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Sex Differences in Hearing
Implications for best practice in the classroom

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"Hearing" is not a unitary phenomenon, but is a complex sensory experience. Many sex differences have been identified in the parameters underlying the experience of hearing, perhaps most importantly in the relationship between the objective amplitude of auditory stimuli and the subjective experience of loudness. These sex differences may have important implications for best practice in the classroom.

Introduction

What happens when you hear?

Hearing is not a unitary phenomenon. Every sound has a particular *pitch* and *timbre*; every sound has a particular *amplitude*, usually measured in decibels (dB); and every sound has a *location* in three-dimensional space. These parameters of pitch, timbre, loudness, and location, are processed in distinct ways in the auditory system and may lead to different individuals experiencing the same sound in different ways. Two people may hear the same sound very differently, even though these two people might have the same threshold auditory acuity.

Although speech and language pathologists are familiar with individual differences on parameters related to hearing, most classroom educators are not familiar with these issues. Some teachers do not fully understand the relevance of these topics to the classroom. In this paper, I will review evidence of sex differences in many of the parameters which comprise human hearing, including auditory thresholds, sound localization, and Stevens' *n,* the exponent which relates the perceived loudness of a stimulus to its physical amplitude (more about that below). Some of these sex differences were reviewed by McFadden (1998), who commented:

> *. . .simple intuition handles well the idea that complex behaviors and structures – higher order functions – can differ between the sexes, but it stumbles over the existence of sex differences in what are regarded to be simple, low-level functions and structures. Why this counterintuition? Perhaps because the existence of sex differences in simple, low-level abilities carries the implication that they – both the sex differences and the abilities – have, all along, been more important than has been appreciated.* (McFadden, 1998, p. 262)

Even though researchers such as McFadden have recognized the existence of sex differences in hearing, many classroom educators are not aware of these findings, as noted above, and therefore have not been able to use them to enhance their teaching.

In this paper, I will review what is known about sex differences in hearing across a variety of parameters. I will attempt to connect the emerging research on sex differences in hearing to practical implications for teaching in the classroom. By making this connection between the underlying science and classroom practice, I believe we can better understand the role that the teacher's voice plays in how a student experiences the classroom. I will also consider implications for the single-sex and coed classroom, with particular attention to the question of what child is suited for the single-sex classroom – and what child might do better in the coed classroom – based on these parameters.

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Stevens' *n*

How loudly is that teacher speaking? It seems like a simple question. Go to an electronics store and purchase a sound meter. Sit at the back of the classroom with your sound meter switched on (as I do, when I visit classrooms) and record how loud the teacher's voice is, as heard at the back of the classroom. I find that this soft-spoken teacher registers around 54 dB on my sound meter. This other teacher with a louder voice registers about 64 dB on the meter. So, I have documented an objective difference of roughly 10 dB in the loudness of these two teachers' voices. But how big a difference is 10 dB?

The physical amplitude of a 64-dB sound is ten times greater than that of a 54-dB sound. A ten-decibel difference always represents a ten-fold difference in amplitude. A 20-decibel difference represents a 100-fold difference in amplitude. A 30-decibel difference represents a 1000-fold difference in amplitude.

But a student is a human being, not an automated sound meter. The student's subjective experience of the sound is not a linear function of the objective amplitude. No human being experiences an 85-dB sound as being 1,000 times louder than a 55-dB sound. The 85 dB sound is louder, certainly, but not 1,000 times louder. How much louder is it?

Psychophysics is the term generally used for that division within psychology which is about understanding the relationship between an objective stimulus – in this case, the physical amplitude of the sound – and the subjective experience – in this case, the perceived loudness. One of the most accomplished psychophysicists of the 20th century, Dr. J. J. Stevens, recognized that for auditory stimuli, the subjective experience can be related to the objective stimulus by a relationship generally referred to today as "Stevens' Power Law" (e.g. Stevens, 1970). In the case of sounds, Stevens' Power Law relates the subjective loudness of a tone L to the physical amplitude of the tone φ:

$$L = k\,\varphi^n$$

where k is a scaling constant and Stevens' n is some number less than 1. The value of n varies from one individual to the next and must be determined experimentally. Stevens' n is a measure of how sensitive a person is to sound – not to be confused with that person's threshold auditory acuity (more about this distinction below).

