I. INTRODUCTION

Sound localization depends on a variety of localization cues present at each ear. Monaural cues arise from the spectral modifications of incoming sound by the external ear and binaural cues arise as a result of differences in the sound at the two ears. At the level of the cochlea, the sensory epithelia encode frequency and project into the auditory nervous system as tonotopic maps of frequency. However, auditory localization depends on higher-order computational processing that extracts the monaural and binaural location cues from this ordered frequency representation. The generation of a neural representation of space, and hence the accurate perception of auditory space, requires a complex integration of both monaural and binaural inputs (see Carlile, 1996a for review).

Physiological investigations of the neural representation of auditory space in the barn owl (Knudsen and Konishi, 1978a, b; Knudsen et al., 1987) and the mammalian superior colliculus (e.g., guinea pig: King and Palmer, 1983; ferret: King and Hutchnings, 1987; Carlile and King, 1994a, b; cat: Middlebrooks and Knudsen, 1984) have demonstrated neurons whose response rates vary systematically as a function of the spatial location of the sound source. The topographic arrangement of these neurons is consistent with the notion of a neural map of auditory space at least at these levels of the central nervous system. Furthermore, there is some evidence for lateral interactions between these “space-mapped” neurons (Knudsen and Konishi, 1978a, b; King et al., 1990). In the study reported here we were interested in examining how this kind of “space-selective” processing might be manifest psychophysically in human subjects.

One way in which psychophysical studies have been used to examine complex sensory processes is via the phenomena of adaptation and aftereffects. Following prolonged exposure to a constant stimulus, a variety of perceptual distortions have been described. Such effects have been demonstrated in early experiments examining the perception of sound location using a range of adapting stimuli. Flugel (1921) and Bartlett and Mark (1922) described an auditory localization aftereffect following exposure to both binaural and monaural sound sources. In these early studies, stimulus levels were manipulated by adjusting the lengths of rubber tubing that delivered the sound stimuli to each ear. Under such stimulus conditions, sounds were lateralized within the head rather than localized in the free-field. The sound stimulus was adjusted by the subjects both prior to and following
stimulation by “fatiguing” tones so that it was perceived to be located in the center of the head. Following stimulation of one ear by an adapting tone, there was a systematic displacement of subsequent binaural stimuli to locations away from the ear to which the adapting tone was presented.

Lateralization experiments by Elffner and Perrott (1966) using headphone presentation of three different tone stimuli (i.e., 700, 1000, and 3000 Hz) demonstrated shifts in the auditory image following prolonged exposure to binaural intensity mismatches of up to 126 min. The results indicated that in most cases, the perceived location of the test stimulus was shifted toward the ear receiving the less intense stimulus. However, in some cases the shift was toward the ear where the adapting stimulus was more intense. These variations might be explained by the mismatch between the frequency of the adapting stimulus and the test stimulus.

Studies by Krauskopf (1954) and Taylor (1962) confirmed the initial observations by Flugel. Both these later experiments were conducted using free-field stimuli. In the first study, subjects adjusted the location of a sound stimulus so that it appeared to lie on the median plane both before and after a 2-min exposure to an adapting broadband stimulus. In the second experiment, subjects indicated the location of the test stimulus using a spatial scale. Prolonged exposure to the adapting stimulus on one side of the median plane shifted the subjects’ perception of the midline away from the adapting stimulus. Taylor (1962) measured the magnitude of this perceived displacement when the separation between the test and adapting stimulus locations was varied. The magnitude of the displacement increased as a function of the increasingly lateral location of the adapting stimulus and peaked at 3° when the adapting stimulus was located at around 30° off the midline. Both free-field and headphone-based studies yield qualitatively similar results. This supports the notion that the headphone-based studies are examining similar processes as those measured in free-field studies, despite some differences in the perceptual experience under each condition.

The results of Curthoys (1968), Elffner and Perrott (1966), and Thurlow and Jack (1973) all confirm the earlier findings of a displacement of perceived target location away from the adapting stimulus: a so-called “repulsion effect.” In a series of headphone-based studies, Thurlow and Jack (1973) demonstrated that offsets of interaural time and interaural level differences were equally successful in generating this aftereffect, although the results were less straightforward when interaural time and level differences were traded off as test and adapting stimuli, respectively.

