Across-frequency interference effects in fundamental frequency discrimination: Questioning evidence for two pitch mechanisms[a)]

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(Received 12 August 2003; revised 30 April 2004; accepted 6 May 2004)

Carlyon and Shackleton [J. Acoust. Soc. Am. **95**, 3541–3554 (1994)] presented an influential study supporting the existence of two pitch mechanisms, one for complex tones containing resolved and one for complex tones containing only unresolved components. The current experiments provide an alternative explanation for their finding, namely the existence of across-frequency interference in fundamental frequency (F0) discrimination. Sensitivity (d') was measured for F0 discrimination between two sequentially presented 400 ms complex (target) tones containing only unresolved components. In experiment 1, the target was filtered between 1375 and 15 000 Hz, had a nominal F0 of 88 Hz, and was presented either alone or with an additional complex tone (''interferer''). The interferer was filtered between 125–625 Hz, and its F0 varied between 88 and 114.4 Hz across blocks. Sensitivity was significantly reduced in the presence of the interferer, and this effect decreased as its F0 was moved progressively further from that of the target. Experiment 2 showed that increasing the level of a synchronously gated lowpass noise that spectrally overlapped with the interferer *reduced* this ''pitch discrimination interference (PDI)''. In experiment 3A, the target was filtered between 3900 and 5400 Hz and had an F0 of either 88 or 250 Hz. It was presented either alone or with an interferer, filtered between 1375 and 1875 Hz with an F0 corresponding to the nominal target F0. PDI was larger in the presence of the resolved (250 Hz F0) than in the presence of the unresolved (88 Hz F0) interferer, presumably because the pitch of the former was more salient than that of the latter. Experiments 4A and 4B showed that PDI was reduced but not eliminated when the interferer was gated on 200 ms before and off 200 ms after the target, and that some PDI was observed with a continuous interferer. The current findings provide an alternative interpretation of a study supposedly providing strong evidence for the existence of two pitch mechanisms. [DOI: 10.1121/1.1766021]

PACS numbers: 43.66.Fe, 43.66.Hg, 43.66.Ba [NFV] Pages: 1092–1104

I. INTRODUCTION

Many of the periodic sounds that we encounter in everyday life are broadband, and contain harmonics that differ widely in the extent to which they are resolved by the peripheral auditory system. A distinction that has informed much experiment and theory is that between the lower harmonics, which are resolved by the peripheral auditory system, and the higher harmonics, which are not (Plomp, 1964; Houtsma and Smurzynski, 1990; Fine and Moore, 1993; Moore and Ohgushi, 1993; Shackleton and Carlyon, 1994). The transition from resolved to unresolved harmonics appears to be around the 10th harmonic, but the exact locus seems to depend on the specific measure (e.g., fundamental frequency discrimination thresholds or the ability to hear out individual components) used to determine this transition (for a discussion see Bernstein and Oxenham, 2003b). The unresolved harmonics interact within auditory filters and, in the case of consecutive harmonics, produce a modulation at a rate equal to the fundamental frequency (F0). A wide body of evidence has shown that although this cue can give rise to a perception of pitch (Burns and Viemeister, 1976; Moore and Rosen, 1979), it is the resolved harmonics that dominate the pitch of broadband sounds (Plomp, 1967; Ritsma, 1967; Ritsma, 1970; Moore *et al.*, 1985). Furthermore, difference limens for F0 (F0DLs) are also lower for resolved than for unresolved harmonics (Houtsma and Smurzynski, 1990).

Early models, proposed to account for the pitch of complex tones, fall into two different classes. In the first, pitch is derived solely from the periodicity arising from the within-channel interaction of multiple harmonics (Schouten, 1940; Schouten, 1970). Such a mechanism would be effective for deriving the pitch of complex tones containing only unresolved components (referred to as ''unresolved complexes'' hereafter). In the second class of models, pitch is derived by a form of ''pattern recognition'' across resolved harmonics (Goldstein, 1973; Terhardt, 1974). This sort of mechanism would be effective for deriving the pitch of complex tones containing resolved components (referred to as ''resolved

[a)]Parts of this work were presented at the 145th meeting of the Acoustical Society of America, Nashville, Tennessee, 28 April–2 May 2003 [J. Acoust. Soc. Am. **113**, 2290 (2003)].
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complexes'' hereafter). A limitation of pattern recognition models is that they have difficulty in accounting for the weak but significant pitch percepts produced by unresolved harmonics (but see Houtsma and Smurzynski, 1990).

In contrast, a modern class of models, based loosely around the concept of autocorrelation, can produce a pitch estimate both from resolved and from unresolved harmonics (Slaney and Lyon, 1990; Meddis and Hewitt, 1991; Patterson *et al.*, 1992). Leaving aside, for the moment (but see Sec. VI), the question of whether the particular implementations of such a unitary model can account for all the findings in the pitch area, there is a more basic problem. This is the question of whether it is *necessary* to assume two separate mechanisms for extracting the pitch or whether one common mechanism would *in principle* be sufficient (Licklider, 1951; Meddis and Hewitt, 1991; Patterson *et al.*, 1992; Moore, 2003). This issue has been discussed repeatedly (Houtsma and Smurzynski, 1990; Carlyon and Shackleton, 1994; Meddis and O'Mard, 1997; Carlyon, 1998; Grimault *et al.*, 2002) and here we present findings which are relevant for this topic.

If there exists only one common pitch mechanism, then one would expect two complex tones with similar fundamental frequencies (F0s) which are presented simultaneously—one resolved and one unresolved—to be processed together, in the same way. The output of the single mechanism, the pitch estimate, would be expected to be dominated by whichever input gives the strongest output. Two pitches might be heard in the presence of strong segregation cues for the two tones, for example, an onset asynchrony. Two pitches might also be heard if the F0s of the two tones differ sufficiently. On the other hand, in the absence of strong segregation cues and large F0 differences, the single pitch perceived probably would be determined to a large extent by those components of the input that give the strongest pitch. Complex tones with resolved harmonics usually give a more salient pitch than complexes containing only unresolved harmonics (see, e.g., Moore and Glasberg, 1986); pitch salience has been determined by comparing subjects' ability to identify simple melodies or to identify musical intervals for high-pass filtered complex tones with various cutoff frequencies (Moore and Rosen, 1979; Houtsma and Smurzynski, 1990), and by comparing thresholds for F0 discrimination (Hoekstra and Ritsma, 1977; Moore and Glasberg, 1988; Houtsma and Smurzynski, 1990; Moore and Glasberg, 1990; Moore and Peters, 1992; Shackleton and Carlyon, 1994). Furthermore, the dominance region for pitch is concentrated around lower harmonic numbers (Plomp, 1967; Ritsma, 1967; Ritsma, 1970; Moore *et al.*, 1985; Dai, 2000). Therefore, one might expect the pitch of two simultaneously presented complex tones—one resolved and the other unresolved—to be dominated by the resolved complex. As a consequence, performance in a task requiring judgement of the pitch of the unresolved complex tone might be strongly impaired by the presence of a fixed-pitch resolved complex tone, even when presented in a different spectral region. In other words, one might see an interference in the pitch domain which is reminiscent of that seen in the modulation domain, i.e., modulation detection and modulation discrimination interference (MDI), (Yost and Sheft, 1989; Yost *et al.*, 1989). In contrast to MDI, which can occur when the interferer is lower in frequency than the target, or vice versa, the ''pitch discrimination interference'' (PDI) would be expected to be asymmetric; more interference would be expected from a resolved complex than from an unresolved complex when judging the pitch of an unresolved complex in a well separated spectral region. This direction of asymmetry would be expected because subjects would try to *ignore* the simultaneous interferer, as it carries no information for the task at hand. The contribution of a resolved interferer to the perceived pitch would be harder to ignore than that of an unresolved interferer, as the former evokes a more salient pitch (see earlier).

