Body Perception from Connected Speech: Determining Speaker Height from Hearing Natural Sentences and Sine-Wave Replicas with and without Pitch

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Abstract

In addition to language, the human voice carries information about the physical characteristics of speakers, including their body size (height and weight). The fundamental speaking frequency, perceived as voice pitch, and the formant frequencies, or resonators of the vocal tract, are the acoustic speech parameters that have been most intensely studied for perceiving a speaker's body size. In this study, we created sine-wave (SW) replicas of connected speech (sentences) uttered by 20 male and 20 female speakers, consisting of three time-varying sinusoidal waves matching the frequency pattern of the first three formants of each sentence. These stimuli only provide information about the formant frequencies of a speech signal. We also created a new experimental condition by adding a sinusoidal replica of the voice pitch of each sentence. Results obtained from a binary discrimination task revealed that (a) our SW replicas provided sufficient useful information to accurately judge the speakers' body height at an above chance level; (b) adding the sinusoidal replica about the voice pitch did not significantly increase accuracy; and (c) stimuli from female speakers were more informative for body height detection and allowed higher perceptual accuracy, due to a stronger correlation between formant frequencies and actual body height than stimuli from male speakers.

   KEYWORDS: sine-wave speech, voice perception, speaker body size, fundamental frequency, formants, pitch.

Introduction

The human voice, which serves as the raw material for spoken language, not only carries language information but also provides considerable information about the speaker's physical appearance, personality, and social characteristics. Extensive research has addressed the relationship between the voice and human listeners' perceptual accuracy of the physical characteristics of the speaker (particularly the body size (Bricker & Pruzansky, 1976; for a review see Kreiman & Sidtis, 2011). Considering people of different ages and sexes, investigators have observed significant correlations between some acoustic parameters of voice, such as the average fundamental frequency (F0) and formant frequencies, and the speaker's body size (Fitch & Giedd, 1999). However, among same sexed adults, correlations have been much weaker (González, 2006).

The voice is produced by vocal folds within the larynx, and it is subsequently filtered by the supralaryngeal vocal tract, giving rise to different formants or resonant frequencies (Fant, 1960). The vocal folds vibrate to produce the fundamental frequency (F0), perceived as voice pitch. As an individual grows, the vocal folds also grow, lowering F0. For this reason, adult voices are deeper than children's voices; and, as women are, on average, shorter than men, their vocal folds are also shorter, making the pitch of a woman's voice higher on average than that of a man's voice. However, within the same sex/age group, the length of the vocal cords bears little relation to height. That is, a tall man does not necessarily have longer vocal cords than a short man, and the same goes for women.

However, beyond pitch alone, the formant frequencies seem to be more informative than F0 about the speaker's body when distinguishing individuals within the same age/sex group. Formants are the resonant frequencies of the vocal tract, and, as the

vocal tract length increases, the formant frequencies decrease, and vice versa (Fitch, 2000). The vocal tract is more constrained than the vocal folds by anatomical structures that are closely related to aspects of body size, including the skull or the skeleton and body length. Consequently, moderate negative correlations have usually been observed between formant frequencies and the speaker's body size (Bruckert, Liénard, et al., 2006; González, 2004, 2006; Pisanski et al., 2014b). On the other hand, correlations between F0 or voice pitch and body size among people of the same sex/age have been found to be very weak or virtually null, because vocal folds are made of soft tissue (Bruckert et al., 2006; González, 2006; Künzel, 1989; Pisanski et al., 2014b; van Dommelen & Moxness, 1995).

Researchers have demonstrated that human listeners can roughly infer a speaker's body height, based on the formant frequencies of the voice (Kreiman & Sidtis, 2011). Unexpectedly, researchers have also revealed that listeners mistakenly infer the speaker's height based on voice pitch (F0) in that they have exhibited a consistent misattribution bias by tending to associate low F0 with tall people and high F0 with short people (Feinberg, et al., 2005; Pisanski & Rendall, 2011; Pisanski et al., 2014b; Rendall, et al., 2007; van Dommelen & Moxness, 1995). Likely, this bias results from an overgeneralization of the physical principle that large or long objects produce low-frequency vibrations, whereas small or short objects produce high-frequency vibrations.

