PSYCHOPHYSICS OF VOICE PITCH AND ATTRACTIVENESS

PSYCHOPHYSICAL PROPERTIES OF PERCEIVED VOCAL ATTRACTIVENESS BASED ON PITCH MANIPULATIONS

By

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Abstract

Experiments have shown that manipulations of vocal fundamental frequency, a physical correlate of voice pitch, alter perceptions of vocal attractiveness. Individual experiments, however, have found different effects of pitch manipulations on attractiveness. One possible explanation for the disparate findings may be differences in the strength of pitch manipulations used between studies. The focus of this thesis is to determine psychophysical properties of vocal attractiveness based on pitch manipulations. Within the thesis, two experiments are described that were designed to find just-noticeable differences in vocal attractiveness based on pitch manipulations. The experiments were also designed to determine if there are limits for voice pitch preferences. Relevant background concepts to the thesis are described in Chapters 2-5, and a manuscript is presented in Chapter 6 that describes the methods and results of the experiment, and gives a discussion of the findings.

In Chapter 2, the basic anatomy underlying vocal production is explained, including the anatomical structures involved in the source-filter model of vocal production.

In Chapter 3, relevant acoustic properties of the voice are described, including fundamental frequency, harmonics, and formant frequencies.

In Chapter 4, the basic anatomy involved in audition is explained, including how sound is propagated through the ear.

In Chapter 5, a brief review of previous psychophysical research on pitch discrimination and perceived vocal traits is given.

In Chapter 6, two experiments are described. Experiment 1 was designed to determine just-noticeable differences in voice pitch discrimination. Experiment 2 was designed to determine just-noticeable differences in voice attractiveness based on manipulations of voice pitch. Experiment 2 was also designed to assess potential limits to voice pitch preferences for supernormal stimuli. Just-noticeable differences in vocal attractiveness were larger than just-noticeable differences in pitch discrimination. Just-noticeable differences in attractiveness were larger in women's voices than men's. There was no limit in men's preferences for high-pitched voices, however there was a limit for women's preferences for low-pitched voices below the natural male pitch range.

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Feinberg, D.R.: Original voice recordings, experimental design, theoretical advisor, data analysis, edited paper

Table of Contents

List of Tables and Figures

Chapter 1: Introduction

1.1 Fundamental frequency and voice attractiveness

The role of voice pitch on attributions of voice attractiveness has been a topic of increasing research focus in recent years. Advances in technology have allowed for accurate manipulations of vocal parameters. This in turn has allowed for controlled studies of voice attractiveness based on manipulations of specific voice parameters.

One voice parameter that affects perceptions of vocal attractiveness is the fundamental frequency and corresponding harmonics (see Feinberg, 2008, for review). Perceptions of fundamental frequency and corresponding harmonics are henceforth referred to as voice pitch. The majority of voice attractiveness research has found that women prefer lower-pitched men's voices (Collins, 2000; Feinberg et al., 2005; Saxton, Caryl, and Roberts, 2006; Feinberg et al., 2006; Bruckert et al., 2006; Feinberg et al., 2008a) while men prefer higher-pitched women's voices (Collins and Missing, 2003; Jones et al., 2007; Feinberg et al., 2008b; Apicella and Feinberg, 2009). There are, however, some discrepancies in the findings between individual studies. For example, one controlled study on the effect of pitch manipulations on vocal attractiveness reported that women only prefer lower-pitched men's voices while in the ovulatory phase of their menstrual cycle, and only in the context of a short-term relationship (Puts, 2005). Another study finds that lower-pitched voices are more attractive than higher-pitched voices, but that lower-pitched voices are not more attractive than average-pitched voices (Riding, Lonsdale, and Brown, 2006).The findings of the aforementioned studies are in contrast to several other experiments, which have found women prefer lower-pitched men's voices independently of menstrual cycle phase or relationship context (Feinberg et al., 2005a; Feinberg et al., 2006; Feinberg et al., 2008a; Apicella and Feinberg, 2009).

1.2 The need to establish just-noticeable differences in voice attractiveness

A possible explanation for the discrepant findings mentioned in the previous section is that different experiments have used various degrees of pitch manipulations to alter perceptions of attractiveness. The differences in pitch manipulations used in previous experiments are outlined in the prepared manuscript at the end of this thesis. Differences in the strength of pitch manipulations could have led some experiments to reveal relationships between voice pitch and attractiveness (Feinberg et al., 2005; Feinberg et al., 2006; Bruckert et al., 2006; Feinberg et al., 2008b; Feinberg et al., 2008a; Vukovic et al., 2008; Apicella and Feinberg, 2009) whereas others have not found such relationships (Puts, 2005; Riding, Lonsdale and Brown, 2006) It is possible that experiments that have not found such relationships may not have manipulated pitch enough to alter voice preferences.

