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Brief report

Control of voice gender in pre-pubertal children

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Adult listeners are capable of identifying the gender of speakers as young as 4 years old from their voice. In the absence of a clear anatomical dimorphism in the dimensions of pre-pubertal boys' and girls' vocal apparatus, the observed gender differences may reflect children's regulation of their vocal behaviour. A detailed acoustic analysis was conducted of the utterances of 34 6- to 9-year-old children, in their normal voices and also when asked explicitly to speak like a boy or a girl. Results showed statistically significant shifts in fundamental and formant frequency values towards those expected from the sex dimorphism in adult voices. Directions for future research on the role of vocal behaviours in pre-pubertal children's expression of gender are considered.

Introducing a recent special issue on gender and relationships, Leman and Tenenbaum (2011, p. 153) draw attention to 'the ways in which children practise future gender roles in everyday interactions with their peers and parents'. Indeed, children are known to exhibit gender-typed patterns of behaviour from a young age. Boys and girls prefer gender-normative toys (Martin, Eisenbud, & Rose, 1995) and play styles (Hay *et al.*, 2011; Munroe & Romney, 2006) and are more likely to choose same-sex peers as playmates (Golombok *et al.*, 2008; Zosuls *et al.*, 2011). We also know that young children are capable of regulating their behaviour in gender-typed ways – what we might call 'self-presentation of gender' – under given social circumstances, such as the presence of a same-sex peer group (Banerjee & Lintern, 2001). With regard to verbal behaviour, much attention has been paid to the content, style, language use, and social dynamics of boys' and girls' conversations (e.g., Leaper & Smith, 2004; Leman, Ahmed, & Ozarow, 2005). Yet, surprisingly, one of the most obvious aspects of gender difference in verbal interactions – the voice itself – has been largely ignored.

Adults can identify the gender of speakers as young as 4 years of age by listening to their voice only (Perry, Ohde, & Ashmead, 2001). In post-pubertal speakers, sex differences in the dimensions of the vocal apparatus give males a lower fundamental frequency (pitch) and lower vocal tract resonances (or formants). Before puberty, boys also speak with lower vocal tract resonances than girls (but with the same pitch: Perry *et al.*, 2001). However, these acoustic differences are not supported by a corresponding anatomical sex dimorphism, suggesting that they have a strong behavioural dimension: children seem to adjust the length of their vocal tract to produce formant frequencies

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characteristic of their gender. See Appendix S1 for details on sex dimorphism in the human voice.

The hypothesis that children control this aspect of their vocal behaviour is plausible in the light of empirical research showing that children from a young age make use of the voice, along with other cues such as faces, in discriminating males and females (see Ruble, Martin, & Berenbaum, 2006). The expression of voice gender is therefore a very promising and objectively quantifiable indicator of gender development in children. So far, though, children's ability to control the gender-related characteristics of their voices has never been directly investigated.

We report here on the ability of 6- to 9-year-old (pre-pubertal) children to shift the frequency components of their voices when they are prompted to alter their perceived gender. Using a paradigm that has previously been successful in revealing adults' ability to control gender-typed acoustic parameters (Cartei, Cowles, & Reby, 2012), we asked children to sound 'like a boy' or 'like a girl' as much as possible and evaluated their capacity to control fundamental frequency and formant frequencies (decreasing their spacing to sound more like a boy, and increasing it to sound more like a girl).

Method

Participants

Voice recordings were obtained from 34 children (15 boys and 19 girls), aged 6–9, M (SD) = 7.04 (1.11). See Table S1 for the detailed age and sex distribution of participants. The children had no history of hearing or speech impediments and were all native speakers of British English. Height and weight were measured for each child, and no sex differences were found, $p > .10$.

Procedure

Recordings were made of the children in one-to-one interactions with the experimenter, in a quiet room at the child's school or at a university laboratory. All audio recordings were made using a Tascam DR07mkII handheld recorder connected to a Shure SM94 microphone. Each participant was shown nine cards with a written and pictorial representation of the target words (e.g., the image of a bed and underneath the word 'bed') and asked to say the words on the cards, first in their normal speaking voice (the instruction was 'please read these words out loud'), then trying to sound as much as possible 'like a boy' or 'like a girl', in alternate order (the instruction was 'now please read these words out loud trying to sound like a girl [or a boy] as much as possible'). The order in which the cards were presented was randomized across participants to avoid serial-order effects.

Acoustic analyses

The speech material consisted of nine non-diphthong vowels of British English embedded in CVC words (/æ/ 'hat', /e/ 'bed', /ɜ:/ 'bird', /i:/ 'feet', /ɪ/ 'pig', /ʌ/ 'duck', /ɒ/ 'box', /ʊ/ 'book', /u/ 'boot'). All acoustic analyses were conducted on the steady portion of each vowel, with PRAAT *v.5.2.17* (Boersma & Weenink, 2011), using a custom written script for batch processing (available from the authors on request).