An asymmetric across-frequency interference effect somewhat similar to the one expected here, has been found for the discrimination of interaural time differences. Low-frequency interferers strongly impair the lateralization of high-frequency targets, while high-frequency interferers have little or no effect on the lateralization of low-frequency targets (McFadden and Pasanen, 1976; Bernstein and Trahiotis, 2001; for a short summary, see Moore, 2003).

The experiments presented here show that such PDI does indeed exist, and reveal some of the characteristics of PDI. Later on we will discuss data by Carlyon and Shackleton (1994), which have been interpreted as evidence for the existence of two separate pitch mechanisms, one for complex tones containing resolved and one for complex tones containing only unresolved components. We will argue that the current findings provide an alternative explanation for their results, and therefore question their evidence for the existence of two pitch mechanisms, which strongly influenced further research.

II. EXPERIMENT 1: THE INTERFERENCE EFFECT AND ITS TUNING IN F0

A. Stimuli

Listeners had to discriminate between the F0s of two sequentially presented complex tones (the targets) which had a nominal F0 of 88 Hz. Each target was bandpass filtered between 1375 and 15 000 Hz (3 dB down points) with a slope of 48 dB per octave; thus it contained a large number of only unresolved components (Carlyon and Shackleton, 1994; Shackleton and Carlyon, 1994). The pitch salience of such a wide-band unresolved complex would be increased relative to a narrow-band version, but it would nevertheless be considerably weaker than for a resolved complex (Kaernbach and Bering, 2001). The target was either presented alone (condition ''None''), or it was accompanied by another complex tone (the interferer). The interferer had an F0 of 88 Hz or higher, and was bandpass filtered between 125 and 625 Hz (3 dB down points) with a slope of 48 dB per octave; thus it contained resolved components only. Note that, as the target and the interferer were filtered into well-separated frequency regions, one would not expect them to interact in the auditory periphery; therefore any effect must be more central. When present, the interferer was gated synchronously with the target, and its F0 relative to the nominal target F0 was unchanged for a block of trials. The independent vari-

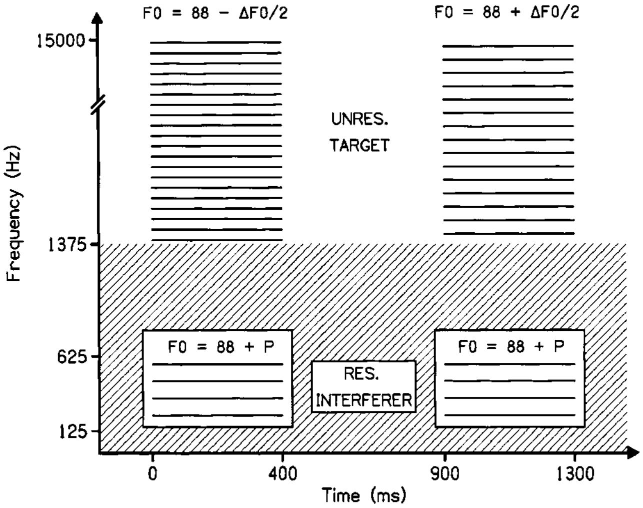

FIG. 1. Schematic spectrograms of stimuli presented over the course of one 2AFC trial in experiment 1.

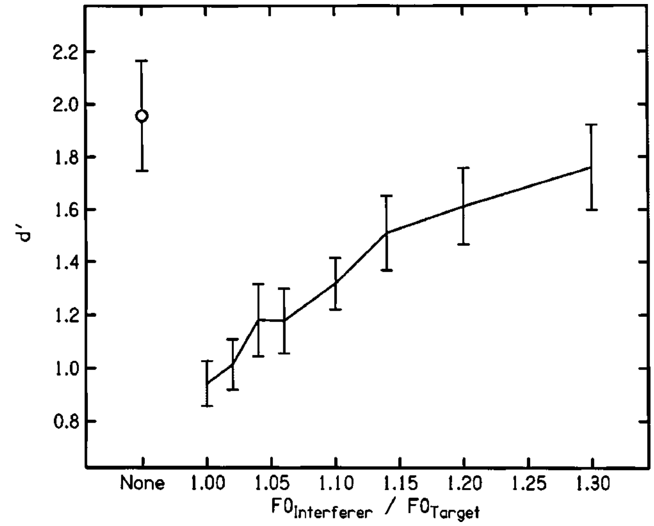

FIG. 2. The mean performance, and the associated standard errors (across subjects) obtained in experiment 1. The circle indicates d' in the absence of an interferer. The solid line indicates d' plotted as a function of the ratio between the F0 of the interferer and the nominal target F0.

able of the first experiment was the amount by which the F0 of the interferer was above that of the nominal target F0; possible values were: 0%, 2%, 4%, 6%, 10%, 14%, 20%, or 30%. The F0 difference between the low-F0 and the high-F0 targets (ΔF0) was fixed for each subject; it was determined in such a way that performance was below 100% correct in the easiest condition and was above 50% correct in the most difficult condition. The following values for ΔF0 were employed: 7.1% for one subject, 3.5% for four subjects, and 2% for the sixth subject.

The F0 of the digitally generated stimuli (see later) was randomly varied over the range $\pm$10% between trials by varying the sample rate (also producing a slight variation in duration and in the filter cutoffs). This F0 randomization discouraged subjects from basing their decision on a long-term memory representation of the sound, and encouraged them to compare the pitch of the two targets presented in each trial. For both target and interferer, the level per component was 45 dB SPL, and components were always summed in sine phase. The nominal stimulus duration was 400 ms, including 5 ms raised-cosine onset and offset ramps. In order to mask possible distortion products, a continuous white background noise, lowpass filtered at the lower cutoff frequency of the target (nominally at 1375 Hz) with a slope of 96 dB per octave, was presented. The overall root-mean-square (rms) level of the noise in the region from 125 to 625 Hz, the nominal frequency band covered by the interferer, was 10 dB below that of the interferer. Schematic spectrograms of the stimuli are shown in Fig. 1.

The complex tones were generated and bandpass filtered digitally. They were played out using a 16-bit digital-to-analog converter (CED 1401 plus), with a sampling rate which was varied between trials over the range 40 kHz $\pm$10%. This led to a variation of F0 and to a concomitant proportional change in the bandpass region of the tones. Stimuli were passed through an antialiasing filter (Kemo 21C30) with a cutoff frequency of 17.2 kHz (slope of 96 dB/oct), and presented monaurally, using Sennheiser HD250 headphones. Subjects were seated individually in an IAC double-walled sound attenuating booth.

B. Procedure

A two-interval two-alternative forced choice task was used to measure percent correct for the fixed values of ΔF0. The subjects were required to indicate the interval containing the target with the higher F0. The interferer was presented in both intervals in each trial. Its F0 was identical in both intervals and fixed at a certain percentage above the nominal target F0 throughout a block of 100 trials. The silent interval between presentations of the two stimulus intervals in a trial was fixed at 500 ms in all conditions (see Fig. 1). Each interval was marked by a light and visual feedback was provided following each response.

The total duration of a single session was about 2 h, including rest times. At least four (mostly five) blocks of 100 trials were run for each condition and subject. The order of the conditions was counterbalanced within and across subjects. One block was run for each condition in turn, before additional blocks were run in any other condition. To familiarize subjects with the procedure and equipment, they participated in at least three sessions, more if practice effects within conditions were seen, before data collection proper was started.