Because voice pitch barely correlates with body size, one would expect that adding pitch information to formant information would not increase accuracy in body size perception. However, Pisanski et al. (2014a) found that although men's voice pitch and physical height were unrelated, the accuracy of the listeners' size assessments from Canadian vowels increased in the presence versus absence of pitch information.

In the present study, we used sine-wave (SW) replicas of Spanish sentences to provide new unique acoustic information from formant frequencies, and we included a new condition in which we added pitch information. The sine-wave (SW) replicas or sinusoidal speech were first used as experimental stimuli and published in *Science* by Remez, et al. (1981). Despite the apparently unnatural speech quality in these replicas, researchers have demonstrated that this type of signal is perfectly intelligible for people with normal hearing, and it allows talker identification (Remez et al., 1981; Remez, et al., 1997; Remez, et al., 1994; for a recent review see Remez, 2021). The SW speech consists of time-varying sinusoidal patterns that follow the trajectories of formant frequencies. As they are "pure" sinusoids that follow the paths of the formants, they only carry information about the frequency pattern of the formants (and the amplitude envelope), omitting any other type of information provided by the human speech. To our knowledge, we are the first to use this type of stimulus in an experiment on the perception of the speaker's body size (height) from listening to the speaker's voice.

Method

Participants

Listening participants were 88 young adults of both sexes (77 females; 11 males; age range 17-39 years; *M* age = 19.56, *SD* = 3.68). All participants were undergraduate psychology students at the University Jaume I (Spain), who were compensated with course credit. All of them voluntarily participated and provided their informed consent. The experimental procedure applied was in accordance with the Deontological and Ethical Committee for studies involving human participants.

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Materials

The content of voice stimuli consisted of a Spanish interrogative sentence ('¿Cuántos años tiene tu primo de Barcelona?' [How old is your cousin from Barcelona?]) recorded from 40 young adult speakers, 20 men and 20 women, who had been university students several years ago, unknown to the participants. These recorded voices were selected from a pool of voice recordings (González & Oliver, 2005) and they were used in other work (Gonzalez-Alvarez & Sos-Peña, 2022); the speakers' heights had been measured with a metric tape affixed to the wall (see Appendix), with male speakers' heights ranging from 160-189 cm *M* height = 176.9, *SD* = = 6.3 cm), which approximates that of the general population of men in Spain (*M* height = 176.6 cm; NCDRISC, 2018). The range of heights of the selected female speakers was 154-175 cm (*M* height = 163.4, *SD* = 7.5 cm), approximating that of the general population of women in Spain (*M* height = 163.4 cm; NCDRISC, 2018). All recorded speakers also provided their informed consent for research participation. From each recording, three types of stimuli were derived.

Natural Sentences (N). The sentences were recorded in a sound-attenuated booth with a Shure SM58 microphone at an approximate distance of 12 cm from the mouth, and a Sony-TCD D-8 digital audiotape (DAT) recorder with a sample frequency of 44.1 kHz. Then, the speech signal was digitally transferred to a PC computer and converted to 16-bit WAV files. Finally, the files were equated in RMS (root mean square) amplitude. The information in the Appendix shows the main acoustic parameters from each speaker's sentence obtained by means of Praat software (Boersma & Weenink, 2016).

Sine-Wave Replicas (SW). From each natural sentence, we created a sine-wave (SW) replica composed of three time-varying sine waves matching the frequency pattern of the first three formants (F1-F3) (see Figure 1). We followed Gonzalez and

Oliver (2005) in our method of creating these sine-wave replicas using the Praat software (Boersma & Weenink, 2016) and applying a Praat script provided by Chris Darwin at: http://www.lifesci.sussex.ac.uk/home/Chris_Darwin/Praatscripts/SWS

Sine-Wave Replicas + Pitch (SWP). From each sine-wave replica, we created a new stimulus by adding a sine wave corresponding to the voice pitch, or fundamental frequency (F0) of the natural sentence. Pitch was extracted from each natural sentence using the Praat software (Boersma & Weenink, 2016), and we applied an algorithm that performed an acoustic periodicity detection on the basis of an accurate autocorrelation method, as described in Boersma (1993).