To establish the degree to which pitch must be altered to affect attractiveness ratings, here, I will measure the just-noticeable difference in attractiveness based on pitch manipulations. Furthermore, determining just-noticeable differences in vocal attractiveness could establish standards in the field for the degree that pitch may be manipulated to alter attractiveness ratings.

Determining just-noticeable differences in voice attractiveness based on pitch manipulations may have implications on research in other studies relating to voice preferences. Recent research indicates that women's voice pitch increases during ovulation (Bryant and Haselton, 2009, but see Chae et al., 2001). It has been suggested that such an increase in pitch may be an example of a cue of ovulation (Bryant and Haselton, 2009). Indeed, vocal cues to ovulation have been found among other primate species, such as the yellow baboon (Semple et al., 2002). In Bryant & Haselton (2009), only 55% of voices changed pitch over the menstrual cycle, and only 55% of people could hear those differences. Thus, establishing just-noticeable differences in women's voice attractiveness will help determine whether the increase in pitch during ovulation found by Bryant & Haselton (2009) is sufficient to alter vocal attractiveness.

Another focus of this thesis is to determine if there are limits on preferences for voice pitch. As stated earlier, men prefer higher-pitched women's voices, while women prefer lower-pitched men's voices. While studies have investigated preferences for various levels of voice pitch, no studies, have assessed whether these preferences remain consistent outside the natural pitch range for men and women. Among many species preferences for super-normal stimuli are associated with directional and/or disruptive selection (Andersson, 1994; Fisher, 1999). Preferences for voice pitch may or may not remain consistent even outside the range of natural frequencies, or they may reverse, showing a dislike for supernormal voice pitch.

1.3 Thesis outline

The aim of this thesis is to establish just-noticeable differences in voice attractiveness and determine whether there are limits on voice pitch preferences. The thesis contains relevant background information in Chapters 2-5. Two experiments relevant to voice pitch preferences are described in Chapter 6.

Basic anatomy of vocal production is explained in Chapter 2. This includes a description of the source-filter theory, the standard model of vocal production (Fant, 1970). The larynx will be especially focused upon, as it is the structure most associated with voice pitch.

Relevant acoustic phonetics of speech, including fundamental frequency, harmonics, and formant frequency is described in Chapter 3. It will also give a brief description of the anatomical processes involved in creating these vocal parameters.

The basic auditory processes involved in hearing is explained in Chapter 4. The ear is divided into three parts: the outer, middle, and inner ear. The anatomy of each part is briefly described, as well as how sound is propagated within the ear. The organization of the central auditory system is also briefly described, to the extent that is relevant to this thesis.

Previous psychophysics experiments on pitch discrimination in speech are explained in Chapter 5. This chapter also includes a description of a previous experiment that employed psychophysics techniques to establish perceptual thresholds for perceived traits based on vocal parameter manipulations (Smith et al., 2005). A discussion of how psychophysics techniques could be used to determine just-noticeable differences for other perceived vocal traits is also included.

Data from two experiments is presented in Chapter 6. Experiment 1 was designed to establish just-noticeable differences in voice pitch. Experiment 2 was designed to establish just-noticeable differences in vocal attractiveness based on pitch manipulations. Experiment 2 was also created to assess potential limits of voice pitch preferences to super-normal stimuli. The methods and procedures used are described, as are the results. A discussion of the findings and the implications they have on the voice research field is given.

Chapter 2: Basic anatomy of the human larynx

The standard model of human vocal production is the source-filter model of vocal production. This model states that vocalizations are produced through an anatomical source (larynx) and modulated through a filter (pharynx, oral and nasal cavities, mouth) (Fant, 1970). This chapter will give a description of the anatomy of vocal production in light of the source-filter model.

2.1 Larynx

Titze (1994) described the anatomical structures of vocal production in depth. The anatomy of the larynx and vocal tract will be briefly described here, although the most intricate details are beyond the scope of this thesis.

