SEX DIFFERENCES IN PERCEIVING AUDITORY 'LOOMING' PRODUCED BY ACOUSTIC INTENSITY CHANGE

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ABSTRACT

Listeners often overestimate the acoustic intensity change of rising compared to equivalent falling intensity tones. The explanation that has been proposed for this effect has centered on the importance of a rising intensity signal in a natural environment. From the perspective of auditory display, this perceptual asymmetry makes acoustic intensity a poor variable choice for the purpose of sonifying dynamic changes in data. However, the salient nature of a rising intensity signal may make it appropriate for marking critical changes in the data. Nonetheless, the origin of this effect is still somewhat in question. Here, we seek to shed some light on the origin by demonstrating sex differences in loudness change that converge with sex-specific theories of spatial ability. We found that males and females both overestimated rising intensity compared to falling intensity, but differed in the magnitude of the perceptual bias. For rising intensity, females perceived more loudness change than males, a finding consistent with a greater sense of warning. For falling intensity, males perceived more loudness change than females. Our data are consistent with the hypothesis that the rising intensity bias is an adaptation to sex-specific evolutionary pressures and that well documented visuo-spatial sex differences are in fact polymodal phenomena that extend to the auditory system.

1. INTRODUCTION

From an evolutionary perspective, the perception of changing acoustic intensity is an important task. Rapidly approaching objects can produce increases in intensity and receding object produce corresponding decreases. "Looming perception" is a multimodal process that can be carried out by the visual system, the auditory system, or both (Lee, Vanderweel, Hitchcock, Matejowsky, & Pettigrew, 1992). The adaptive significance of perceiving looming objects is illustrated by the finding that visual looming stimuli often cause fear or avoidance responses that are not produced by receding stimuli (Ball & Tronick, 1971; Schiff, Caviness, & Gibson, 1962). The primary visual cue to perceiving looming objects is the optical increase in size of the retinal image that occurs as the object approaches. Auditory looming stimuli create an analogous increase in acoustic intensity as they approach, becoming increasingly louder as they draw closer to the listener. The idea that specific patterns of rising intensity change may evoke a natural fear or arousal response in human listeners makes this type of signal particularly intriguing for some specific types of auditory displays.

We begin with the premise that certain patterns of intensity change can be associated with approaching and receding sources, regardless of whether an actual source is moving toward or away from a listener. In other words, simple intensity change (without source motion) may tap into some of the same physiological mechanisms that produce a warning response in the presence of a real approaching source. When compared to vision, the perception of auditory looming has been studied relatively little. Human infants exhibit avoidance behaviors in response to looming sounds (Freiberg, Tually, & Crassini, 2001), and other studies have shown that listeners perceptually overestimate the rising intensity and underestimate the time-to-arrival of a looming sound source (Neuhoff, 1998; Rosenblum, Carello, & Pastore, 1987; Rosenblum, Gordon, & Wuestefeld, 2000; Rosenblum, Wuestefeld, & Saldana, 1993; Schiff & Oldak, 1990). This underestimation of arrival time and subsequent underestimation of source distance (Neuhoff, 2001) may provide the listener with advanced warning of the approaching source and more time than expected to prepare for its arrival. The margin of safety provided by this underestimation may be an adaptive characteristic that has evolved because it provides a selective advantage in dealing with looming sound sources. In fact, some researchers have argued that the primary function of mammalian auditory localization is not to provide an exact estimate of sound source location at all, but to act as a warning system that directs the visual system toward the object and provides input to the listener's perceptual model of the environment (Guski, 1992.; Popper & Fay, 1997). Non-human primates show both behavioral and neural anisotropies consistent with a bias for rising intensity (Ghazanfar, Neuhoff, & Logothetis, 2002; Lu, Liang, & Wang, 2001), and in humans, specific neural streams have been shown to process this perceptual anisotropy (Seifritz et al., 2002).