Pairing of Speech Stimuli. We created 240 pairs of stimuli, 40 for each experimental condition (N, SW, SWP) x speaker's sex (males, females). In each experimental condition by sex of the speakers there were 20 different speakers. Of the total of (20 x 19)/2 = 190 possible different pairs of speakers, 40 pairs were randomly chosen with the only condition that their heights did not differ by less than five centimeters. Each pair was formed by two different stimuli belonging to the same type of stimulus and the speaker's sex, separated by 800 ms of silence. The N/male condition was formed by 40 different pairs of natural sentences from male speakers, whose height differences ranged from 5 – 19 cm (*M* height difference = 9.3, *SD* = 3.9 cm); half of the pairs included the taller man in the first place, and half included the taller man in the second place. The N/female condition was formed by 40 different pairs of natural sentences from female speakers, whose height differences ranged from 9 – 17 cm (*M* height difference = 13.9 *SD* = 3.0 cm); half of the pairs included the taller woman in the first place, and half included the taller woman in the second place. The pairs of speakers were the same for the other two experimental conditions (SW, SWP). These 240 pairs

were divided into four sets of 60 pairs (10 per each type of stimuli x speaker sex), to ensure that neither pair of speakers was repeated within the same set.

Procedure

Each participant was randomly assigned to one of the four sets of stimuli, resulting in a total of 60 size assessment trials per participant. No pair of speakers was repeated for any participant. Participants individually performed the experiment in six short sessions of ten stimuli of the same type of stimulus/speaker sex condition. The order of the sessions was randomized through the participants, although the first session was always with natural sentences (N). At the beginning of each session, participants were informed as to whether the speakers were men or women.

On each trial, participants were presented, through headphones, with the voices of two speakers' of the same stimulus condition (N, SW, SWP) and speaker's sex (males or females). Voices were played consecutively and separated by 800 ms of silence. After listening to the pair of voices, participants were asked to indicate which of the two voices belonged to the taller speaker by selecting the corresponding button on the screen. On each trial, participants could listen to the pair of voices again at will by clicking on a play button. In the SW and SWP conditions, participants were told that the voices were distorted but belonged to real people.

Statistical Analyses

The data were analyzed using the Statistical Package for Social Sciences (SPPS, version 29; IBM Corp, NY, 2022). For each participant, we obtained the average percentage of correct answers in each experimental condition and speaker sex. These data were analyzed by submitting the *SD*s and the confidence intervals [95% CI] to an analysis of variance (ANOVA) to study the significance of the main factors and their interactions. We also calculated the values of the partial eta squared (η^2_p) to measure the

effect size of the variables in the ANOVA model. This parameter calculates the proportion of variance explained by a given variable of the total variance. The effect size interpretations for η^2_p values are: .01 = small, .06 = medium, and .14 = large (Cohen, 1988).

Results

Figure 2 shows the proportions of accurate judgments of speaker height for each stimulus condition (Natural sentences, N; Sine-wave replicas, SW; Sine-wave replicas + Pitch, SWP), separated by the speaker's sex. Keeping in mind that the chance level for this binary discrimination level was 0.500, every value was significantly higher than chance, except for the SW-males condition (0.516; p = .404). Total values indicated that Natural sentences reached the highest level of accuracy, 0.643, 95% CI [0.617, 0.668], followed by the Sine wave + Pitch condition, 0.564 [0.534, 0.593], and the Sine wave condition, 0.559 [0.530, 0.587].