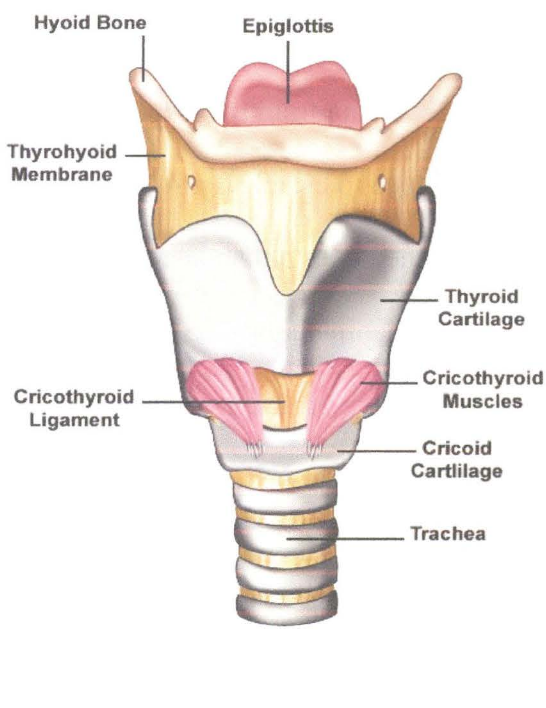

Figure 2.1 - Anterior view of the larynx showing the thyroid and cricoid cartilages and trachea (www.biologycorner.com)

The larynx (Figure 1) is a cartilaginous structure that is suspended within the neck and lies anterior to the esophagus. The larynx is the part of the respiratory airway, and is connected to the lungs through the trachea. The epiglottis, a flap of elastic cartilage, lies directly superior to the larynx. When swallowing, the epiglottis folds down to prevent bolus from entering the larynx.

When breathing and/or vocalizing, the epiglottis folds up into the pharynx (see Section 2.2 for details on the pharynx), opening the airway. The larynx is suspended in the neck by sphincter muscles that allow it to move both vertically and horizontally within the neck. For instance, when swallowing, the larynx moves up and tucks under the epiglottis, and moves forward within the neck to allow the esophagus to expand. The need for mobility precludes the development of bony structures within the larynx. The only bone in the vocal tract, apart from vertebrae, is the hyoid bone, though even this bone moves independent of the rest of the skeleton. At the inferior border of the larynx is the trachea, which is surrounded by 15-20 cartilaginous tracheal rings. The trachea itself is 10-16 mm long and forms the primary bronchi of the lungs at its base. Superior to the tracheal rings is the cricoid cartilage, which encompasses the entire laryngeal airway at the base of the larynx. It is both wider and taller than the tracheal rings. It also forms a full circular structure around the airway, whereas the tracheal rings do not connect anteriorly, forming C-shaped structures. The thyroid cartilage lies superior to the cricoid cartilage. The thyroid cartilage is perhaps the most prominent cartilage of the larynx, with two plate-like laminae that join anteriorly, forming an angle at the front of the neck. The most superior part of this angle, the thyroid notch, is externally visible in men, and is known as the "Adam's Apple". The posterior portions of the two laminae have elongated knobs at either end, the superior and inferior cornu. The inferior cornu connects to the cricoid cartilage, and the superior cornu connects to the hyoid bone. The hyoid bone is not technically a part of the larynx, however it serves to connect the larynx to the pharynx, and may protect the soft tissue that lie posterior to it.

Within the larynx, the arytenoid cartilages lie superior to the posterior portion of the cricoid cartilage. The vocal cords extend from the arytenoid cartilages to the interior portion of the thyroid cartilage (Figure 2). The vocal cords are crucial for vocalization, and vary in length and thickness depending upon levels of circulating sex hormones during puberty and adult-life (Beckford et al., 1985; Harries et al.; 1999; Abitbol, Abitbol, and Abitbol, 1999; Dabbs and Malinger, 1999). The vocal cords can be adducted and abducted, bringing them together or moving them apart, respectively. The arytenoid cartilages can be moved anteriorly, which shortens and thickens the vocal cords. The open area between the vocal cords is known as the glottis, and is the narrowest airway passage through the larynx.