Comparison of the absolute magnitude of the aftereffect across previous studies is complicated by the fact that the duration of the adapting stimuli varied considerably (from 10 s to a few minutes), the acoustic environments varied (headphone, free-field, anechoic) and in some free-field studies, free head movement was allowed. However, despite these differences there is a general finding of a “repulsion” effect. Curthoys proposed that the auditory spatial aftereffect resulted from a level-dependent adaptation of the ear closest to the adapting stimulus that was greater than the adaptation in the further ear. He suggested that this unequal adaptation would lead to a shift of subsequently perceived locations away from the more adapted ear. The changes in the magnitude of the effect with increasing displacement of the adapting stimulus from the midline observed by both Taylor and Curthoys is in fact consistent with what is known about the location-dependent changes in interaural level differences (Carlile and Pralong, 1994) and the resulting difference in the adaptation of the two ears. This overall explanation of the auditory spatial aftereffect is dependent on the assumption that the sensitivity of the auditory system to interaural level differences is sufficiently dominant to explain the effects observed. However, such an explanation only explores how adaptation to ILD cues affects perception of the target location and ignores the potential roles of the ITD and spectral cues. Indeed, the work of Thurlow and Jack (1973) also indicate a role for interaural time cues in the generation of this aftereffect. In addition, in experiments using VAS stimuli where the interaural time cues have been set in conflict with other localization cues, there is some evidence to suggest that perception of spatial location is dominated by the interaural time difference cue when low frequencies are present (Wightman and Kistler, 1992).

However, a number of predictions can be made based on the adaptation model discussed previously (Curthoys, 1968). If the adapting stimulus is located to one side of the anterior midline, all the target positions, whether they be located between the adapting stimulus location and midline or between the adapting stimulus and interaural axis, would be predicted to shift toward the anterior midline and therefore toward the location of the less adapted ear. Furthermore, an adapting stimulus located directly in front of the subject (where interaural differences are zero) would adapt both ears equally and should result in no auditory spatial aftereffect. In this study we examined these aftereffects using a head pointing localization task for stimuli presented in anechoic free space (Carlile et al., 1997) where the subject had no preconceptions of the potential locations of the stimuli. In addition to testing the above-mentioned predictions, this approach also allowed an examination of the adaptation aftereffect over the dimensions of azimuth and elevation.

II. METHODS

We examined the ability of a total of fifteen human subjects to localize a sound source or a visual target before and after exposure to a free-field adapting auditory stimulus. The behavioral methods used in assessing localization accuracy have been described in detail previously (Carlile et al., 1997). Briefly, all training and testing took place in a dark, anechoic chamber. Within the chamber, a robot arm carrying a stimulus speaker and a light emitting diode (LED) could be moved to almost any location on the surface of an imaginary sphere surrounding the subject. A single-pole coordinate system was employed to describe stimulus position with azimuth 0° and elevation 0° (0°/0°) directly ahead on the audio-visual horizon of the subject. Upward elevation and rightwards azimuth increased positively. The position of the head was tracked using an electromagnetic positioning system (Polhemus, Isotrak). The receiver was mounted on top of the subject’s head using an adjustable head strap. A visual reference system, placed directly in front of the subject con-
sisting of red and green colored LEDs, worked in conjunction with the head tracker and could be used to indicate to the subjects the position of his or her head relative to the stimulus coordinate system. This system was used to aid the subject in placing his or her head in the calibrated start position at the beginning of each trial. In a supplementary experiment, the visual reference system was also used to assist the subject in keeping his or her head stationary during prolonged exposure to the adapting stimulus. Subjects underwent a period of training to assist them in reliably pointing toward the perceived target location with the nose. Once satisfied he or she was correctly indicating the perceived location of the target, the subject pressed a hand-held button and the position of his or her head was recorded (for details see Carlile et al., 1997).