A 3 (Stimulus condition: N, SW, SWP) x 2 (Sex of speakers: male, female) ANOVA found a significant main effect of the Stimulus condition, F (2, 174) = 18.19, MS_e = 0.022, p < .001, η^2_p = .173, and a significant main effect of the Sex of speakers, F (1, 87) = 22.05, MS_e = 0.025, p < .001, η^2_p = .202, because the female speakers received higher rates of accurate judgments (0.620, 95% CI [0.598, 0.642]) than the male speakers (0.556, 95% CI [0.535, 0.577]). The Stimulus condition x Sex of Speaker interaction did not reach statistical significance, F (2, 174) < 1. Within-subject contrasts showed, as expected, that accuracy from the Natural sentences (N) was significantly higher than accuracy from the other conditions, F (1, 87) = 23.66, MS_e = 0.026, p < .0001, η^2_p = .214. However, the within-subject contrast did not find a significant difference between the scores from SW vs. SWP conditions, F (1, 87) < 1. Similarly,

this difference (SW vs. SWP) did not reach significance for only male speakers, F (1, 87) = 1.267, MS_e = 0.052, I= .263, η^2_p = .014, or only female speakers, F (1, 87) < 1.

Discussion

Our data clearly suggested that the formant information contained in the sine-wave replicas (SW) of natural sentences were useful for listeners who attempted to judge the speakers' body size at an above chance level in a binary discrimination task. Nevertheless, the level of accuracy listeners reached did not equal the score obtained from listening to natural sentences, indicating that, beyond the formants, natural speech contains additional information useful for discriminating the speaker's height. González and Oliver (2004) found that actual height was the strongest predictor of perceptual judgments from a spoken sentence in both male and female speakers, suggesting that there may be other acoustic predictors of body size beyond the pitch and the formants. In the Gonzalez and Oliver (2004) study, the partial correlation between actual height and judgments of "taller" in a binary discrimination task reached 0.51 for male stimuli after removing the influence of F0 and F1–F4. On the other hand, adding information about the voice pitch of each sentence in our experiment did not help increase the level of accuracy.

Our findings also revealed that stimuli recorded from the female speakers were more informative for judging the speakers' body size than the stimuli recorded from male speakers. As mentioned above, we acoustically analyzed the stimuli used in our experiment, attending particularly to the natural sentences that served as the basis for creating the other two experimental conditions. Data in the Appendix, separated by speakers' sex, includes the speakers' heights and the acoustic parameters corresponding to the means of F0 (fundamental frequency), F1 (first formant), F2 (second formant),

and F3 (third formant). We also, included the average frequency of the three formants, and the dispersion between formants $[((F2 − F1) + (F3 − F2)) / 2]$. The correlations within the same sex group between speakers' heights and speech parameters were generally null or moderate, consistent with what has been found by other investigators (Barsties, et al., 2016; Gonzalez, 2004, 2006; Owren, 2011; Pawelec, et al., 2020; for a review see Pisanski et al., 2014b). The highest correlations with speakers' heights corresponded to the second formant (F2, r = −0.306, accounting for 9.4% of the variance or r^2) for male speakers, the second formant (F2, r = −0.472, accounting for 22.3% of the variance), and the formant average (r = −0.355; accounting for 12.6% of the variance) for female speakers. The fact that the correlations between speakers' heights and formant frequencies were somewhat higher for female speakers, especially for the formant average, might explain why the participant assessments were more accurate for female stimuli. Note that part of the superiority of the height-formant correlation for perceiving female speakers could be because female heights were more variable than male heights. Pisanski et al. (2014b) conducted a large meta-analysis of vocal indicators of body size in adult men and women, including 295 correlation coefficients derived from 39 independent samples across participants in five different continents. They concluded that (a) formant-based estimates of vocal tract length explained about 10% of height within sexes and (b) voice pitch (F0) explained only 2% of the variance in predicting men's height and 0.5% of the variance in predicting women's height. Our stimuli yielded a correlation of r = −0.209 (accounting for 4.4% of the variance) between height and voice pitch (F0) for male samples, and a null correlation (r = −0.003; with no variance predicted) for female samples. This difference could explain why, in the case of the male stimuli, the SW replicas + pitch gave a

slightly higher accuracy (0.543) than the SW replicas alone (0.516), although this small increase was nominal.