Sagi, D'Alessandro, and Norwich (2007) measured the variability in subjects' identification of the loudness of tones at different intensities, and were thereby able to derive estimates of n for their subjects. Averaging across all frequencies and intensities, for females they obtained a value for n (mean ± SD) of 0.3053 ± 0.0561; for males they obtained a value for n of 0.2218 ± 0.0443. This difference was significant ($p = 0.009$).

D'Alessandro and Norwich (2009) obtained estimates of Stevens' n by measuring subjects' relative adaptation to sounds. For test tones of 50 dB, they obtained a value of n for females (mean ± SD) of 0.37 ± 0.08, while the value for males was 0.23 ± 0.05. For applied test tones of 60 dB, for females they obtained a value for n of 0.26 ± 0.08, while the value for males was 0.08 ± 0.03.

Sagi, D'Alessandro and Norwich (2007, p. 69) comment that the higher value of n for women compared with men "implies that females are more sensitive to a given physical range of tones than are males." As they note (p. 68), earlier work by McGuinness (1974) provides support for this assertion. McGuinness measured the sensitivity of women and men to loud tones. Across a wide range of frequencies, from 250 Hz to 8 kHz, she found that women's average maximum comfort level was consistently about 8 dB lower than that of men (see Figure 1). Elliott (1971) reported similar findings in children as young as 5 years old.

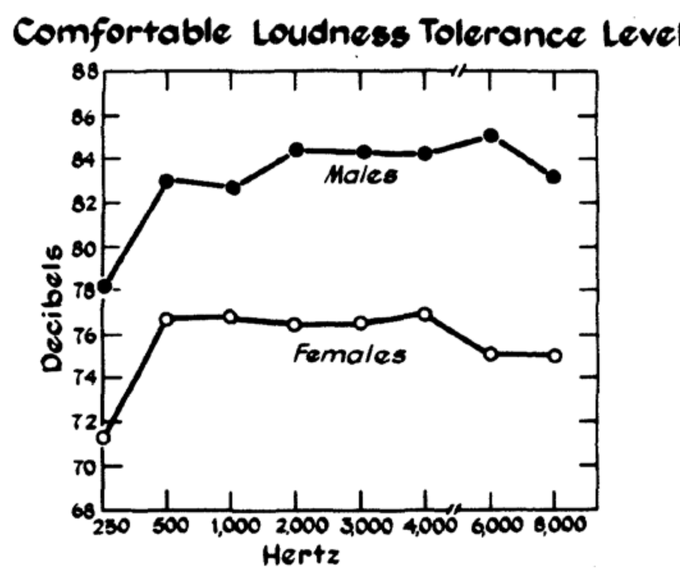

Figure 1: *Comfortable loudness curves for females and males, reproduced from McGuinness, 1974.*

Rogers and colleagues (2003) measured subjects' most comfortable listening level and subjects' acceptable background noise level. Their subjects included 25 females and 25 males, all between 19 and 25 years of age, and all with normal hearing. The most comfortable listening level for females was 36.2 decibels; for males it was 42.1 decibels, or about 6 decibels louder. This difference was significant ($p = 0.009$). In other words, males preferred speakers to speak about 6 decibels louder, on average, compared to the loudness preferred by females. Likewise, the acceptable background noise level for females was 24.8 decibels, while for males it was 31.7 decibels, or about 7 decibels louder. This difference was, again, significant ($p = 0.007$). To express this finding another way: males tolerated significantly louder background noise than females did.

Psychophysical investigations in which subjects' sensitivity to sound is measured directly, such as each the studies mentioned above, consistently find that the average female is more sensitive to sound than the average male. However, other studies have merely *asked* subjects whether or not they were sensitive to sound. For example, Weinstein (1978) devised a questionnaire, never independently validated, of noise sensitivity. Weinstein categorized a subject as being insensitive to noise if they agreed with statements such as:

1. I wouldn't mind living on a noisy street if the apartment I had was nice.

3. No one should mind much if someone turns up his stereo full blast once in a while.

15. In a library, I don't mind if people carry on a conversation if they do it quietly.

Conversely, a subject was judged to be "noise-sensitive" if they agreed with statements such as "*I get mad at people who make noise that keeps me from falling asleep or getting work done*" (#19) or "*I get annoyed when my neighbors are noisy*." (#7) Weinstein shows no awareness of how the social construction of gender might influence subjects' answers to his questionnaire. In the 1970's, when Weinstein administered this questionnaire, young women were demonstrably less likely than males to agree with statements which began "*I get mad at people who . . .*" Getting mad at people was not a desirable trait for young women in the 1970's. Likewise, other things being equal, young women in the 1970's would have been more likely than young men to agree with statements which begin with "*I don't mind if . . .*" or "*No one should mind if . . .*" Giving in, not minding, letting the other person have their way is a well-documented attribute of traditional femininity in patriarchal cultures, a category which arguably includes American culture in the 1970's. No wonder that women in Weinstein's study were not more likely to identify themselves as sensitive to noise. Similar methodological problems underlie other claims of a lack of sex differences in noise sensitivity: for more on this point, please see www.mcrcad.org/ellermeier.htm.