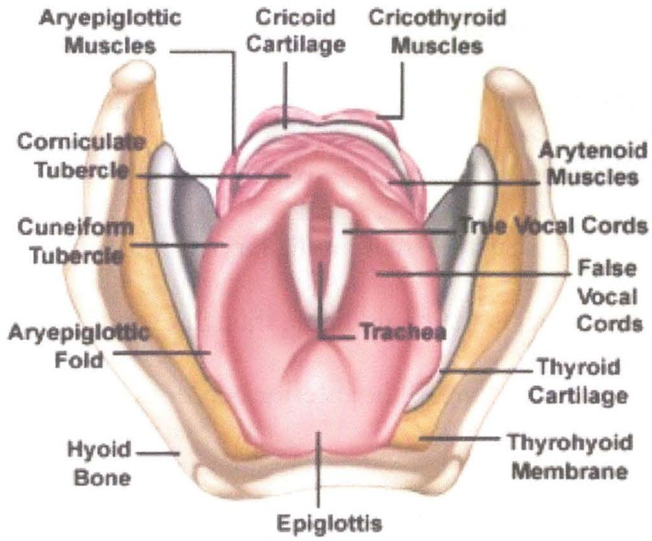

Figure 2.2 – Superior view of the larynx. Note the vocal cords surrounding the glottis (www.superiorviewfees.com).

2.2 Vocal tract

The supralaryngeal vocal tract (henceforth referred to as the vocal tract) is considered the filter in the source-filter theory of vocalization (Fant, 1970). The vocal tract lies superior to the larynx and consists of the pharynx, oral and nasal cavities, and the mouth (Figure 3). The pharynx lies directly superior to the larynx, and is important in both respiration and consumption of food and liquids. As stated before, when breathing or vocalizing, the epiglottis folds up into the pharynx, creating a respiratory passage from the lungs through the trachea, larynx, pharynx, oral and nasal cavities, and mouth. The vocal tract is responsible for the modulation of vocalizations. Shaping the vocal tract by moving the tongue and lips and jaw will create different vowel sounds (Ladefoged, 1982). The vocal tract is also responsible for creating formant frequencies, which will be discussed in later chapters.

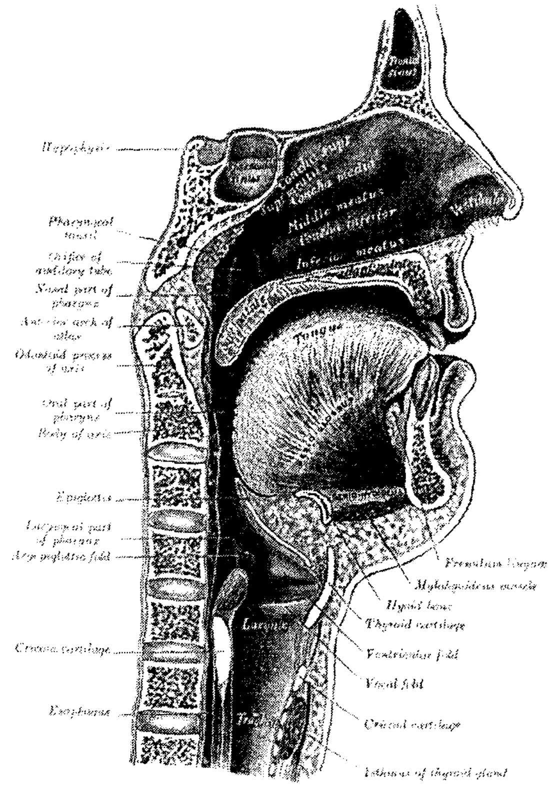

Figure 2.3 – Sagittal view of the vocal tract showing pharynx, oral and nasal cavities, and mouth (Gray, 1918).

This is but a very brief overview of the anatomical structures that produce vocalizations. A more comprehensive review of the anatomy related to human vocalizations is beyond the scope of this thesis, but can be found in several other sources (Titze 1994; Ladefoged 1982; Stevens, 2000).

Chapter 3 contains an explanation of how these anatomical structures relate to acoustic parameters of speech.

Chapter 3: Voice production

3.1 Myoelastic-aerodynamic theory of vocal production

Van den Burg (1958) first described the myoelastic-aerodynamic theory of voice production. This model states that vocalizations are produced through Bernoulli forces causing adducted vocal cords to be drawn together and pushed apart, leading to vocal cord oscillation. Oscillation is sustained by the natural elasticity of the vocal cords. The oscillation of the vocal cords cuts exhalation into small bursts of air, producing (along with modification in the vocal tract) audible vocalizations. If the vocal cords are not adducted enough, expiration will not induce full vocal cord oscillation. Furthermore, if vocal cords are wide apart during exhalation, vocal cord oscillation will not occur, producing whispers.