Limitations and Directions for Further Research

A limitation of this study was the asymmetry of this sample of listener-participants, all of whom were undergraduate psychology students comprised mostly of females. This asymmetry was not a serious problem since we did not aim to compare the listeners' gender in relation to perceptual accuracy. However, future investigators may wish to address that question. Secondly, we used sine-wave replicas created from Spanish sentences. As Spanish is a Romance language in which syllables play a crucial role as units of articulation within the connected speech (i.e., a syllable-timed language), future investigators should determine whether a stress-timed Germanic language, such as English would produce different results. Finally, we used a non-demanding task from a perceptual-cognitive point of view, asking participants to choose, between just two voices, the one that corresponds to the taller person. Future research might explore the results with a more demanding task, such as directly estimating height in centimeters and/or analyzing other physical aspects of the body, such as weight, using sine-wave replicas.

Conclusions

We employed sine-wave replicas of sentences to study the perception of body height from human voices for the first time. This type of stimuli allows a rigorous experimental control since it provides information solely and exclusively on the formants (resonances of the vocal tract) without any other information from the speech signal spectrum. Our results show that human listeners can perceive body height from this information alone and that adding vocal pitch does not significantly increase accuracy. Most previous studies used intact samples of vowels or syllables (usually in

English), but we used connected speech in Spanish. Connected speech is more than the sum of a series of phonemes since it comprises a dynamic and coarticulated succession of speech sounds forming syllables as units of articulation, particularly in Spanish (Gonzalez-Alvarez & Sos-Peña, 2022). The time-varying trajectories of the vocal formants might operate as sources of inference about the articulator apparatus's biomechanical properties—mass, mobility, and inertial characteristics.

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Conflict of Interest

The authors declare they have no conflict of interest.

FIGURE CAPTIONS

Figure 1. Spectrograms of Three Examples of Experimental Stimuli.

*Note: (*A) Natural (N) sentence ('¿Cuántos años tiene tu primo de Barcelona?' [How old is your cousin from Barcelona?]) uttered by a male speaker. (B) Sine wave (SW) replica derived from the above natural sentence composed by three sine waves following the frequency pattern of the first three formants (F1-F3). (C) Sine wave replica + Pitch (SWP), the same replica with the Pitch or Fundamental Frequency (F0) of the natural sentence added. B and C are scaled up in the vertical axis; the soft vertical stripes of C correspond to the beginnings and ends of the pitch wave.

Figure 2. Mean Proportions Correct in a Binary Discrimination Task on the Speakers' Body Height.