Following the period of training, the baseline localization accuracy of each subject was determined (see Carlile et al., 1997). Subjects were required to localize a 150-ms noise burst (200 Hz–14 kHz±3 dB; 60 dB SPL) from 76 test positions. Subjects completed 4 such tests prior to undertaking the adaptation experiments, and the localization performance of each subject was within the normal range previously reported by this laboratory (Carlile et al., 1997).

Four adaptation experiments were carried out in the course of this study: two primary adaptation experiments and two supplementary experiments, the details of which are described below. In all experiments the testing procedure was divided into preadaptation and adaptation blocks of localization trials. Localization accuracy was determined over a spatial area surrounding the adapting speaker: Twelve test locations were arranged as two concentric rings centered on the location of the adapting stimulus with a spherical radius of around 6° and 17°, respectively. Stimuli were located on each ring with roughly equal circumferential spacing (see Fig. 1). In two separate experiments, adapting stimuli were located directly in front at 0°/0° (test positions: 0°/−15°; −15°/−8°; 15°/−8°; 0°/−5°; −5°/−2°; 5°/−2°; 0°/0°; −5°/2°; 5°/2°; 0°/5°; −15°/8°; 15°/8°; 0°/15°) and 30° to the right of the midline (test positions: 30°/−15°; 15°/−8°; 45°/−8°; 30°/−5°; 25°/−2°; 35°/−2°; 30°/0°; 25°/2°; 35°/2°; 30°/5°; 15°/8°; 45°/8°; 30°/15°). The location of the adapting stimulus was also included in the set of test locations. In each block, stimuli were presented 3 times at each of the 13 positions giving a total of 39 localization trials per block. Subjects completed 3 blocks for each test condition. This resulted in 9 repeat localization trials for each location and test condition, for a total of 117 localization trials per subject per test condition. Localization judgments were plotted using a spherical plotting and analysis package (SPAK: Leong and Carlile, 1998). We chose to illustrate these data using spherical means as this avoids the need to make assumptions about the type of coordinate system to employ (e.g., a single or double pole projections for azimuth and elevation). The mean (or centroid) of the cluster of localization estimates for each test location was calculated and plotted for each subject (see Fig. 1) along with the standard deviation of each distribution. Further methodological, graphical, and statistical analyses are described in the following where appropriate.

In the two primary adaptation experiments, ten subjects were tested using the adaptation stimulus directly ahead (0°/0°) and eight subjects were tested using the adaptation stimulus located at 30° to the right of the subject (30°/0°). Both positions were located on the audio-visual horizon and five of the subjects were common to both experiments. The adapting stimulus was a continuous broadband noise (similar to the target stimuli), initially presented for 4 min at the beginning of each block of trials and then for 15 s between each localization trial. During exposure to the adapting...
stimulus, the subject was requested to remain in a fixed position facing directly ahead (0°/0°) during which time a LED at 0°/0° was illuminated to assist in this task. In the supplementary adaptation experiments (see the following), the head position indicator was also used to help the subject maintain head position for the duration of the adapting stimulus. Following exposure to the adapting stimulus, the localization test was repeated with the exception that the adapting stimulus was presented for 15 s between each test stimulus. Thus, subjects localized 39 positions per block and each block took between 20 and 25 min of testing. The order of the stimulus positions was randomized within each block. There was at least a 24-h break between each block of adaptation tests to minimize the effects of any prolonged adaptation aftereffect (see also Curthoys, 1968).

III. RESULTS

A. Principal adaptation experiments

Prior to any adaptation, each subject’s localization performance was measured using the 13 test locations. Each subject displayed some localization bias in the preadaptation tests (Fig. 1) although the overall magnitude of the errors was within the range of localization errors seen in a larger population of subjects (see Carlile et al., 1997). To illustrate the range of subject-related localization bias, example control localization results are plotted for four subjects for sound locations around 0° azimuth, 0° elevation (Fig. 1). For one subject illustrated, most targets were consistently localized as slightly too high [Fig. 1(a)] whereas for another, particular locations were systematically localized as too low [e.g., Fig. 1(b)]. In a third subject the localizations were systematically too rightward [Fig. 1(d)] whereas in a fourth, the errors were more randomly directed [Fig. 1(c)].