To the extent that males and females have faced different evolutionary challenges, they have evolved different physiological and psychological mechanisms to deal with those challenges. Perceiving the path of an approaching object and estimating its distance or time-to-arrival is an inherently spatial task, and differential performance on visuo-spatial tasks has been shown to be one of the most the most robust sex differences in cognitive processing (Kimura, 1999). Studies typically show that men perform better on tasks that require dynamic visuo-spatial manipulation (Collaer & Nelson, 2002; Collins & Kimura, 1997; Dabbs, Chang, Strong, & Milun, 1998) and that women perform better on tasks that require visuo-spatial memory (Alexander, Packard, & Peterson, 2002; Duff & Hampson, 2001; McBurney, Gaulin, Devineni, & Adams, 1997). These findings appear to reflect the sexual division of labor during hominid evolution, between predominantly male hunters and predominantly female gatherers (Eals & Silverman, 1994; Halpern, 1980; Jochim, 1988; Silverman & Phillips, 1998). Male hunters would be best served by superior visuo-spatial transformation abilities in order to track prey across unfamiliar terrain and to use projectile weapons (Kolakowski & Malina, 1974). Female gatherers would be best served by superior spatial memory abilities in order to locate edible plants and remember those locations during subsequent growing seasons (McBurney et al., 1997; Silverman & Phillips, 1998).

Curiously, almost all of the research that has demonstrated sex differences in spatial tasks has involved vision (Kimura, 1999; Voyer, Voyer, & Bryden, 1995). Yet, there is considerable physiological and behavioral evidence that demonstrates a strong correspondence between the perception of visual and auditory space (Auerbach & Sperling, 1974; Gutfreund, Zheng, & Knudsen, 2002; Knudsen, 2002; Stein & Meredith, 1993; Zwiers, Van Opstal, & Paige, 2003). The auditory and visual systems work together to provide information about the spatial location and movement of objects in the environment. Given this correspondence, we hypothesized that males and females would show analogous sex differences in audio-spatial processing of stimuli associated with approaching and receding sound sources. Specifically, we predicted that females would perceive a greater loudness change in rising versus falling intensity than males. Since rising intensity can specify source approach, a stronger perceptual bias for rising intensity would provide more advanced warning of approaching sound sources providing more time to prepare for the approaching source. On the other hand, males might benefit from a smaller bias because of the spatial transformation involved in perceiving looming objects and the greater spatial precision required in tracking and hunting prey. To examine this hypothesis, we presented male and female listeners with rising and falling intensity tones and asked them to indicate the amount of loudness change that occurred in each sound.

2. METHOD

In Experiment 1, our participants were 50 male and 50 female undergraduate students. In Experiment 2, we tested another 50 male and 50 female undergraduates, none of which had participated in the first experiment. All participants were between the ages of 18 and 25 years. All reported normal hearing, and none was aware of the hypothesis being tested. In each experiment, we presented listeners with 1 kHz triangle waveform tones that changed in intensity and were 2 s in duration. The slopes of the rising and falling sound amplitudes were exponential. Stimuli were sampled at 44.1 kHz, were generated by a 16 bit sound card, and were presented diotically via Sony MDR-v600 headphones. Listeners were seated in a sound attenuating booth and indicated the magnitude of loudness change by moving a slider on a 150 mm computerized visual analog scale (VAS) after each trial.

In Experiment 1, we presented listeners with tones that either increased from 65 to 85 dB or decreased from 85 to 65 dB sound pressure level. In Experiment 2, we examined the effect of different intensity levels, which could indicate sources at different distances or sources with different intensities; listeners heard "soft" tones that increased or decreased between 40 and 70 dB, and "loud" tones that increased or decreased between 60 and 90 dB. Given equal source intensities, "loud" and "soft" tones would specify "near" and "far" source trajectories respectively. In each experiment, each type of stimulus was presented 10 times, and all stimuli were presented in random order. The mean of the 10 VAS ratings in each condition was used as the unit of analysis..