Relevance to the Classroom

The sex differences noted above suggest that **the average boy may need the teacher to speak more loudly** – roughly 6 to 8 decibels more loudly – **if the average boy is to hear the teacher as well as the average girl hears**.

If a particular classroom is arranged with children sitting in the same seats day after day, and the teacher is at the front of the classroom, then moving an inattentive boy from the back of the classroom to the front may be beneficial. I have personally been involved in the evaluation and ongoing supervision of boys in my own practice whose academic performance improved substantially after they were moved from the back row to the front. However, in my experience this intervention is reliably effective only with the youngest boys, in kindergarten or first grade. It is less reliably beneficial for older boys, and may even be counter-productive for boys in middle school and high school. How come?

If girls and boys are allowed to sit wherever they like in a coed classroom, typically there will be one or two studious boys in the front row, with most of the girls in the front or middle rows; the "jock" boys are more likely to sit toward the back of the room, with the rowdiest boys typically occupying the back row of seats. If a teacher in a classroom of 8th-graders moves an inattentive boy from the back row to the front, then that boy's first priority often may be to prove to his buddies in the back row that he is not a teacher's pet, that he remains "one of the guys." As a result, he may become more disruptive and inattentive in the front row than he was in the back row.

Another application of the sex differences in hearing noted earlier is that **boys typically tolerate a higher level of background noise in the classroom, compared with girls:** about 6 to 8 decibels higher. The hum of a buzzing fan, or the sound of fingers tapping on a desk, may be quite annoying to a girl or to the (female) teacher, but is less likely to annoy a boy.

Over the past nine years, I have had the opportunity to visit many all-boys classrooms both at public schools and at independent schools. I have found that **the most effective teachers in all-boys classrooms often speak more loudly** than less effective teachers. This doesn't mean shouting; a teacher should never shout or yell at a student. But successful teachers in all-boys classrooms often have discovered on their own – usually without any knowledge of sex differences in Stevens' *n* – that most boys are more attentive and more engaged when the teacher speaks in a louder tone of voice. These teachers are also more likely to allow boys to tap their fingers or pencils on the desk.

The existence of sex differences in Stevens' *n* creates a problem for the coed classroom. If the teacher speaks more loudly, some girls may complain that the teacher is shouting. If the teacher speaks quietly, some of the boys may drift off and daydream. One solution to this problem is to offer single-sex classrooms. Another solution is to offer selective amplification equipment, also referred to as assistive listening devices, e.g. the Lightspeed SoundPak™. With these devices, the teacher wears a microphone, but her voice is amplified only for students who need it.

Significant variation within each sex

Each of the studies cited earlier, demonstrating sex differences in Stevens' *n*, also documented substantial variation *among* males and *among* females. Some males are very sensitive to sounds, including background noise; and some females are less sensitive than some males are. This variability may provide one guide to identifying students, especially boys, who might *not* benefit from inclusion in a single-sex classroom.

Observers who visit all-boys classrooms and all-girls classrooms within the same school often note that the all-boys classroom is louder and noisier (e.g. Hampel, 2007; Sherman, 2008). Sometimes the teachers have had formal professional development (PD) in which they have learned about sex differences in Stevens' *n*, and consequently those teachers make a deliberate effort to speak more loudly in their boys' classrooms. When I lead such PD workshops, I always try to discuss the significance of Stevens' *n*, with appropriate attention to the variation within each sex as well as the differences between sexes. More often, teachers simply discover by trial-and-error that they are more effective in the boys' classroom when they speak more loudly.

However, not all boys benefit when the teacher speaks more loudly. Some boys are acutely sensitive to sound. These boys may have an auditory processing disorder, also referred to as central auditory processing deficit or central auditory processing disorder (DeBonis & Moncrieff, 2008). Such a boy may be disadvantaged by being placed in an all-boys classroom. He would likely do better with a soft-spoken teacher in a coed classroom. Auditory processing disorder would not be grounds for keeping a girl out of an all-girls classroom, however, because all-girls classrooms are not typically louder than coed classrooms.