The script calculated the mean fundamental frequency (F_0), the perceptual correlate of voice pitch, with lower F_0 resulting in lower-pitched voices. Additionally, the script estimated the centre frequencies of the first four formants (F_1 – F_4) of each vowel. The difference between any two adjacent formant frequencies, also defined as formant spacing, was then calculated ($\Delta F = F_{i+1} - F_i$) and used for analysis as this gives a more accurate estimate of global vocal tract adjustments than individual formant values. Longer vocal tracts produce lower formant spacing, which give voices a more baritone quality (see Appendix S2 for details of acoustic analyses and Tables S2 and S3 for descriptive statistics for a wider range of acoustic parameters).

Results

Table 1 summarizes the mean values and standard deviations for fundamental frequency and formant spacing in the three conditions.

Age and sex differences in the natural voice

We first performed a series of ANCOVAs to test the effects of sex and age (continuous covariate) on the acoustic parameters F_0 and ΔF of children's natural voices. There was a significant effect of age on mean F_0 , with F_0 decreasing as children get older, $F(1, 34) = 4.88, p = .035$. No significant main effect of sex was found, $F(1, 34) = 0.07, p > .10$. There was a main effect of sex on children's natural ΔF , with boys speaking with a 43 Hz lower ΔF than girls, $F(1, 34) = 4.23, p = .048$. There was a non-significant tendency of ΔF to decrease with age, $F(1, 34) = 3.95, p = .056$.

Ability to control voice gender

We assessed the ability of boys and girls to shift different acoustic parameters by testing the main effect of condition (three-level within-subject factor: natural, masculinized, feminized) on the acoustic parameters with a repeated measures ANOVA within each sex. We also investigated whether any of the shifts between natural voices and the two conditions were significantly associated with age by calculating the difference between the natural and masculinized or feminized conditions and regressing these difference variables on age.

The ANOVAs on F_0 showed that the main effect of condition was significant in boys, $F(1.18, 16.48) = 14.09, p = .001$, and in girls, $F(1.22, 21.94) = 6.93, p = .011$. Within-sex contrasts revealed that, when asked to sound as much like a boy as possible, boys did not significantly lower F_0 compared with the natural condition, $F(1, 14) = 1.04, p > .10$. In contrast, when feminizing their voices, they significantly raised their F_0 by 23.2% (3.59

Table 1. Mean (SD) in Hz for fundamental frequency (F_0) and format spacing (ΔF) of boys and girls in the masculinized, natural, and feminized conditions

Sex	Parameter	Masculinized	Natural	Feminized
Boys	F_0	243.5 (32)	249.6 (29)	307.2 (62)
	ΔF	1,284 (69)	1,313 (68)	1,355 (80)
Girls	F_0	234.6 (30)	249.1 (26)	270.2 (50)
	ΔF	1,301 (67)	1,355 (46)	1,389 (53)

ST) from 249.6 to 307.2 Hz, $F(1, 14) = 16.18, p = .001$. Simple regression revealed that the magnitude of this upward shift increased with age, $R^2 = .34, F(1, 14) = 6.68, \beta = .58, p = .023$. Correspondingly, girls significantly lowered their $F0$ by 5.8% (1.04 ST) from 249.1 to 234.6 Hz, $F(1, 18) = 10.11, p = .005$, when masculinizing their voices, but did not significantly raise $F0$ when feminizing them, $F(1, 18) = 3.09, p = .096$. Age was not significantly related to girls' $F0$ difference scores, $\beta_s = -.01$ and $.19, ps > .100$.

The corresponding ANOVAs for ΔF showed that condition had a significant effect in both boys, $F(1.18, 16.54) = 16.35, p = .001$, and girls, $F(2, 36) = 24.19, p < .001$. Within-sex contrasts revealed that both sexes significantly lowered ΔF (by 2.2% in boys, $F(1, 18) = 31.63, p < .001$, and by 3.9% in girls, $F(1, 18) = 20.21, p < .001$) to sound more masculine and significantly raised it to sound more feminine (by 3.2% in boys, $F(1, 14) = 8.20, p = .013$, and 2.5% in girls, $F(1, 18) = 10.48, p = .005$). No significant associations were found between ΔF difference scores and age, $\beta_s = -.04$ to $.27, ps > .100$.