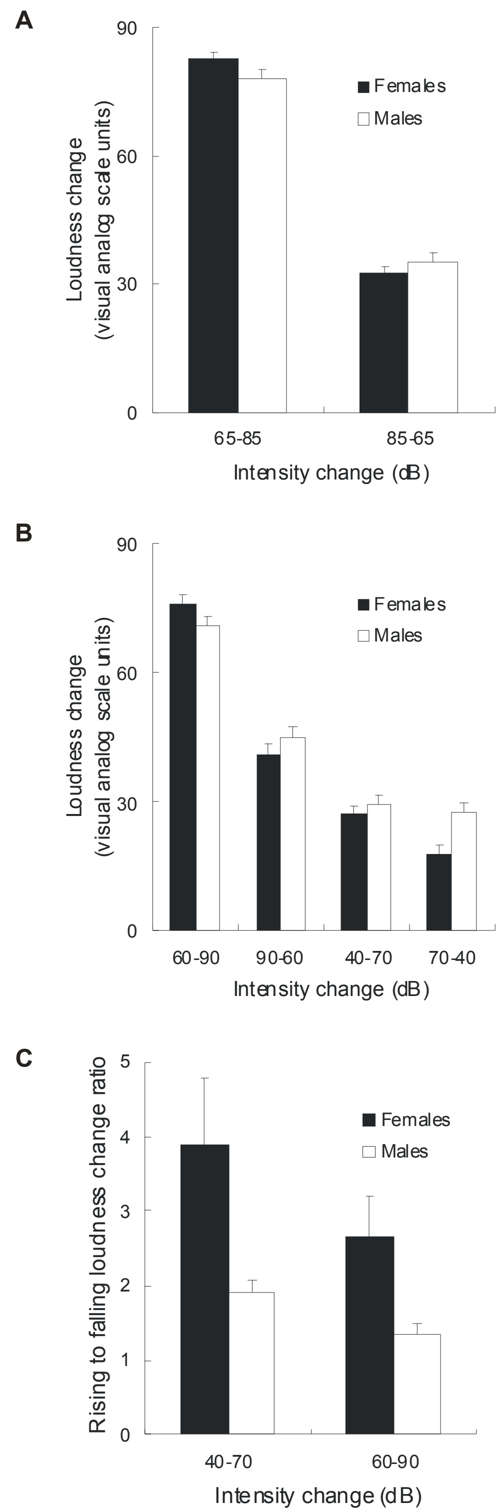

Figure 1. *Loudness change results from Experiments 1 and 2. **(A)** In Experiment 1, rising intensity changed in loudness more than falling (for both sexes). Moreover, the direction of intensity change (rising or falling) interacted with sex. For rising intensity, females perceived more loudness change than males, but for falling intensity, males perceived more loudness change than females **(B)** In Experiment 2, females exhibited a rising intensity bias for both "soft" and "loud" tones. Males only exhibited a margin of safety bias for "loud" stimuli that could indicate a close source. **(C)** Rising to falling loudness ratios in Experiment 2 were significantly larger for females than for males at both levels.*

3. RESULTS

In Experiment 1, we confirmed that rising intensity changed in loudness more than equivalent falling intensity ($F_{1, 98} = 812.0$, $p < .001$), a finding that is consistent with an adaptive bias for looming auditory motion irrespective of sex. Moreover, we found a significant interaction between sex and direction of change ($F_{1, 98} = 4.2$, $p < .05$, Fig. 1A). For rising intensity, females perceived more loudness change than males, a finding that is consistent with a greater sense of warning in females in response to an approaching source. However, for falling intensity, males perceived more loudness change than females, a finding consistent with a priority in males for pursuing departing sound sources.

In Experiment 2, we confirmed in a second set of subjects that rising intensity again changed in loudness more than falling intensity ($F_{1, 98} = 137.7$, $p < .001$). We also found that “loud” tones were perceived to change more than “soft” tones ($F_{1, 98} = 422.6$, $p < .001$, Fig 1B). These results are consistent with a perceptual priority for approaching sources that are nearby (or loud). Moreover, we found a significant interaction between sex and intensity range ($F_{1, 98} = 4.8$, $p < .05$) and between sex and direction of intensity change ($F_{1, 98} = 7.2$, $p < .01$). For “loud” tones, the results confirmed those found in Experiment 1. For “soft” (or distant) tones, females exhibited the “margin of safety” bias, whereas males did not. Thus, females exhibited a bias for rising intensity regardless of intensity level, whereas males only exhibited bias for stimuli that indicated a “near” source. To quantify the size of the perceptual bias, we calculated the ratio of rising-to-falling loudness change (mean rising VAS rating/mean falling VAS rating) for each listener. A ratio of 1 would indicate equal loudness change perceived for rising and falling intensity and no perceptual bias. Loudness change ratios were significantly larger for females than for males ($F_{1, 98} = 9.0$, $p < .01$; Fig. 1C).