The all-boys classroom is not the best choice for all boys. Where single-sex classrooms are available, teachers and parents should avoid placing boys with auditory processing disorders in an all-boys classroom.

Stevens' *n* is not the only auditory parameter in which significant sex differences has been documented – although sex differences in Stevens' *n* may be the most relevant issue for classroom educators. It is important nevertheless to recognize that significant sex differences in auditory parameters appear to be the rule rather than the exception, at least in our species. In the remainder of this paper, I briefly review evidence of sex differences on other parameters relevant to hearing, such as language acquisition, auditory thresholds, otoacoustic emissions, and sound localization.

Language acquisition

A greater value of Stevens' *n* for females compared with males suggests that a sound of a particular intensity will, on average, be more salient for females than for males. This finding may help explain sex differences in vocabulary among toddlers. Lutchmayer, Baron-Cohen, and Raggatt (2002) found that the average vocabulary of 18-month-old boys was 41.8 words (SD = 50.1), which was less than half the average for girls, who had a mean vocabulary of 86.8 words (SD=83.2). This different was significant, $p = 0.001$. At 24 months, these researchers found that the average boy had a vocabulary of 196.8 words (SD=126.8), or about 72% of the vocabulary for 24-month-old girls, 275.1 words (SD=121.6); this difference, although smaller, was still significant, $p = 0.01$. Likewise, in a sample of 1,127 25-month-olds, Roulstone, Loader, Northstone, and Beveridge (2002) found that girls had a significantly larger vocabulary than boys, with a Cohen's d of 0.34, $p < 0.0001$.

However, the sex difference in vocabulary quickly diminishes as children grow up. For example, among 268 five-year-olds, Matthews, Ponitz and Morrison (2009) found no sex difference in vocabulary on a picture naming test. Hyde and Linn (1988) performed a meta-analytic review of 165 studies of sex differences in verbal ability; they found a Cohen's $d = 0.02$ for vocabulary, i.e. no significant difference. It should be noted that Hyde and Linn explicitly excluded any study which involved children three years of age and younger. Although Hyde and Linn (p. 55) initially state that "No restriction on selection of studies was made according to age," later on the same page they acknowledge that "One other group of studies was excluded: those dealing with early language learning by children in the age range of 18 months to 3 years."

Sex differences in vocabulary and other language skills among children under 3 might be attributed to sex differences in the rate of maturation. However, it is also possible that young girls acquire more vocabulary earlier, on average, in part because sounds may be more salient for girls than for boys, again reflecting the sex differences in Stevens' n. To put this another way: while environmental factors are important for every child, the (auditory) environment may be more influential in language development for young girls than for young boys. In this regard it may be relevant to consider the findings of Van Hulle, Goldsmith, and Lemery (2004), who investigated language acquisition in monozygotic and dizygotic twins 20 to 38 months of age. They found that genetic factors accounted for 20% of the variance in boys, but only 8% of the variance in girls, while the impact of shared environment was slightly lower in boys (53% of the variance) than in girls (77% of the variance).

Auditory thresholds

The findings mentioned above concern suprathreshold auditory stimuli. Other investigators have found small but significant sex differences in threshold auditory acuity, particularly at higher frequencies. Corso (1959) was among the first to report that females have superior auditory acuity (i.e. lower thresholds) compared with same-age males, particularly for test frequencies above 2 kHz. The same general finding – adult females having more sensitive hearing at high frequencies, compared with same-age males – has been replicated in other studies of adults (e.g. Chung, Mason, Gannon, and Willson, 1983; Royster, Royster, and Thomas, 1980), including studies with Caucasian, African-American, and Asian adults (Dreisbach and colleagues, 2007; Shahnaz, 2008).

Among children, sex differences in auditory acuity are relatively small, but become larger throughout adolescence. As Roche and colleagues (1978, p. 1593) observe, "The cause of the marked sex difference in the changes in auditory thresholds between early adolescence and young adulthood is unknown. Noise exposure may be greater for teenage boys than for girls; alternatively, various biological factors may account for all, or part of, the sex difference." Three decades have passed since these authors made this statement, and we still cannot say with confidence why 18-year-old boys do not hear as well as 18-year-old girls. Hearing loss is more common among boys than girls at all ages; at age 13, boys are about 50% more likely than girls to fail screening hearing tests at multiple test frequencies (Costa, Axelsson, and Aniansson, 1988). Axelsson, Jerson, and Lindgren (1981) found that boys are more likely than girls to engage in noisy leisure activities, which may increase the risk of boys sustaining noise-induced hearing loss at an early age. Boys are more likely than girls to be involved in activities such as woodworking, and hunting with firearms, which are associated with a greater risk of hearing loss (Clark, 1991; Dalton, Cruickshanks, Wiley, Klein, Klein, and Tweed, 2001).

