However, this effect was weaker than that of including a tone of identical pitch to the probe tone. This finding indicates that pitch is represented in memory in the forms of both pitch height and pitch class, so that the system underlying memory for pitch is bidimensional in nature. The bidimensionality of musical pitch has been argued by others (Meyer, 1904; Ruckmick, 1929; Bachem, 1948; Shepard, 1964, 1982; Pickler, 1966; Risset, 1969; Deutsch, 1969, 1973, 1982, 2013; Deutsch *et al.*, 2008; Burns and Ward, 1982; Patterson, 1986; Ueda and Ohgushi, 1987; Warren *et al.*, 2003).

Other general findings from this study concern the overall performance levels of the two groups. Both the AP possessors and the AP nonpossessors had received considerable musical training, and the performance levels of both these groups were considerably higher than would be expected from participants who were not selected on the basis of training. More specifically, Deutsch (1970b) selected participants on the basis of error-free performance in judging similar tone pairs that were separated by a silent retention interval, without any further selection criteria. These participants made 32.3% errors in a task that was very similar to that presented here. In the present study, the overall error rate was 20.3% for the AP nonpossessors and 7.64% for the AP possessors.

The performance level among AP possessors was far superior to that of matched AP nonpossessors, even though they had a considerably more difficult task to perform. This finding is in accordance with earlier work demonstrating a pitch memory advantage for AP possessors (Bachem, 1954; Siegel, 1974; Ross *et al.*, 2004; Rakowski and Rogowski, 2007). The advantage may be explained in part by the ability of AP possessors to label the tones they hear and so to compare the test and probe tones by their labels, employing a multiple-encoding strategy (Siegel, 1974; Zatorre and Beckett, 1989). In addition, it could reflect enhanced short-term memory for sounds in general. The latter suggestion is supported by findings by Deutsch and Dooley (2013) that the auditory digit span was larger among AP possessors than among a control group that was matched in age, age of onset of musical training, and overall musical experience. Further, Van Hedger *et al.* (2015a) found that adults with higher auditory working memory capacity were more able than others to acquire AP categories. Concerning the neurological basis for the enhanced short-term memory for pitch in AP possessors, the evidence points in particular to the left superior temporal region (Schulze *et al.*, 2009) and the left dorsolateral prefrontal cortex (Zatorre *et al.*, 1998); see also the review by Loui (2014). It is interesting, however, that despite their excellent overall performance in the present short-term memory task, the judgments of the AP possessors were subject to an illusion produced by a single tone that was embedded in a sequence of six tones.

Several issues arise from this study concerning the generalizability of the findings. One issue concerns the position of the illusion-inducing tone within the intervening sequence. According to the present model, the effects should be stronger when this tone is placed early in the intervening sequence rather than late. Previous research using this basic paradigm has confirmed this effect (Deutsch, 1970a, 1972). Other issues concern the effects of changing the duration of the silent interval before or after the intervening tones. In an earlier informal study, increasing the silent interval between the test tone and the first intervening tone reduced the overall error rate. It is expected that the illusion-producing tone would have a weaker effect in such a condition, since it would be further removed in time from the test tone. Furthermore, in this informal study, increasing the time delay between the last intervening tone and the probe tone increased error rates. It is expected that the effects of the illusion-producing tone would also be stronger here, since it would be closer in time to the test tone relative to the probe tone. Another issue is whether the effects documented here would hold using tones of different timbre, such as the piano, and we are planning to investigate this in further experiments.

V. CONCLUSION

The study presented here documents a number of characteristics of short-term memory for pitch in AP possessors. This is shown to be substantially more accurate than in AP nonpossessors, controlling for age and for age of onset and duration of musical training. However, it is subject to illusory conjunctions of pitch and time and so can be distorted or enhanced by a single tone that is embedded in a sequence of six other tones. The findings are also in accordance with a model of the system underlying short-term memory for pitch presented by Deutsch (1972), and they show that this system involves both pitch height and pitch class.

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