C. Subjects

In this and all following experiments, subjects ranged in age from 19 to 41 years, and their quiet thresholds at octave frequencies between 250 and 8000 Hz were within 15 dB of the 1969 ANSI standard. In all experiments, one of the subjects was the first author. In experiment 1, six subjects participated in all nine conditions. Four of the six subjects had considerable musical experience, and these were the ones with the lower values of ΔF0.

D. Results and discussion

Figure 2 shows the results averaged over all subjects and the corresponding standard errors. Performance in terms of

d' is plotted as a function of the ratio between the F0 of the interferer and the nominal F0 of the target. Performance was best, with a d' value of about 1.96, in the absence of an interferer (leftmost symbol, None). Performance was worst, at a d' value of about 0.94, when the interferer's F0 was at the nominal target F0 (ratio of one). With increasing difference between the interferer's F0 and the nominal target F0 performance recovered slowly. When the F0 of the interferer was 30% above the nominal target F0, performance was nearly, but not quite, back to that observed without any interferer (a d' value of 1.76).

To determine the statistical significance of the results, a repeated-measures one-way ANOVA (with nine levels for the factor condition) was calculated, using the mean d' value for each subject and condition as input. This showed a highly significant main effect of condition [$F(8,40)=21.6$, $p<0.001$].[1] Calculation of simple contrasts showed that all conditions with an interferer differed significantly from condition None. For the eight parameter values the following F values and significance levels were obtained. 0%: $F(1,5)=27.7$, $p=0.003$; 2%: $F(1,5)=34.1$, $p=0.002$; 4%: $F(1,5)=36.4$, $p=0.002$; 6%: $F(1,5)=29.4$, $p=0.003$; 10%: $F(1,5)=22.2$, $p=0.005$; 14%: $F(1,5)=23.1$, $p=0.005$; 20%: $F(1,5)=20.2$, $p=0.006$; 30%: $F(1,5)=13.6$, $p=0.014$.

In summary, F0 discrimination between two targets containing only unresolved components was clearly impaired in the presence of a tone complex with resolved components and an F0 similar to the nominal target F0. Importantly, this was true even though the target and interferer were filtered into well-separated spectral regions. Thus, peripheral interactions were unlikely to be responsible for this effect. The interference effect showed tuning between the F0s of target and interferer, which again suggests that the effect does not have a peripheral origin. Subjectively, the increase in F0 difference between target and interferer led to increased perceptual segregation of the two sounds. For interferers with an F0 within 10% of the nominal target F0, perceptual segregation was reported to be either absent or weak. When the interferer's F0 was 20% or 30% above that of the target, two sound sources were perceived. Nevertheless, a small impairment in F0 discrimination was still observed.

III. EXPERIMENT 2: EFFECT OF LEVEL OF SYNCHRONOUSLY GATED LOWPASS NOISE

The first experiment showed that the interference effect depended on the similarity between the interferer's F0 and the nominal F0 of the target. The second experiment provided a further test of whether the interference effect depends on the pitch characteristics of the added sound, or simply the presence of energy in the dominance region of pitch of the F0 of the target. The lowpass-filtered white noise—presented continuously in the first experiment—was now gated synchronously with the complex tone interferer and the target, in order to avoid them being segregated due to onset asynchrony. Thus, the added sound now consisted of a tonal and a noise component, and the level of the noise component was varied. Because the lowpass noise spectrally overlapped with the complex tone used as interferer in experiment 1, increasing the noise level would lead to a decrease in the tonality of the added sound, i.e., to a decrease in pitch strength and/or loudness of the tonal component of the added sound, due to the decrease of the tone-to-noise ratio in the spectral region containing the complex tone.

A. Stimuli and procedure

The basic stimuli and procedure were the same as in experiment 1, with the following exceptions. The level of the lowpass white noise was either the same as in experiment 1, i.e., 10 dB below that of the complex tone interferer in the frequency band covered by the tone (condition −10 dB), or it was 10 dB above that of the complex tone interferer in the frequency band covered by the tone (condition +10 dB). For the latter, the tone-to-noise ratio was around threshold. The noise was gated synchronously with the tones. In order to produce synchronously gated noise, we used digitally generated 400 ms bursts of white noise which were lowpass filtered digitally. Twenty different versions of noise bursts were pregenerated and stored on disk. One out of these 20 realizations of noise was chosen at random for each presentation in order to avoid masking effects that are specific to a particular "frozen" noise sample (Hanna and Robinson, 1985). The values for ΔF0 were 7.1% and 3.5% for all subjects.

Five blocks of 100 trials each were run for each condition and subject. The order of the conditions was counterbalanced within and across subjects. One block was run for each condition in turn, before additional blocks were run in any other condition. Subjects participated in at least one practice session before data collection proper was started.

Five subjects participated in all four conditions; three of them had considerable musical experience. Three of the five subjects were the same as in experiment 1, two of whom participated in experiment 2 before they ran in experiment 1.

B. Results and discussion

Figure 3 shows the mean results and the corresponding standard errors. The left and the right pairs of columns show d' values for F0 discrimination with ΔF0 equal to 3.5% and 7.1%, respectively. The white and black columns are for noise levels of −10 and +10 dB, respectively, re the level of the complex tone interferer in the band covered by the tone. As expected, overall performance was higher when the ΔF0 was 7.1% than when it was 3.5%. More importantly, in both cases performance *improved* when the level of the lowpass noise was increased by 20 dB. These results were confirmed by the outcome of a repeated-measures two-way ANOVA (with factors ΔF0 and level of noise). The main effects of ΔF0 [$F(1,4)=70.1$, $p<0.01$] and level of noise [$F(1,4)=26.9$, $p<0.01$] were highly significant, while the interaction between the two was not significant.

In summary, F0 discrimination performance in the presence of a complex tone interferer filtered into a spectrally remote region was improved by increasing the level of a lowpass noise which spectrally overlapped with and was gated synchronously with the interferer. This is one of the rare occasions where more noise helps (Warren, 1970; Carlyon, 1987; Plack and Viemeister, 1992; Plack and White, 2000a; Carlyon *et al.*, 2002a). More noise probably helped,

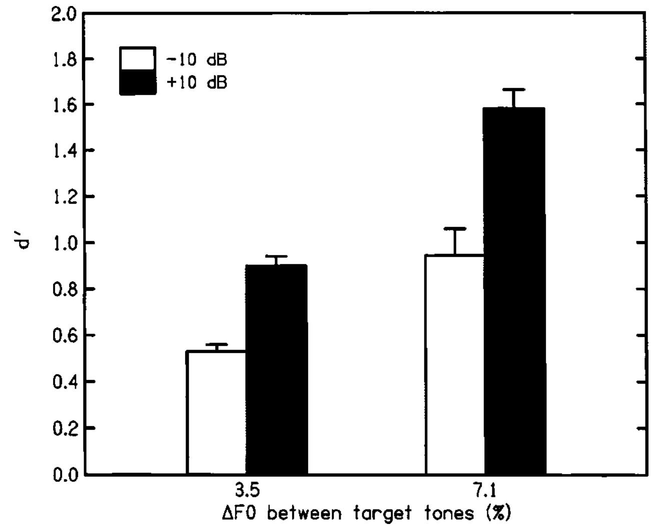

FIG. 3. The mean performance, and the associated standard errors (across subjects) obtained in experiment 2. d' for F0 discrimination is plotted as a function of ΔF0 (3.5% and 7.1%) between the two target tones. The white and black columns are for noise levels of −10 and +10 dB, respectively, re the level of the interferer in the band covered by the interferer.

because it reduced the perceived tonality of the added sound, i.e., the pitch strength and/or loudness of the tonal component of the added sound. This finding provides converging evidence that the interference effect does not primarily depend on the amount of energy present in the dominant region for pitch for the F0 used, and rules out an origin for the interference effect at a very peripheral stage of processing. Together with the findings from experiment 1, it suggests interference at the level of pitch processing itself.