Discussion

Our analyses confirmed that boys displayed narrower formant frequency spacing than girls in their natural voice (Perry *et al.*, 2001), and revealed that speakers of both sexes shifted this parameter along the existing sex dimorphism when asked to alter their voice gender. They also revealed that, despite the confirmed absence of sex differences in the fundamental frequency of pre-pubertal children's natural voices, both boys and girls adjusted this parameter when imitating the opposite sex in line with the sex differences present in adults.

Given the absence of sex differences in overall anatomical vocal tract length before puberty (Fitch & Giedd, 1999; Vorperian *et al.*, 2011), sex differences in formant spacing suggest that children behaviourally adjust their vocal tract length via lip protrusion (or spreading) and/or larynx lowering (or raising) to advertise their sex in their natural voice. The fact that children further control this parameter when altering the gender of their voice provides tentative support for this hypothesis: both sexes lowered their formant spacing to masculinize their voice and raised them to feminize it, as previously observed in adults (Cartei *et al.*, 2012). While the vocal tract adjustments observed here are only temporary, and in response to an explicit request, they nevertheless provide the first evidence that children have the ability to manipulate these acoustic properties to achieve gender-typed voices. The specific nature of the articulatory gestures involved could be studied more directly using cine-MRI.

The role of $F0$ in the expression of voice gender appears to be more nuanced. In the natural voice condition, $F0$ was not significantly different between boys and girls, consistent with most acoustic data (Lee, Potamianos, & Narayanan, 1999; Sachs, Lieberman, & Erickson, 1973) and with the absence of sex dimorphism in the development of vocal fold and laryngeal morphology reported by previous anatomical studies (Kahane, 1978; Titze, 1994). This suggests that $F0$ may not play a role in advertising sex in pre-pubertal children's voices when they are in a neutral context. However, children lowered their mean $F0$ when asked to masculinize their voices, whereas they raised it when feminizing their voices. The shifts of $F0$ were significant when children were asked to sound like the opposite gender, in line with what was previously reported in adults (Cartei *et al.*, 2012). Evidently, children have (at least implicitly) some knowledge of adult sex differences in $F0$ and may use it to vary the gender of their voice. Moreover, and notwithstanding our relatively small and gender unbalanced sample, there

was evidence that boys' manipulation of $F0$ to feminize their voices increased with age. Interestingly, children did not significantly shift $F0$ to exaggerate their own gender, in contrast to observations in adults (Cartei *et al.*, 2012). Further studies with a larger, more balanced sample, across a wider age range, are warranted to confirm these results and further investigate the use of $F0$ to express gender in line with age and gender differences. In addition, our study was limited by its reliance on assessing single-word vocal production within a restricted laboratory context; future research can fruitfully target children's natural speech in different settings.

Self-presentation of gender through the voice?

The 'size-code' hypothesis (Ohala, 1984), which predicts that callers make a conventionalized use of primarily size-related acoustic variation to communicate motivational information, has received support from both non-human (Reby *et al.*, 2005) and human (Puts, Hodges, Cardenas, & Gaulin, 2007) studies showing that males lower their frequency components to sound more dominant. We propose that, because in humans, $F0$ and ΔF are primarily indexes of sex rather than size, speakers primarily use a 'gender code', whereby they control these cues to vary the vocal expression of their gender.

As noted earlier, certain social contexts – such as the presence of same-sex peers – may trigger gender-typed behaviour (Banerjee & Lintern, 2001). The present study raises the question of whether the control of acoustic parameters as reported in this study contributes to this self-presentation of gender. Several studies (Biernat, 1991; O'Brien & Huston, 1985; Serbin, Poulin-Dubois, Colburne, Sen, & Eichstedt, 2001) have found that Western children acquire gender stereotypes in behaviour and appearance by 3 years of age (and increase their gender-typed associations as they get older), but to our knowledge, no research has focused on the acquisition and role of voice stereotypes in children. The development of voice control in the expression of gender in children's everyday speech therefore remains to be studied. Moreover, given the importance of social environment on children's gender identity, future studies should examine the role of parental-child interactions, peer interactions, and child-directed media (i.e., advertising, cartoons) on voice gender acquisition and development in a range of cultures and societies.

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Supporting Information

The following supporting information may be found in the online edition of the article:

Table S1. Distribution of male and female speakers.

Table S2. Mean and standard deviation (*SD*) in Hz for the acoustic parameters (*F0*, *F0SD*, *F0CV*, *F1–F4*, ΔF) of boys in the masculinized, natural, and feminized conditions.

Table S3. Mean and standard deviation (*SD*) in Hz for the acoustic parameters (*F0*, *F0SD*, *F0CV*, *F1–F4*, ΔF) of girls in the masculinized, natural, and feminized conditions.

Appendix S1. Acoustic expression of gender in the human voice.

Appendix S2. Acoustic analysis details.