Note: Data separated by experimental conditions (Natural sentences, Sine waves replicas, and Sine waves + Pitch) and speakers' sex. Error bars represent plus and minus one standard error of the mean.
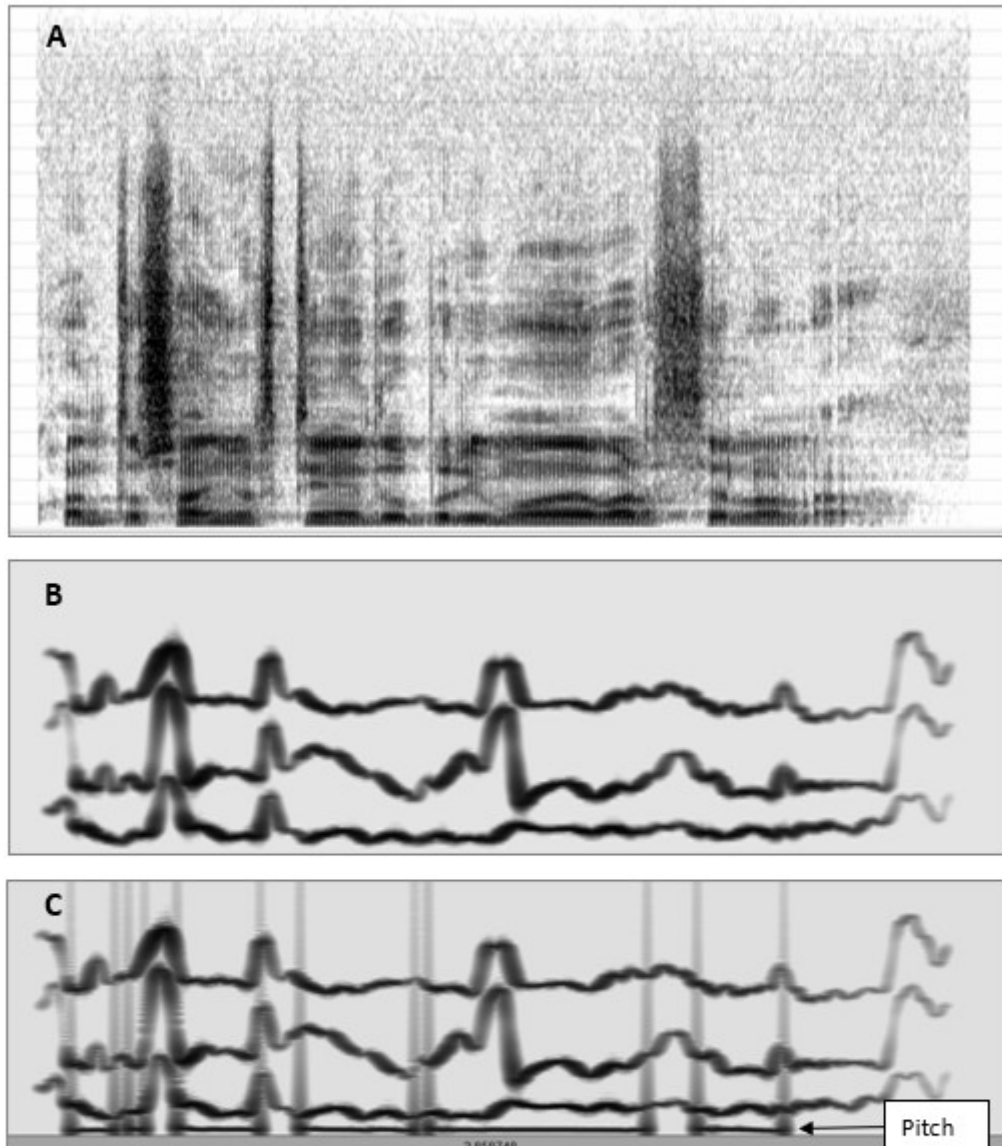
Figure 1. Spectrograms of three examples of experimental stimuli. A) Natural (N) sentence ('¿Cuántos años tiene tu primo de Barcelona?' [How old is your cousin from Barcelona?]) uttered by a male speaker. B) Sine wave (SW) replica derived from the above natural sentence composed by three sine waves following the frequency pattern of the first three formants (F1-F3). C) Sine wave replica + Pitch (SWP), the same replica with the Pitch or Fundamental Frequency (F0) of the natural sentence added.
Note: B and C are scaled up in the vertical axis; the soft vertical stripes of C correspond to the beginnings and ends of the pitch wave.
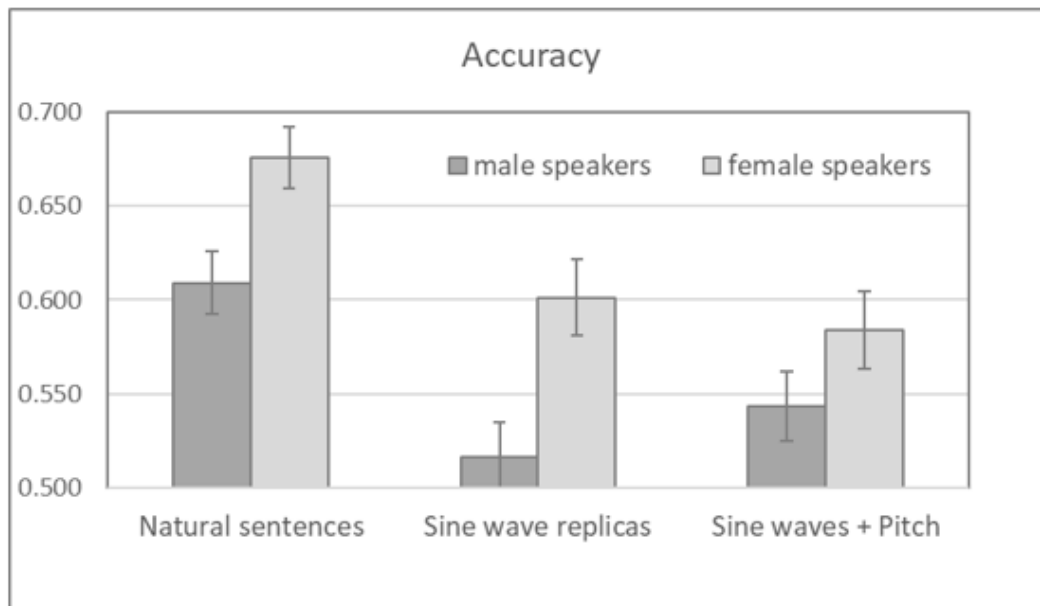
Figure 2. Mean proportions correct in a binary discrimination task on the speakers' body height. Data separated by experimental conditions (Natural sentences, Sine waves replicas, and Sine waves + Pitch) and speakers' sex. Error bars represent plus and minus one standard error of the mean.