Otoacoustic emissions

Some subtle sex differences in the auditory system are evident at birth. Many nations employ otoacoustic emissions (OAE) screening as a means of detecting babies born with congenital hearing loss. Otoacoustic emissions are sounds produced by the cochlea, either spontaneously or in response to a transient click or noise. OAEs, whether spontaneous or transient-evoked, are believed to reflect the sensitivity of cochlear amplifiers (e.g. McFadden, 1998). Although one early study of OAEs in 100 newborns did not report a significant effect of gender (Johnsen, Bagi, Parbo, and Elberling, 1988), most subsequent studies with larger sample sizes have found that girl babies produce significantly greater-amplitude and more numerous OAEs compared with boys (Aidan, Lestang, Avan, and Bonfils, 1997; Berninger, 2007; Burns, Arehart, and Campbell, 1992; Cassidy and Ditty, 2001; Morlet and colleagues, 1995; Thornton, Marotta, and Kennedy, 2003). The same pattern of sex differences in OAEs – with females producing more numerous and greater-amplitude OAEs compared with same-age males – has been documented in adults (Bilger, Matthies, Hammel, and Demorest, 1990; McFadden, 1993; Shahnaz, 2008; Talmadge, Long, Murphy, and Tubis, 1993), so this effect cannot be attributed to sex differences in the pace of maturation.

One might reasonably wonder whether sex differences in auditory thresholds or otoacoustic emissions might explain differences in Stevens' *n*. The evidence suggests that these differences probably do *not* explain sex differences in Stevens' *n*. For more on this point, please see www.mcrcad.org/mcguinness.html.

Binaural beats and sound localization

While females do demonstrate an advantage over males in early language acquisition, in threshold auditory acuity, and in the production of OAEs, there is some evidence that males, on average, may have some advantage on parameters related to the localization of sounds. Langford (1994) tested the ability of 24 males and 26 females to discriminate whether a band of noise (600 to 800 Hz) delivered to both ears via headphones arrived simultaneously or not. To achieve 85% accuracy on this task, females required on average an interaural difference in time of arrival of about 185 μs, whereas males on average required an interaural interval of only about 135 μs (see Figure 2).

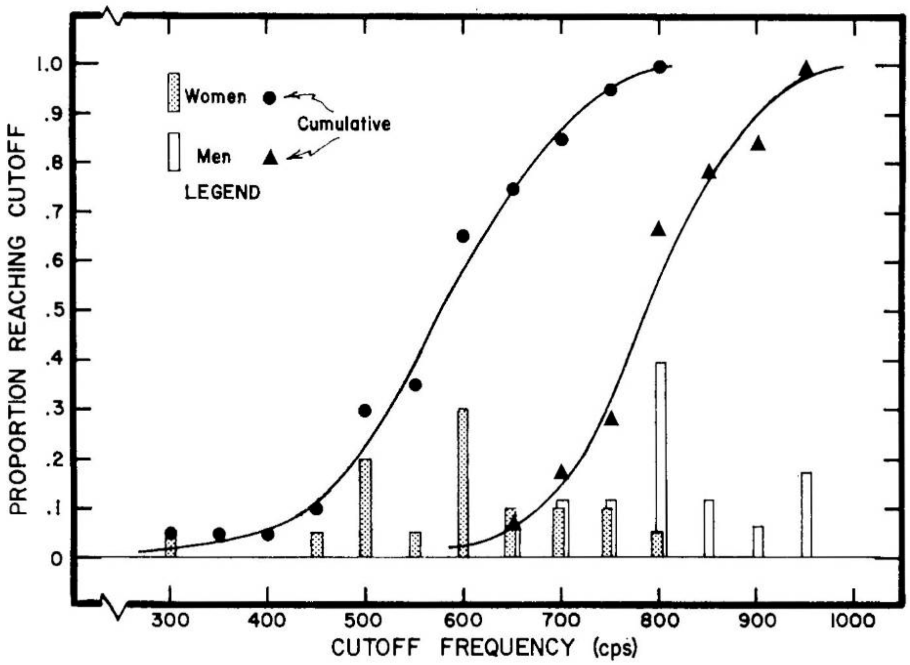

Figure 2: *Bar graphs illustrate the proportion of male and female subjects whose cutoff frequency is scaled on the abscissa. Cumulative distributions of the same data are also plotted (Tobias, 1965). © Informa Healthcare. Reprinted with permission.*