IV. EXPERIMENT 3: PITCH SALIENCE VERSUS ENVELOPE MODULATION OF THE INTERFERER

The first two experiments showed that the tonality of the added sound and the similarity between the F0s of the target and interferer played a crucial role in PDI. In an attempt to further clarify the characteristics of the interference process, the next two experiments explored the role of two other aspects of a complex tone interferer, its resolvability and its degree of envelope modulation.

Resolved components are dominant in determining the pitch of a complex tone (Plomp, 1967; Ritsma, 1967; Ritsma, 1970; Moore *et al.*, 1985), and the pitch produced by complex tones containing resolved components is more salient than that produced by complexes containing only unresolved components (Houtsma and Smurzynski, 1990; Shackleton and Carlyon, 1994). As mentioned in the Introduction, if there exists only one common pitch mechanism, then one might expect the pitch estimate to be dominated by whatever components of the input give the strongest pitch. Therefore, one would predict more interference on F0 discrimination between two unresolved target tones by a resolved interferer than by an unresolved one. In contrast, if there exist two different *independent* pitch mechanisms whose outputs can be assessed independently, then one would not expect to see any PDI in the presence of a resolved interferer. However, PDI would be expected in the presence of an unresolved interferer, as this would feed into the same pitch mechanism for unresolved components as the target. If two *non*independent pitch mechanisms exist, then interference would be expected with both, resolved and unresolved interferers.

In the latter case, the relative amount of interference observed in the presence of a resolved or an unresolved interferer might depend on when the interference occurs. If the inteference across mechanisms occurs relatively early, then one might expect the unresolved interferer to be more disruptive than the resolved interferer. The reasoning for this is as follows. First, only an unresolved complex would feed directly into the putative pitch mechanism specific for unresolved components. Second, the unresolved interferer will produce a higher degree of envelope modulation at the outputs of the excited auditory filters than a resolved one. As the pitch of the unresolved target complex will partly or mainly be derived from envelope cues, one might expect more interference from an added complex with a strongly modulated internal envelope than from one with less modulation, i.e., an interference that is related to MDI *within* the putative specific pitch mechanism for unresolved complexes might be present. If the interference across mechanisms occurs at a late stage, i.e., after the pitch within each mechanisms has been estimated, then one might expect more interference in the presence of a resolved than an unresolved interferer, due to the more salient pitch evoked by the former. Experiments 3A and 3B investigated these possibilities.

A. Experiment 3A

1. Stimuli and procedure

The basic task and procedure were the same as in the first experiment. The stimuli differed in the following way: Listeners had to discriminate between the F0s of two sequentially presented target tones which had a nominal F0 of either 88 or 250 Hz. Each target was bandpass filtered between 3900 and 5400 Hz (3 dB down points, a slope of 48 dB/oct); thus, for both F0s it contained only unresolved components (Plomp, 1964; Carlyon and Shackleton, 1994). The target was either presented alone, or it was accompanied by an interferer with an F0 which was identical to that of the nominal target F0. The interferer was bandpass filtered between 1375 and 1875 Hz (3 dB down points, slope of 48 dB/oct). For the 88 Hz F0 this meant that the interferer's components were unresolved, while for the 250 Hz F0 they were resolved. As in the previous experiments, the level per component was 45 dB SPL for both target and interferer. For all subjects ΔF0 was equal to 3.5%.

To mask possible distortion products, a continuous pink background noise was presented with a spectrum level of 15 dB SPL at 1 kHz; this level was comparable to that of the lowpass-filtered white noise background used in experiment 1. Five blocks of 100 trials each were run for each condition and subject. The order of the conditions was counterbalanced within and across subjects. One block was run for each condition in turn, before additional blocks were run in any other condition. Subjects participated in at least one session, before data collection proper was started.

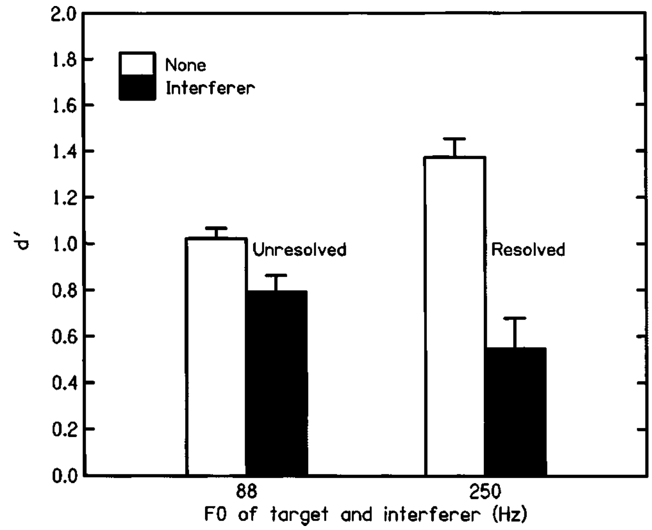

FIG. 4. The mean performance, and the associated standard errors (across subjects) obtained in experiment 3A. d' for F0 discrimination is plotted as a function of condition. The left two columns are for targets with a nominal F0 of 88 Hz, and the right two columns are for targets with a nominal F0 of 250 Hz. The white and black columns show performance in the absence and in the presence of an interferer with F0 corresponding to the nominal target F0, respectively.

Seven subjects participated in all four conditions. Five of them had considerable musical experience. Five of the seven subjects had also taken part in experiment 1, and five had also participated in experiment 2.

2. Results and discussion

Figure 4 shows the mean results and the corresponding standard errors across subjects. The left two columns are for targets with a nominal F0 of 88 Hz, and the right two columns are for targets with a nominal F0 of 250 Hz. The white and black columns show d' in the absence and in the presence of an interferer, respectively. The results show that adding an interferer with an F0 which is identical to the nominal F0 of the target always impaired performance. The important finding here is that performance was impaired more when the interferer was resolved than when it was unresolved. These results were confirmed by the outcome of a repeated-measures two-way ANOVA (with factors F0 and interferer), which showed that the main effect of the presence of the interferer $[F(1,6)=63.2,\ p<0.001]$ and the interaction between F0 and presence of the interferer $[F(1,6)=23.2,\ p=0.003]$ were both highly significant; the effect of the presence of the interferer was significant for the 88 Hz F0 $[F(1,6)=9.6,\ p=0.021]$ and highly significant for the 250 Hz F0 $[F(1,6)=61.7,\ p<0.001]$. There was no main effect of F0.

In summary, performance was impaired most in the presence of the interferer which contained resolved components, i.e., dominant components with regard to pitch. This interferer had the more salient pitch, but a smaller degree of envelope modulation than the unresolved interferer. These results are not consistent with predictions based on the concept of two seperate pitch mechanisms, whose outputs can be assessed independently.

B. Experiment 3B

1. Stimuli and procedure

The basic task and procedure were the same as in experiment 3A. However, the stimuli differed. The characteristics of the interferer were manipulated in a different way from experiment 3A so that the pitch and the spectral region of the interferer stayed constant, even though the resolvability of the harmonics and the pitch strength were varied.