For the purpose of plotting the adaptation results we were concerned that pooling localization data across subjects with different systematic biases would obscure changes produced by the experimental manipulation. Figure 2 plots the centroid of the control responses (open squares) for the subject shown in Fig. 1(b) indicating a general downward bias in this subject’s preadaptation localization response. Following preadaptation testing, the subjects were then exposed to the adapting stimulus as described previously and his or her localization performance remeasured. The principal effect of the adaptation was to displace the localization away from the adapting speaker location as can be seen by the radial shifts in the adaptation responses (open circles) compared to the control responses (open squares) (Fig. 2). However, in cases where the underlying control localization bias was toward the location of the adapting speaker then the extent of this effect would be underestimated if plotted in terms of the actual location of the target. In addition, combining data across subjects with the opposite directional biases would act to cancel any effect due to adaptation. To correct for this bias, all the subjects’ responses were normalized in the following way. The centroids for both the preadaptation and adaptation responses were shifted by an identical amount to remove the bias in the preadaptation response at each target position. This process is equivalent to subtracting the bias in the preadaptation response from both preadaptation and adaptation response centroids at each target location, and results in the corrected preadaptation centroids falling exactly on their respective target locations [cf. Figs. 2 and 3(b)]. Thus, the deviation of the centroid of the adapted response from the actual location represents the effects of the adaptation with the underlying systematic bias removed. These data were calculated for each subject, the shifted responses were then pooled and variations across the population were calculated for each test location. In Fig. 3 the adaptation data have been plotted for the same four individual subjects illustrated in Fig. 1 to indicate again the range of the adaptation aftereffect.

The centroids of the normalized localization estimates are plotted for the adapting speaker located at 0°/0° (Fig. 4) pooled from all ten subjects tested at this location. The surrounding ellipses represent the standard deviation of the pooled normalized localization estimates for each location. The perception of spatial location in the vicinity of the adapting source was systematically distorted following exposure to the adapting stimulus. We have quantified this by calculating the spherical angle between the location of the adapting stimulus (at the center of the array) and each of the centroids of the location judgments for both the preadaptation and adaptation conditions. With the exception of the test location corresponding to the location of the adapting stimulus the differences between these two angles indicated that there was a shift in perceived location away from the adapting stimulus following adaptation (mean 2.6° ± 5.4°; mean ± s.d.).

When the adapting stimulus was located at 30°/0°, a similar pattern of distortion was evident (Fig. 5). Stimulus locations between the midline and the adapting stimulus were localized toward the anterior midline, and locations to the right of the adapting stimulus were shifted mainly upward or downward. The average extent of the adaptation-induced shifts for the 30°/0° location of the adapting speaker was within the range of localization errors seen in a larger population of subjects.
was $3.7^\circ \pm 7.9$. Compared to $0^\circ/0^\circ$, the scatter of the data for any one test location was greater for the adapting stimulus location of $30^\circ/0^\circ$.

To test if there was a significant radial displacement produced by exposure to the adapting stimulus, a paired t-test compared (a) the spherical angle between the preadapted localization centroid and the location of the adapting speaker with (b) the spherical angle of the adapted localization centroid and the location of the adapting speaker. This was carried out for both the adapting speaker locations $0^\circ/0^\circ$ and $30^\circ/0^\circ$ (Table I) and in both cases there was a highly-significant increase in the spherical angle as a result of the adapting stimulus ($p<0.01$). This indicates a significant radial shift in the perceived location away from the location of the adapting stimulus.

### B. Supplementary adaptation experiments

#### 1. Supplementary experiment 1

In the two experiments reported previously the subjects were requested to keep facing forward during the course of exposure to the adapting stimulus. To aid this process subjects were provided with a visual reference point located at $0^\circ/0^\circ$. However, we were concerned as to whether small head
movements may have occurred during the course of the pro-
longed exposure to the initial 4-min adapting stimulus. Rela-
tive changes in the location of the adapting stimulus may
have the potential to “dilute” or reduce the location-de-
dependent adaptive effect. To test this we devised a means of
using the head tracking system to simultaneously monitor the
exact position of the head at 10 Hz during the course of the
adapting stimulus presentation.