Appendix

Speaker heights and acoustic parameters of stimuli (natural sentences), separated by speakers' sex (M: men; W: women). Voice parameters are means of F0 (fundamental frequency), F1 (first formant), F2 (second formant), F3 (third formant), average of F1-F3, and dispersion between formants [((F2-F1) + (F3-F2))/2].
Acoustic analysis were performed with Praat software (Boersma & Weenink, 2016).

				Male Speakers								Female Speakers				
Speakers	Height (cm)	F0 (Hz)	F1 (Hz)	F2 (Hz)	F3 (Hz)	Formant Average (Hz)	Formant Dispersion (Hz)	Speakers	Height (cm)	F0 (Hz)	F1 (Hz)	F2 (Hz)	F3 (Hz)	Formant Average (Hz)	Formant Dispersion (Hz)
M1	177	158.5	519	1553	2501	1524	991	W1	157	241.0	545	1861	2999	1802	1227
M2	180	113.6	528	1577	2498	1534	985	W2	175	230.2	599	1854	3048	1834	1225
M3	172	188.9	534	1695	2845	1691	1156	W3	154	199.4	599	1967	3090	1885	1245
M4	181	144.3	387	1579	2626	1530	1120	W4	158	215.7	585	1788	2900	1757	1158
M5	179	140.2	455	1633	2557	1548	1051	W5	156	228.7	590	1892	3208	1897	1309
M6	189	100.3	499	1422	2610	1510	1056	W6	170	205.9	510	1853	3021	1795	1256
M7	175	155.0	467	1555	2586	1536	1059	W7	156	216.9	654	1894	3068	1872	1207
M8	160	118.4	395	1575	2505	1492	1055	W8	168	190.7	589	1838	3061	1829	1236
M9	170	129.9	483	1612	2605	1567	1061	W9	172	213.9	539	1753	2845	1712	1153
M10	176	149.6	450	1645	2732	1609	1141	W10	167	196.4	558	1769	2922	1749	1182
M11	175	142.1	447	1531	2567	1515	1060	W11	158	202.7	533	1874	3021	1809	1244
M12	175	134.4	383	1463	2478	1441	1047	W12	157	236.9	524	1821	2950	1765	1213
M13	172	127.3	473	1501	2389	1454	958	W13	155	236.2	559	1806	3032	1799	1237
M14	180	127.7	388	1560	2465	1471	1039	W14	171	205.6	504	1720	2981	1735	1238
M15	173	179.9	477	1620	2752	1616	1137	W15	168	215.0	465	1774	2937	1725	1236
M16	185	149.9	553	1595	2735	1628	1091	W16	170	200.7	595	1872	2950	1806	1178
M17	183	123.6	376	1493	2547	1472	1085	W17	175	274.1	573	1779	3023	1792	1225
M18	184	131.5	500	1559	2525	1528	1012	W18	156	218.2	512	1780	2980	1758	1234
M19	175	132.3	398	1528	2591	1506	1097	W19	167	196.6	601	1801	2864	1755	1132
M20	178	166.8	495	1641	2838	1658	1171	W20	157	211.3	541	1872	2876	1763	1168
Correlation with Height		-.209	.215	-.306*	.062	-.003	-.038			-.003	-.115	-.472**	-.250	-.355*	-.199

*: significant at the .10 level (1-tailed); **: significant at the .05 level (1-tailed)