4. DISCUSSION

Our results demonstrate that listeners exhibit a bias to hear rising intensity change in loudness more than equivalent falling intensity and that the magnitude of this bias is more pronounced for women than for men, particularly for sounds that are loud (or in spatial terms, “close”). Thus, our findings support the hypothesis that the bias for rising intensity may have evolved because it provides a selective advantage in processing looming acoustic sources (Ghazanfar et al., 2002; Neuhoff, 1998; Neuhoff, 2001; Seifritz et al., 2002). We acknowledge that intensity change is one of several other acoustic cues to source motion that were not present in our stimuli. In addition to intensity change, approaching sound sources in real environments also undergo spectral changes due to the decrease in atmospheric high-frequency damping as the source approaches, and the ratio of direct-to-reverberant sound increases. Nonetheless, intensity change is the most informative cue to judging arrival time of a looming acoustic source (Rosenblum et al., 1987), and studies of visual looming similarly limit their visual cues to optical expansion even though other less informative cues are present in real environments. Moreover, brain imaging and psychophysical studies have shown that diotically presented intensity change alone can produce the percept of auditory motion and is sufficient for activating neural streams known to process auditory motion (Seifritz et al., 2002). In addition, perceptual studies have shown that auditory motion can be induced with stimuli that use a more impoverished set of cues than those employed here (Perrott & Strybel, 1997). Finally, real three-dimensional auditory looming and recession with a full set of acoustic cues tends to result in an even greater perceptual bias than when a single cue such as intensity change is presented in isolation (Neuhoff, 2001).

It is possible that the sex differences shown here are due to social or experiential factors. Women may have less experience with sounding objects in motion than men. Thus, evaluating evolutionary hypotheses about human behavior requires converging evidence from different methodologies and theoretical perspectives. Besides demonstrating sex differences, other key criteria include, observing similar behavior in closely related species, and identifying concomitant physiological mechanisms (Buss, Haselton, Shackelford, Bleske, & Wakefield, 1998). Our conclusions regarding the evolutionary origins of a bias for rising intensity are supported by both phylogenetic and neurophysiological evidence. First, non-human primates have been shown to exhibit a strikingly similar perceptual bias for rising intensity (Ghazanfar et al., 2002). Rhesus monkeys orient over twice as long to a looming tone than to a receding tone. This behavioral anisotropy may be the result of anisotropic cortical processing. A recent study has shown that a greater proportion of primary auditory cortical neurons are selective for rising intensity than falling intensity (Lu et al., 2001). Furthermore, the human brain mechanisms that process this perceptual bias have also recently been identified. Imaging work has demonstrated that specific motion sensitive neural streams show anisotropic responses to rising versus falling intensity tones (Seifritz et al., 2002). Rising intensity tones preferentially activate a neural network responsible for attention allocation, motor planning, and the translation of sensory input into ecologically appropriate action. All of these processes suggest preparation for the arrival of a looming acoustic source.

5. CONCLUSIONS

Our data demonstrate a characteristic of dynamic loudness perception that may provide a selective advantage in processing approaching acoustic sources. The biological salience of auditory looming appears to be reflected in the increased perceptual magnitude of its loudness change. From the perspective of auditory display, these results suggest that dynamically rising intensity may be a particularly useful acoustic characteristic for drawing a user’s attention. The demonstration of sex differences in this anisotropic perceptual bias, although relatively small in effect size, provides converging evidence for the evolutionary origins of the phenomenon and suggests that well-documented sex differences in visuo-spatial abilities are accompanied by corresponding differences in audio-spatial processing.

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