Using this apparatus we studied the head movements of
four additional subjects during adaptation experiments con-
ducted at 0°/0°. Three of these subjects were also provided
with feedback at 10 Hz as to the location of the head with
respect to the stimulus coordinate system (see Sec. II: When
the head was properly aligned a central green LED was lit;
otherwise, the direction of any misalignment was indicated by
the appropriately placed red LED). This monitoring indi-
cated that there were continual small changes in the position
of the head, particularly during the 4-min initial exposure to
the adapting stimulus. The mean deviation recorded in the
one subject who did not receive head-position feedback was
4.5° with a peak deviation of 17.7°. By contrast, mean head
deviation for the three subjects who did receive feedback
was in general less than 1° with peak deviations ranging
from 2.0° to 2.4°.

To examine the potential effect of small head movement
during exposure to the adapting stimulus we compared the
adaptation of the three subjects who received head position
feedback with the ten subjects tested at the same location
who did not. Those subjects who received head position
feedback demonstrated a mean displacement of the perceived
locations of the test stimuli by 3.7°. This shift was signifi-
cantly larger than the displacement observed in those sub-
jects who received no head position feedback (2.6°; Students
t-test, $p<0.01$; see Table I). These data indicate that feed-
back to the subject about relative head position plays an
important role in head stabilization under these conditions.
Consequently, the adaptation-induced displacement in the
perceived location observed in the two experiments reported
above might well be an underestimate of the adaptation ef-
fect. That is, the measured displacement may have been
larger had head position information been provided to the
subjects during adaptation.

2. Supplementary experiment 2

Two previous studies indicate the potential for a shift in
the perceptual frame of reference following exposure to an
adapting or concurrent auditory stimulus (Chandler, 1961) or
to some posturally related stimuli (Lackner, 1974). For ex-
ample Chandler (1961) demonstrated that a binaural imbal-
ance in dichotically presented tonal stimuli could result in a
misperception of the visual vertical by up to one degree. We
were interested to determine if the adaptation effect observed
here was the result of an auditory sensory adaptation, a dis-
turbance of spatial reference, or a reduction in motor capac-
ty to indicate a specific position in space. To identify the
extent of the contribution of any nonauditory sensory com-
ponent to the displacement of the perceived location of the
auditory targets we carried out the same experiment de-
scribed previously (supplementary 1) with the exception that
the subjects were required to indicate the location of a visual
target both before and after exposure to an adapting auditory
stimulus. Four subjects were used, two of whom had contrib-
uted data to the principal adaptation experiments.

As in the first supplementary experiment, these subjects
were also provided with head position information during the
course of the adapting stimulus. The auditory adapting
stimulus was located at 0°/0° and each subject carried out a
total of 117 visual localization trials over the 13 test loca-
tions for the preadaptation condition and 117 trials for the
adaptation condition. As before, the experiments were car-
ried out in the darkened anechoic chamber but the visual
stimulus was a 150-ms flash emitted from a red LED carried
by the robot arm. As would be expected, subjects were quite
accurate in indicating the position of the visual stimulus.
When pooled across the four subjects, visual localization fol-
lowing auditory adaptation was found to be radially dis-
placed by a mean of 0.6° compared with the preadapted vi-
sual localization. A paired t-test indicated that although this
difference was small, it was statistically significant ($p
<0.01$) and of similar magnitude to the auditory-induced
displacement of the visual vertical previously reported by
Chandler (1961). These data indicate that a small displace-
ment effect can be attributable to cross-modal or other non-
sensory spatial distortion. However, when compared to the
magnitude of the displacement of the auditory targets follow-
ing exposure to an adapting auditory stimulus this accounts
for less than 16% of the observed auditory effect measured
under the same conditions.