The nominal F0 of the target was 88 Hz and it was bandpass filtered between 1500 and 15 000 Hz (3 dB down points, a slope of 48 dB/oct); thus, it contained many components, all of which were unresolved. The target was either presented alone, or it was accompanied by an interferer, which was bandpass filtered between 250 and 750 Hz (3 dB down points, slope of 48 dB/oct). The interferer either had an F0 of 88 Hz, in which case its components were added in sine phase (condition 88-Sine), or it had an F0 of 44 Hz with components added in alternating phase (condition 44-Alt). In condition 88-Sine, the interferer's components were resolved, while they were expected to be unresolved in condition 44-Alt (Moore, 1993; Moore and Ohgushi, 1993). In the latter, the pitch of the interferer approximately corresponded to that of the 88 Hz F0 sine-phase complex (Flanagan and Guttman, 1960; Shackleton and Carlyon, 1994). Note, however, that the pitch of the alternating-phase complex was less salient than that of the sine-phase complex, while its degree of envelope modulation at the output of the auditory filters was greater. The latter follows from the fact that resolved components produce hardly any envelope modulation at the output of auditory filters centered on the frequency of the resolved components, while auditory filters centered at the frequency of unresolved components show an envelope modulation with a modulation rate corresponding to the repetition rate of the original waveform (see, e.g., Fig. 6.6 in Moore, 2003). For the 88 Hz F0 interferer, the level per component was 45 dB SPL (as in the experiments before), while for the 44 Hz F0 interferer the level per component was reduced to produce the same rms level for the two interferers.

For all subjects ΔF0 was equal to 3.5%. As in experiment 1, a continuous white background noise was presented with an overall rms level that—in the frequency region of the interferer—was 10 dB below that of the interferer. It was lowpass filtered at the lower cutoff frequency of the target (nominally 1500 Hz) with a slope of 96 dB per octave. Between four and five blocks with 100 trials each were run for each condition and subject. The order of the conditions was counterbalanced within and across subjects. One block was run for each condition in turn, before additional blocks were run in any other condition. Subjects participated in at least one session, before data collection proper was started.

Seven subjects participated in all three conditions. Four of them had considerable musical experience. All subjects took part in at least one of the earlier experiments before participating in this one.

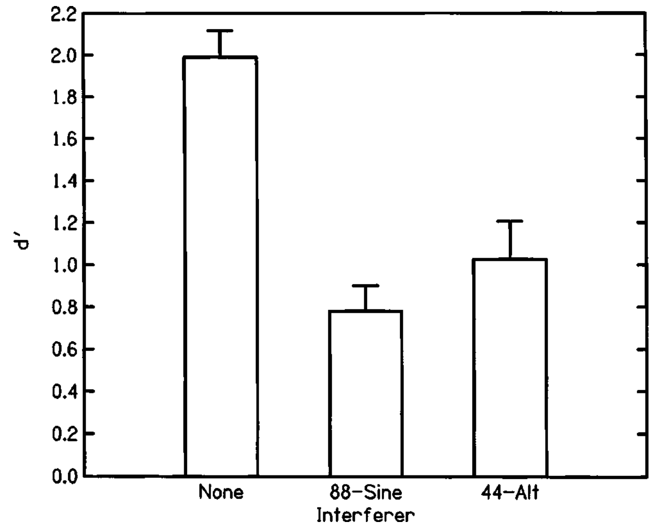

FIG. 5. The mean performance, and the associated standard errors (across subjects) obtained in experiment 3B. d' for F0 discrimination of a nominal 88 Hz target, bandpass-filtered into a frequency region between 1500 and 15 000 Hz, is plotted for each type of synchronously gated interferer (bandpass filtered between 250 and 750 Hz).

2. Results and discussion

Figure 5 shows the mean results and the corresponding standard errors across subjects. As was expected, both interferers reduced performance relative to that without an interferer [88-Sine: $F(1,6)=48.6$, $p<0.001$; 44-Alt: $F(1,6)=21.0$, $p<0.01$]. However, the question of interest here was whether condition 88-Sine would lead to worse performance than condition 44-Alt. Importantly, performance was significantly worse in condition 88-Sine than in condition 44-Alt. This was confirmed by the outcome of a repeated-measures one-way ANOVA [$F(1,6)=6.93$, $p<0.05$] in which only d' values from conditions 88-Sine and 44-Alt were used, in order to avoid getting a significant effect because of the difference between performance in the absence and in the presence of an interferer. Even though the size of the effect was small (the average difference between d' values in the two interferer conditions was 0.25), only one out of seven subjects showed a small difference (the smallest absolute difference of all subjects with a value of 0.04) in the opposite direction. In summary, performance was impaired most in the presence of the interferer which contained resolved components and had the more salient pitch. The higher degree of envelope modulation for the alternating-phase interferer did not produce more impairment than that observed for the interferer whose envelope was less modulated. Thus, the findings from experiment 3B are in agreement with those from experiment 3A.

Overall, the findings from experiments 3A and 3B indicate that the PDI observed with an unresolved target depends more on the pitch strength of the interferer than on the presence of unresolved components, which produce a higher degree of envelope modulation in the auditory periphery. These findings are not compatible with the existence of two independent pitch mechanisms whose outputs can be assessed independently. The current findings are consistent with either interaction in one common pitch mechanism, or, the existence of two pitch mechanisms whose outputs cannot be consciously assessed independently but instead are combined at a later stage. In the latter case, the outputs of the two pitch mechanisms would have to be combined at a *later* stage (after the individual pitch estimates have been derived), in order to explain that PDI is larger for a resolved interferer than for an unresolved interferer; the estimated pitch from the pitch mechanisms for resolved components would be more salient than the estimated pitch from the mechanism for unresolved components, and thus could dominate the consciously perceived pitch.

V. EXPERIMENT 4: EFFECT OF ONSET ASYNCHRONY OF INTERFERER

In all the experiments described so far, the interferer and the target were gated synchronously. This would have promoted perceptual grouping of the two. The last two experiments investigated the role of perceptual grouping in PDI. Onset asynchrony is one of the strongest cues for perceptual segregation (Darwin and Carlyon, 1995; Gockel, 2000). For example, Darwin and Ciocca (1992) showed that the influence of a mistuned fourth component on overall pitch of a complex tone was eliminated once the onset asynchrony between the mistuned component and the remaining harmonic complex was increased to 320 ms. As the remaining complex contained harmonics 1–12, this shows that *within* one pitch mechanism the contribution of part of the sound on the overall pitch can be reduced in the presence of a strong cue for perceptual segregation. Therefore, for the present experiments it was expected that introducing an onset asynchrony between interferer and target would reduce or even eliminate the interference effect.