Investigation of binaural beats has yielded some complementary findings. Binaural beats are perceived when a pure tone is delivered to one ear while another pure tone, differing from the first usually by about 3 Hz, is delivered to the contralateral ear. Binaural beats are most easily perceived when the tones are low-frequency; as the frequency rises, the subject's ability to detect the beats will diminish, until finally the subject is no longer able to perceive binaural beats. The frequency at which an individual subject loses the ability to detect binaural beats is referred to as the cutoff frequency (e.g. Licklider, Webster, and Hedlun, 1950). Tobias (1965) determined the cutoff frequency for 20 females and 20 males. For females, the cutoff frequency averaged 595 Hz, compared with 811 Hz for males. This difference was significant ($p = 0.001$); indeed, as Tobias observed (p. 180), "the distributions overlap only slightly" (see Figure 2). As McFadden (1998, p. 267) observes, "the existence of binaural beats strongly suggests that the temporal periodicities of the tones at the two ears are being preserved in their individual neural encodings, and, further, that the two neural streams are interacting at some central site(s) to produce the experience of a beat. Logic strongly suggests that the same site(s) responsible for sound localization are responsible for binaural beats."

Lewald (2004) reported that males were significantly more precise with regard to localizing sound monaurally ($p < 0.0001$), but only when the right ear was tested; he found no gender differences in monaural localization when the left ear was tested. Lewald noted a trend for males to be more accurate in binaural localization, but this trend did not reach significance ($p = 0.06$). In Lewald's study, males performed more accurately when using their right ear, while females performed more accurately when using the left ear; this difference was significant ($p = 0.001$). Lewald also expressed frustration that most previous studies of auditory localization have failed to disaggregate data according to sex: "Either the gender of the subjects was not mentioned, or data for females and males were not reported separately, or the number of subjects was insufficient for reliable conclusions" (p. 93).

Why do boys have bigger heads (but not bigger bodies) than girls the same age? We have just considered some evidence that males may enjoy some advantage in auditory processes related to sound localization. How is that possible, in view of the fact that females seem to have an advantage in auditory acuity? The answer may be: because males have bigger heads, filled with air.

Humans have four pairs of paranasal sinuses: maxillary, ethmoid, sphenoid, and frontal. Because the sinuses are empty air pockets, they allow the head to be larger without being heavier. Paranasal sinuses are significantly larger in males than in females, not only in adults (Filho, Neto, and Voegels, 2008; Tatlisumak and colleagues, 2008) but also in prepubescent children (Prossinger 2001; Spaeth, Krügelstein, and Schlöndorf 1997). Pediatricians have long recognized that boys have larger heads than girls, even as infants, and the standard comparison charts that have been used by all pediatricians for decades are separate for girls and for boys (e.g. Eichorn and Bayley, 1962). Boys at 5 and 10 years of age have significantly bigger heads than girls, even though they do not differ from girls in height (e.g. Lenroot and colleagues, 2007, p. 1070).

Clifton and colleagues (1988) suggested that the larger heads of boys might allow boys to localize sounds better than girls. They also demonstrated that sex differences in the head circumference of children have been stable in datasets collected over a span of 60 years.

Females may have an advantage in some areas, particularly in regard to auditory acuity, while males may have an advantage in others, particularly in regard to the localization of sounds. Why? What is the point of sex differences in hearing? Neuhoff, Planisek, and Seifritz (2009) have suggested that sex differences in hearing may have an adaptive function, i.e. they may have evolved because they had survival value. Sex differences in OAEs similar to the sex differences observed in human OAEs have also been documented in rhesus monkeys (McFadden and colleagues 2006), and sheep (McFadden and colleagues, 2009). However, our mission here has not been to consider the evolutionary origin of these sex differences, but rather their significance for educational best practice.

Conclusion

The average girl hears the same sound with greater sensitivity than the average boy. This sex difference has significant implications for classroom practice. Educators can accommodate these differences either by offering single-sex classrooms, or by providing selective amplification in coed classrooms. However, boys with auditory hyperacuity might be disadvantaged by being assigned to an all-boys classroom.

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