IV. DISCUSSION

This study indicates that exposure to a broadband sound
for a number of minutes results in a shift in the perceived
location of subsequent sound sources located in the vicinity
of the adapting stimuli. There was a general pattern of radial
displacement of stimuli away from the location of the adap-
ting stimuli. This was particularly marked for sounds located
directly ahead, and less so for sources 30° to the right of the
midline where there was a more pronounced shift in the per-
ceived elevation of the test stimuli.

These findings are generally consistent with and extend
the previous studies of auditory spatial aftereffects. Such
studies have shown perceptual effects for stimulus locations
about the anterior midline following adaptation using both
free-field (e.g., Taylor, 1962; Curthoys, 1968) and
headphone-based stimuli (e.g., Thurlow and Jack, 1973). A
general finding was a shift of the perceived judgment of tar-
get stimuli placed around the midline as located further away from the adapting stimulus located off the median plane (Curthoys, 1968) or toward the middle of the head for the lateralized stimuli (Thurlow and Jack, 1973). Thurlow and Jack (1973) also report a small “repulsion” effect for a midline adapting stimulus using headphone-based stimuli. This is consistent with the results reported here for the free-field adapting stimulus at 0° azimuth. In two previous free-field studies (Taylor, 1962; Curthoys, 1968), the peak adaptation-induced shift was 3° when the adapting stimulus was located at 30° degrees off the midline. This is within the range of the average shifts noted in this study (2.6°–3.7°).

Previously such shifts had been explained in terms of a simple level-based adaptation model resulting in adaptation-induced changes in apparent interaural level differences (in particular see Curthoys, 1968). That is, if the adapting stimulus resulted in greater adaptation in the near ear compared to the far ear, the effective ILDs caused by the subsequent target stimuli would be distorted to favor the ear further from the adapting stimulus and the location of the perceived test stimulus would be shifted toward the further (less adapted) ear.

For location judgments made following adaptation at 0° azimuth/0° elevation, the simple adaptation model of Curthoys predicts that there should be no differences in the perceived location of target stimuli following adaptation as the level of the adapting stimulus was equal in both ears. However, the data in this study demonstrated a clear radial shift in perceived locations for all target stimuli in the vicinity of the adapting stimulus at azimuth 0°/elevation 0°. In addition, the distortion of perceived location encompassed both dimensions of azimuth and elevation, an entirely new observation. This upward shift in perceived location was most pronounced for adapting stimuli located at azimuth 30°/elevation 0°, particularly in the case of the targets located lateral of the adapting stimulus where the direction of the mean shift was rotated more vertically. Again, for the azimuth 30°/elevation 0° location a simple adaptation model would have predicted a straightforward shift toward the anterior midline for all target locations surrounding the adapting speaker.

Clearly, mislocalization produced by differential adaptation of each ear is insufficient to explain the pattern of mislocalization seen in the subjects in this study. In addition, a simple level-based adaptation model fails to account for cues such as interaural time difference cues (ITDs) and spectral cues. Unambiguous localization is most likely to be dependent on the integration of all these different cue types (Middlebrooks, 1992; see Carlile, 1996a, b for review). This is consistent with the neurophysiological findings in the mammalian auditory system. In the deep layers of the mammalian superior colliculus, the map of auditory space relies on neurons with relatively restricted spatial receptive fields which are shaped by the neurons selectivity for a small range of binaural and spectral cues (Palmer and King, 1982; King and Palmer, 1983; Carlile and Pettigrew, 1987; Middlebrooks, 1987; King et al., 1990; Carlile and King, 1994a b).

These physiological data, together with similar findings in the owl (see, e.g., Knudsen et al., 1987; Olsen et al., 1989), indicate that these neural representations of auditory space are dependent on the integration of two or more types of cues. Such neurons may provide the basis for segregated processing of different regions of space. That is, their sensitivity to a limited range of convergent cues results in their being “tuned” to a specific location in space and the topographic organization of the neurons results in a neural map that is isomorphic with two-dimensional auditory space.