A. Experiment 4A: Asynchronous interferer

1. Stimuli and procedure

The basic task and procedure were the same as in the first experiment. Five conditions were tested. The first condition (None), was a replication of condition None in experiment 1; the unresolved target with a nominal F0 of 88 Hz, bandpass filtered between 1375 and 15 000 Hz was presented together with a low-level continous lowpass-filtered white noise background. The second condition (CN−10), replicated the condition named ‘‘0’’ of the first experiment. It differed from condition None only through the presence of a synchronously gated resolved interferer with an F0 of 88 Hz (bandpass filtered between 125 and 625 Hz). The third condition (AsyInt) was new; while the target had the same 400 ms duration as before, the interferer started 200 ms before and stopped 200 ms after the target. Since the silent time between the two intervals within a trial was kept constant at 500 ms, this meant that the targets were now separated in time by 900 ms. To check whether the increased time between the two target stimuli might affect performance, a fourth condition (LongIsi) was run in which no interferer was presented and where the targets were separated by 900 ms. Finally, the fifth condition (CN+10) was similar to condition CN−10, except that the level of the continuous lowpass filtered noise was increased by 20 dB. This condition was included to check whether the lowpass noise could re-

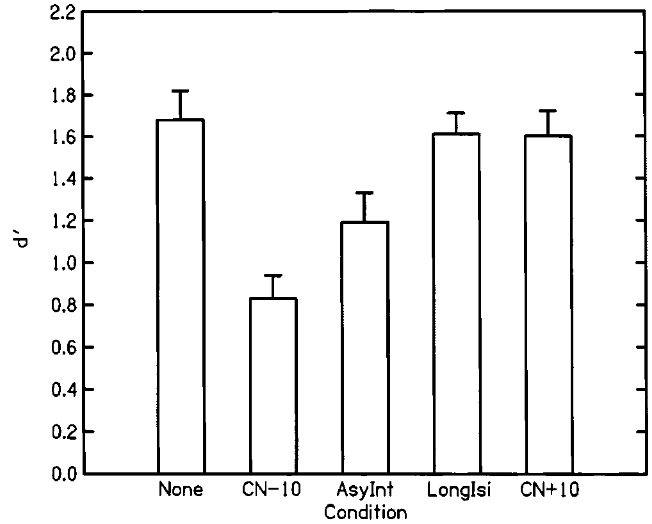

FIG. 6. The mean performance, and the associated standard errors (across subjects) obtained in experiment 4A. d' for F0 discrimination of a nominal 88 Hz target, bandpass filtered into a frequency region between 1500 and 15 000 Hz, is plotted for the five conditions used. See text for details of the conditions.

store performance back to that observed in the absence of an interferer, when presented at a high level so that it would nearly mask the interferer; and presented continuously, so that it would very likely be segregated from the target.

For five subjects, ΔF0 was 3.5% and for the sixth it was 2%. Four to five blocks of 100 trials were run for each condition and subject. The order of the conditions was counterbalanced over subjects. One block was run for each condition in turn, before additional blocks were run in any other condition.

Six subjects participated in all five conditions. Five of the six subjects had considerable musical experience, and five subjects took part in at least two of the previous experiments. Subjects participated in at least one practice session (three for the fresh subject), before data collection proper was started.

2. Results and discussion

Figure 6 shows the mean results and the corresponding standard errors across subjects. Performance in condition CN−10 was reduced by about 0.9 d' units compared to that observed in the absence of an interferer (None). This reduction was very similar to that observed in experiment 1 for identical stimuli. When the interferer was gated asynchronously with the target (condition AsyInt), performance improved relative to that observed for synchronous gating (condition CN−10). However, performance in condition AsyInt was lower than in condition None. Performance in condition LongIsi was similar to that in condition None. This means that the increased time between the two target stimuli within a trial was not the reason for the impairment observed in condition AsyInt. Finally, performance in condition CN+10 was similar to that observed in condition None. This shows that a continous lowpass noise which spectrally overlaps with the interferer, and which is intense enough to nearly mask it, can bring performance back to that observed in the absence of an interferer. Note that one would not necessarily expect to see the same restoration effect with a *synchronously* gated lowpass noise of the same level. Remember that the results of experiment 2 showed improved performance with increased level of a synchronously gated lowpass noise. Performance in condition +10 dB for ΔF0 of 3.5% in experiment 2 was lower than that observed here with continous presentation of the same lowpass noise (condition None was not measured in experiment 2). Thus, it seems that gating the noise synchronously with the target might impair performance. However, the subjects were not all the same in experiment 2 and experiment 4A, and the subjects in common participated in experiment 4A after they ran in experiment 2. Therefore, this conclusion has to be treated with some caution.

To examine the statistical significance of the results, a repeated-measures one-way ANOVA (with five levels for the factor condition) was calculated, using the mean d' value for each subject and condition as input. This showed a highly significant main effect of condition [$F(4,20)=30.3$, $p<0.001$]. Calculation of simple contrasts, with condition None as the reference condition, showed that only condition CN−10 [$F(1,5)=67.2$, $p<0.001$] and condition AsyInt [$F(1,5)=14.4$, $p=0.01$] differed significantly from condition None. Performance in condition AsyInt was significantly better than that observed in condition CN−10 ($p=0.01$).

To summarize, asynchronous gating of the interferer and target reduced PDI relative to that caused by a synchronously gated interferer. Under the assumption that one single pitch mechanism exists, this would mean that perceptual segregation due to the 200 ms onset and offset asynchrony took place before the pitch estimate was derived and thus was able to influence the output of the pitch mechanism, at least to a certain degree. As mentioned earlier, Darwin and Ciocca (1992) reported that perceptual segregation due to onset asynchrony eliminated the contribution of a single mistuned harmonic to the overall pitch of a complex tone. As the mistuned harmonic was a low resolved harmonic and the harmonic complex contained resolved harmonics this gave evidence for the influence of perceptual segregation affecting the pitch of stimuli that would be processed *within* one pitch mechanism, i.e., either within the mechanism for the pitch of resolved components or within the common pitch mechanism. Hence, onset asynchrony can reduce across-frequency integration of information, even when that integration clearly occurs within a single pitch mechanism. This means that the observed reduction in PDI due to onset asynchrony cannot be used as an argument in favor of two pitch mechanisms.

In the present experiment, the imposed 200 ms asynchrony was not as effective in reducing the observed PDI as the continous higher-level lowpass noise. Therefore, we investigated in experiment 4B whether PDI could be eliminated by presenting the interferer continuously.

B. Experiment 4B: Continuous interferer

1. Stimuli and procedure

The task and procedure were the same as in experiment 4A. Three conditions were tested. The first two conditions, None and Syn.I. were replications of conditions None and

CN−10 in experiment 4A, respectively. The only difference from the corresponding conditions in experiment 4A was the absence of random variation of sample rate across trials in the present experiment (see later). In the third condition, the 88 Hz F0 interferer was presented continuously (condition Cont.I.); this was the only difference with respect to condition Syn.I. To produce a continuous interferer, the harmonic complex was generated and filtered in advance, and was then recorded on audio CD. During the experiment, it was played from audio CD and fed into a separate attenuator, whose output was then added via a headphone buffer to the target stimuli and the continuous low-level noise. This setup did not allow us to randomize the sample rate of the target and interferer together. Thus, there was no random variation of the sample rate of the stimuli in experiment 4B. Without random variation of the sample rate between trials, the task was easier. Thus, to avoid ceiling effects, ΔF0 was reduced to 2% for three subjects, and was kept at 3.5% for the fourth subject. Four to seven blocks of 100 trials were run for each condition and subject. The order of the conditions was counterbalanced over subjects. One block was run for each condition in turn, before additional blocks were run in any other condition.

Four subjects participated in all three conditions. All of them had participated in experiment 4A. Three of the four had considerable musical experience and were those who showed more impairment in condition AsyInt in experiment 4A than other subjects. The fourth subject had only shown a very slight impairment in performance in condition AsyInt. The other two subjects from experiment 4A, both with considerable musical experience, were no longer available. One of these had shown a medium impairment and the other had shown hardly any impairment in condition AsyInt. Subjects participated in at least one practice session before data collection proper was started.