In the visual system there are psychophysical and neurophysiological data which suggest the presence of specific detectors or channels which account for the perception of particular features of the visual field (see, e.g., Barlow, 1990). It is not unreasonable to postulate that neurons coding for discrete regions of auditory space might also be indicative of some form of channel processing of auditory spatial perception. In other words, in the absence of a receptorotopic representation of auditory space, it is likely that a computationally based representation of auditory space is comprised of a large number of neurons coding for different spatial locations (see Knudsen et al., 1987). In such a scheme and particularly where the receptive fields are relatively large, the perception of auditory space might be dependent on the ensemble output of this neural array. Such a concept is illustrated in Fig. 6 where the topographic arrangement of neurons with spatially restricted receptive fields is represented by a mosaic of overlapping receptive fields. Borrowing from the visual literature, each neuron can be conceived of as a separate processing channel “tuned” to a particular area of space. Such a model may also provide a plausible explanation of the effects of auditory spatial adaptation. The down regulation of an individual channel by a prolonged stimulus exposure would change the resulting balance of outputs from the remaining channels, which in turn results in the sensory aftereffect observed (see Fig. 6; Mather, 1980; Wade, 1994).
Thus the down regulation of the auditory spatial channel centered on the adapting stimulus could subsequently affect the balance of outputs from the channel array for subsequent adjacent locations and result in the outward shift in the perception of nearby locations.

The assumptions of the model are straightforward and biologically plausible: namely, that localization processing is mediated through a large mosaic of overlapping spatial channels (receptive fields) and that the perception of location is derived from the output of the array. As discussed previously, examples of neurones that could form the biological substrate of such a system have been found in the mammalian and avian superior colliculus and in the avian MLD. Such models have previously been referred to as “distribution shift” models and provide a powerful framework for examining the characteristics of individual channels or receptive fields (see in particular Mather, 1980). The psychophysical data demonstrating the auditory spatial aftereffect are consistent with this kind of stimulus cue processing. In this model, the down regulation of the spatial channel centered on the adapting stimulus would subsequently affect the balance of outputs from the channel array and result in a shift in the perception of nearby locations away from the location of the adapting stimulus. From the current data we are unable to determine if the adaptation is likely to occur at the point of high-level convergence of the various localization cues, within the underlying processing streams, or a combination of the two. If the adaptation was occurring at the level of the processing of individual localization cues, it would also be of considerable interest to determine if each cue was equally adapted or if there was some form of differential adaptation across ITDs, ILDs, and spectral cues.

Such “distribution” shift models of auditory spatial aftereffects also provide a consistent basis for interpreting previous studies of auditory spatial aftereffects. It is of interest that this conception is also related to the early ideas behind the Köhler–Wallass theory of figural aftereffects when translated into a place code of auditory localization processing (see in particular Krauskopf, 1954) and are also related to the place models developed to explain localization “funneling” (see Thurlow et al., 1965).

Such a “channel” model of localization processing may also be useful in interpreting experiments using multiple concurrent stimuli. In two recent brief reports, the localization of speech sounds with concurrent distracters or maskers have been described (Hawley et al., 1999; Hartung and Braasch, 1999). In the case where noise has been used as a concurrent distracter, a displacement of the apparent location of the target speech away from the distracter has been reported (Hartung and Braasch, 1999). By contrast, when speech has been used as a distracter, a low incidence of mislocalization toward the distracter is reported (Hawley et al., 1999). On the other hand, where nonspeech concurrent sounds were used as targets and distracters the effects were reported as being highly subject dependent (Wightman and Kistler, 1997). Of interest, the latter short report notes that one consistent effect of the concurrent distracter was on the disruption of the elevation component of the localization. Unfortunately, the significant differences in the methodology between these previous studies and the current study complicate any test of the proposed “channel” model.

Studies of the neural representation of auditory space in the owl (Knudsen and Konishi, 1978a, b) and ferret (King et al., 1990) have also provided some neurophysiological evidence of lateral interactions between space-tuned neurons. This begs the question of the potential effects of lateral interactions between the proposed hypothetical localization channels. Such interactions could have important functional consequences by enhancing the contrast between specific spatial auditory locations. Contrast in this context might apply to separating out foreground sounds of interest (e.g., speech) from background noise. This kind of streaming of information has also been shown to be reliant on localization processing (Plomp and Mimen, 1981).

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