2. Results and discussion

Figure 7 shows the mean results and the corresponding standard errors across subjects. Performance in condition Syn.I. was reduced by about 0.87 d' units relative to that observed in the absence of an interferer (None). This reduction was very similar to that observed in experiment 4A for identical stimuli, except for the roving of the sample rate between trials. For the continuous interferer, performance was much improved relative to that observed in condition Syn.I.; however, it was still somewhat below that in condition None. The main interest of the present experiment was to test whether presenting the interferer continuously would restore performance to that observed in the absence of an interferer. To assess this, a related measures *t* test was calculated on the data from those two conditions. This showed that performance in condition None was significantly better than in condition Cont.I. [$T(3)=3.1$, $p_{\text{one-sided}}=0.027$]. For comparison, the same test, calculated for the same four subjects only on the data from conditions None and AsyInt in experiment 4A, resulted in $T(3)=3.8$ and $p_{\text{one-sided}}=0.016$.

In summary, presenting the interferer continously markedly reduced PDI relative to that caused by a synchronously gated interferer. The reduction was greater than found for an

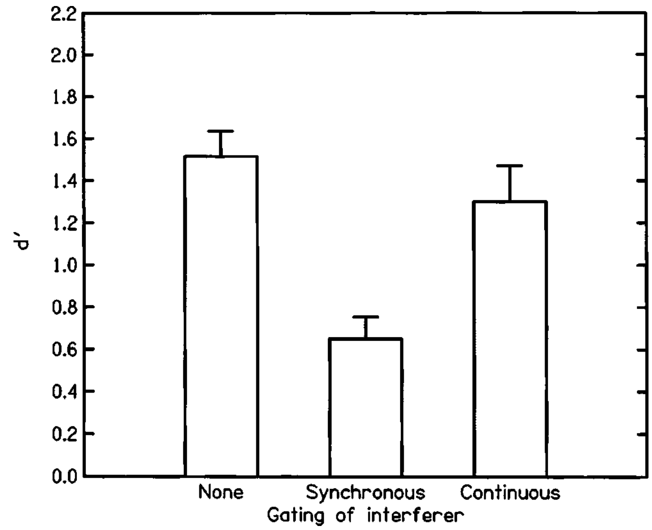

FIG. 7. The mean performance, and the associated standard errors (across subjects) obtained in experiment 4B. d' for F0 discrimination of a nominal 88 Hz target, bandpass filtered into a frequency region between 1500 and 15 000 Hz, is plotted for the three conditions used. See text for details of the conditions.

asynchronously presented interferer. However, performance was still slightly below that observed in the absence of an interferer.

VI. GENERAL DISCUSSION

Evidence for a new type of interference in the pitch domain has been presented. F0 discrimination between sequentially presented complex tones containing only unresolved components was impaired in the presence of a simultaneous complex tone containing resolved harmonics, even though target and interferer were filtered into well separated spectral regions. The interference effect was tuned to the similarity between the F0s of target and interferer, indicating a central origin. A relatively broad tuning was observed; interferers with an F0 of 20%–30% above that of the target still produced a small impairment in F0 discrimination, even though interferer and target were clearly segregated. This tuning is much wider than that observed for the influence of a mistuned harmonic on the pitch of the overall harmonic complex; Moore *et al.* (1985) showed that pitch shifts caused by a mistuned harmonic approached zero at about 8% mistuning (with the maximum pitch shift arising at about 2%–3% mistuning). Also, Moore *et al.* (1986) found that a harmonic was sufficiently mistuned to be heard as a separate tone with mistunings between 1.3% and 2%, an amount of mistuning where the harmonic would still significantly contribute to overall pitch. Thus, a duplex region existed where sounds were perceptually segregated but nevertheless information from the two sounds was combined to some extent when determining the overall pitch. Subjective reports in experiment 1 of the present study support the existence of a duplex region in PDI too; even when target and interferer were perceptually segregated, a small interference effect was present. The generally broader tuning found in PDI than that found with a single mistuned harmonic might be a consequence of the fact that in the former paradigm the pitch investigated (via discrimination of F0) was that of an unresolved target complex while in the latter paradigm the investigated pitch was that of a complex tone containing resolved components. The former would have a less salient pitch than the latter even when presented alone. And of course, in the former the interferer was a complex tone containing several resolved components while in the latter the ''interference'' arose from one individual component only. These points might explain why PDI extends to greater F0 separations and might also explain why, even with a continuous interferer, some residual PDI was observed. Note that even though the influence of a mistuned component on overall pitch and its tuning characteristic has often been discussed in terms of a harmonic sieve (Moore *et al.*, 1985; Moore *et al.*, 1986; Darwin *et al.*, 1994) this does not imply that such an influence and tuning can *only* be represented within a class of models where pitch is derived by a pattern matching process across resolved harmonics (Goldstein, 1973; Terhardt, 1974).

The existence of PDI is compatible with the notion of one common pitch mechanism for resolved and unresolved components. The specific characteristics of the results are consistent with the dominant pitch produced by the resolved harmonics ''swamping'' the estimate of the F0 of the unresolved target, and with this interference occurring in a common pitch mechanism. Alternatively, if two different pitch mechanisms exist, then the existence of PDI indicates that they are not independent. Furthermore, the specific characteristics of PDI demonstrated in experiments 3A and 3B indicate that if two mechanisms exist, then the output of these two mechanism seems to be combined compulsorily at a relatively late stage, and the conscious pitch estimate is dominated by the more salient *output* of the resolved mechanism.

One of the most influential studies providing positive evidence for the existence of two pitch mechanisms was presented by Carlyon and Shackleton (1994). Their subjects had to compare the pitch of two simultaneously presented complex tones. The stimuli they used were quite similar to the ones employed here. The tones were bandpass filtered in either a LOW (125–625 Hz), MID (1375–1875 Hz), or HIGH (3900–5400 Hz) spectral region, and had an F0 of either 88 or 250 Hz. Depending on the combination of spectral region and F0, the complexes contained either mainly resolved harmonics (88-LOW, 250-LOW, 250-MID) or only unresolved harmonics (88-MID, 250-HIGH, 88-HIGH). The two complexes whose pitch had to be compared were always filtered into two different spectral regions.

Carlyon and Shackleton (1994) also measured performance for F0 discrimination of each of the complex tones alone (for each nominal F0 and spectral region) in the classical way, i.e., the tones were presented sequentially on their own. Performance in this sequential, within spectral region task was then used to estimate the noise associated with the encoding of F0. Within the framework of a model based on signal detection theory, those estimates were then used to derive predictions for F0 discrimination performance in experimental conditions where two complexes were presented *simultaneously*. The results showed that performance in the simultaneous task was worse than predicted when the two complexes differed in resolvability, but was not worse than predicted when they were both resolved. Note that the authors excluded from further analysis the simultaneous condition with two unresolved complexes because an additional cue was present in this specific condition. In order to explain why performance was worse than predicted when the simultaneous complexes differed in resolvability, but was not worse than predicted when they were both resolved, an additional ''translation noise'' was assumed; this was supposed to arise when the output from two different pitch mechanisms had to be compared. The need to assume an extra translation noise when predicting performance in the simultaneous F0 discrimination task from that observed in the sequential F0 discrimination task is the evidence Carlyon and Shackleton (1994) presented for the existence of two pitch mechanisms.[2]

The current experiments showed that the presence of an additional resolved complex tone significantly impaired F0 discrimination between two sequentially presented unresolved complexes. Thus, even though the two target tones had the *same* resolvability, performance was impaired simply due to the presence of another complex tone with similar F0. This means that Carlyon and Shackleton's (1994) performance predictions for F0 discrimination between two simultaneously presented complex tones probably were too high as they were based on performance measured in conditions were each stimulus was presented alone. Predicted performance would have been lower had predictions been derived from base line conditions where the sequentially presented target complex was accompanied by another complex tone.

A similar reasoning was used by Moore *et al.* (1984) with regard to the question of what constitutes the correct base line condition to determine the precision of the representation of individual components of a complex tone at the input to a central pitch processor (Goldstein, 1973). Moore *et al.* (1984) argued that the right measure was not the frequency DL of each component in isolation, but rather the frequency DL of each component when presented within the complex tone; they showed that, contrary to Goldstein's conclusion, no extra noise within channels conveying information from the periphery to the central processor was needed to account for precision of the estimate of the residue pitch, if the latter condition was used as base line. Similarly, the current study shows that probably no extra translation noise is necessary to explain the finding of Carlyon and Shackleton (1994) that performance was lower than predicted in conditions with two simultaneous tones differing in resolvability. Thus, the current findings question the basis of Carlyon and Shackleton's (1994) argument for two distinct pitch mechanisms.

Compatible with this, Micheyl and Oxenham (2003) did not find any evidence for translation noise when F0 discrimination was measured for two complex tones presented sequentially. In the study of Micheyl and Oxenham (2003) (see also Oxenham *et al.*, 2004) the sequentially presented complex tones were filtered into either the same or a different spectral region. Depending on the nominal F0 used in a given condition, this resulted in the two tones either having the same or different resolvability. Their results showed that there was a large noise related to the comparison of F0 across spectal region, i.e., the timbre difference between the two sounds resulting from filtering into different spectral regions severely impaired performance. They did not need to assume an additional noise in order to successfully predict performance in conditions where the resolvability of the two tones differed based on performance observed in conditions where the two tones had the same resolvability.

In summary, the present results provide an alternative interpretation for the findings of Carlyon and Shackleton. The current findings are compatible with either the notion of one common pitch mechanism for resolved and unresolved components, or with the notion of two different mechanisms whose outputs at some higher stage cannot be accessed independently. Theoretically, one possible realization of such a higher stage interference could be an interference in memory. It has been shown that same/different judgements on pairs of complex tones separated by some time interval (around 4–5 s) was significantly impaired if other tones with similar pitch were presented during the retention interval (Semal and Demany, 1991; Semal and Demany, 1993). A similar interference in memory might have caused the PDI in the current experiments where two complex tones have been presented simultaneously. However, the fact that onset asynchrony significantly reduced PDI (experiment 4A) argues against an explanation of PDI mainly in terms of interference in memory. The onset asynchrony led subjects to perceive two sound sources instead of one (at least for small differences between the F0s of target and interferer where PDI was largest). In Semal and Demany's experiments several sound events were always heard, and introducing differences between the timbres of the target sounds and the interfering sounds hardly affected the observed pitch interference in auditory short-term memory. In contrast in the present experiment, PDI was substantially reduced when subjects heard two sound sources due to the onset asynchrony. Furthermore, the onset asynchrony in experiment 4A led to subjects hearing the interferer alone after presentation of the target in the first interval and before presentation of the target in the second interval. Thus, according to the ''interference in memory'' hypothesis one might even expect performance to be *worse* in the presence of onset asynchrony than with synchronous onsets of target and interferer. Therefore, it seems unlikely that PDI was mainly caused by a higher-stage interference in memory. Under the assumption that two pitch mechanisms exist, PDI rather seems to occur at the level where a conscious pitch estimate is derived.

A particularly influential example of a unitary model, termed the ''autocorrelogram'' model, can also account for the fact that, for a given F0, the lower harmonics give rise to a more salient pitch than do the unresolved harmonics (Meddis and Hewitt, 1991; Meddis and O'Mard, 1997). This latter prediction arises from a deterioration in phase locking with increasing frequency. However, this model has also been challenged (Carlyon and Shackleton, 1994; Shackleton and Carlyon, 1994; Carlyon, 1998; Kaernbach and Demany, 1998; Plack and White, 2000b; Kaernbach and Bering, 2001; Carlyon *et al.*, 2002b). One example comes from an experiment by Shackleton and Carlyon (1994), who showed that, when two complexes of different F0s are filtered into the same spectral region, the DLF0 still depends strongly on resolvability—even though the accuracy of phase locking is the same in the two cases, causing the model to predict no consistent effect of resolvability (Shackleton and Carlyon, 1994; Carlyon, 1998). This and other findings question the ability of the autocorrelogram model—in its current form—to account for all the data on the pitch of resolved and unresolved harmonics. Modifications like restricting and varying with center frequency the range of interspike intervals that can be analyzed as suggested by Moore (1997) and Bernstein and Oxenham (2003a) might improve on this. We conclude that, although existing models of pitch perception fail to capture the effects of resolvability on DLF0s, much of the experimental evidence is consistent with a unitary, but as yet unspecified, pitch mechanism.

VII. SUMMARY AND CONCLUSIONS

(1) Experiment 1 showed the existence of pitch duscrimination interference (PDI). F0 discrimination between two sequentially presented complex tones containing only unresolved components was severely impaired in the presence of another complex tone with similar F0 and resolved components, even though the target and interferer were filtered into well separated spectral regions. PDI decreased with increasing difference in F0 between the interferer and the target.

(2) Experiment 2 demonstrated further the crucial role of the tonality of the added sound in PDI. Increasing the level of a synchronously gated lowpass noise which spectrally overlapped with a complex tone interferer reduced PDI.

(3) Experiment 3A showed that PDI was larger when the interferer contained resolved components than when it contained only unresolved components. In experiment 3B, PDI was larger for a resolved interferer with components added in sine phase and F0 identical to the nominal target F0 than for an unresolved interferer with components added in alternating phase and F0 half that of the nominal target F0, but with a pitch equal to that of the target. This indicates that the pitch salience of the interferer plays a crucial role in PDI while its degree of envelope modulation after auditory filtering is less important.

(4) Experiment 4A showed that an interferer gated on 200 ms before and off 200 ms after the target produced less PDI than when gated synchronously with the target. Interference could be reduced further by presenting the interferer continuously; however, even then some residual impairment was observed (experiment 4B).

The current findings provide an alternative explanation for Carlyon and Shackleton's (1994) pattern of results; there might be no need to postulate additional translation noise when comparing F0 estimates for resolved and unresolved harmonics. The observed interference in the pitch domain between simultaneously presented complex tones that are well separated in spectral region might explain their pattern of results. The current results are consistent with the existence of one common pitch mechanism and question Carlyon and Shackleton's evidence for two pitch mechanisms.

ACKNOWLEDGMENTS

This work was supported by EPSRC Grant No. GR/R65794/01. The authors thank Brian Moore for helpful discussions and comments on an earlier version of this paper. They also thank Chris Darwin, Christophe Micheyl, Andy Oxenham, and Neil Viemeister for helpful comments.

[1]Throughout the paper, if appropriate, the Huynh–Feldt correction was applied to the degrees of freedom (Howell, 1997). In such cases, the corrected significance value is reported.

[2]The evidence is *not* their finding that in the simultaneous F0 discrimination task performance was better when the two complexes had the same resolvability status than when they differed in resolvability. This finding on its own does not provide an argument for the existence of two pitch mechanisms (even though it is sometimes used as if it would). The reason for this is that performance for F0 discrimination of unresolved complexes alone was worse than that of resolved complexes alone. Therefore, it had to be expected that in a task which requires the combination of the two, performance would be limited by the harder task. This logic explained why F0 discrimination of two simultaneously presented resolved complexes would be expected to be better than F0 discrimination of one resolved and one unresolved one. Thus, comparison between performance levels obtained in the various conditions with simultaneously presented pairs of complexes as such cannot and was not used by the authors when they argued in favor of two pitch mechanisms.

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