To start vocal cord oscillation, pressure builds in the lungs, creating a force on the underside of adducted vocal cords. When enough pressure has built up in the lungs (the phonation threshold pressure), the vocal cords are forced apart, releasing a small puff of air. Once this burst of air has been released, the pressure under the vocal cords drops, drawing the vocal cords back together. This causes pressure to once again build up in the lungs, and the process repeats itself. This process occurs many times a second, and leads to a sustained oscillation of the vocal cords. The sustained vocal cord oscillation leads to phonation. Vocalizations can be analyzed through several vocal parameters, some of which will be discussed here.

3.2 Fundamental frequency

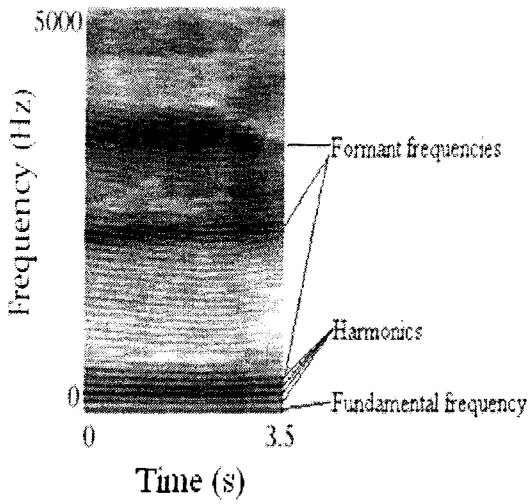

Figure 3.1 – A spectrogram of human voice showing fundamental, formant, and harmonic frequencies (adapted from Feinberg, 2005).

Fundamental frequency and corresponding harmonics are the primary physical correlates of voice pitch. Fundamental frequency is most often the lowest frequency of a periodic waveform (Titze, 1994). As mentioned before, when negative pressure in the lungs reaches the phonation threshold pressure, sustained oscillation of the vocal cords produces small puffs of exhaled air. It is perhaps easiest to visualize fundamental frequency by drawing analogies to standing waves of a string. In such an analogy, the vocal cords could be considered two strings that are fixed at both ends, given that they are "docked" at the arytenoid and thyroid cartilages (Titze, 1994). When air is push through the adducted vocal cords, the cords will begin to oscillate. As is the case in strings, the rate of vocal cord oscillation is dependent on the mass and length of the cords, and how much force is being applied to them. At any given force, the rate of vocal cord oscillation is inversely proportional to the mass and length of the vocal cords. Fundamental frequency of speech is related to the number of vocal cord oscillations per second. Thus, individuals with longer, thicker vocal cords will have lower fundamental frequency. An equation can be made from the variable factors involved in fundamental frequency:

$$F0 = \frac{1}{2L} * \sqrt{\frac{\sigma}{\rho}}$$

In this equation, F_0= Fundamental frequency, L=length of the vocal cords, σ=stress, and ρ=vocal cord density (Titze, 1994).

3.3 Harmonics

When the phonation threshold pressure is reached, the vocal cords are set into oscillation. The fundamental frequency is the number of vocal cord oscillations per second. A waveform will produce frequencies at integer multiples of the fundamental frequency (Figure 5). These are known as harmonics (Titze, 1994). Given that harmonics are directly related to fundamental frequency, harmonics are also dependent on the mass and length of the vocal cords, and the stress applied to them. The frequency difference between successive harmonics is equal to the fundamental frequency. The amplitude of harmonic frequencies depends on the amount of

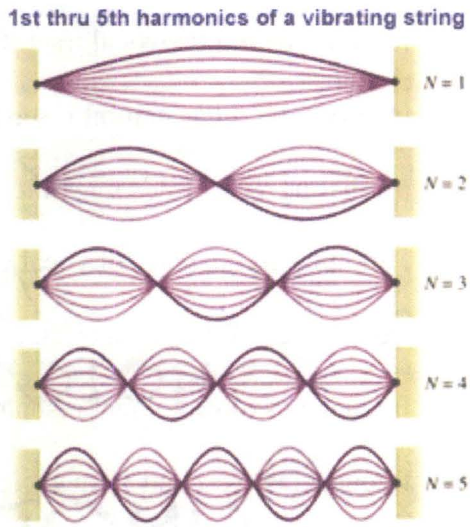

Figure 3.2 – Diagram showing fundamental frequency (N=1) and corresponding harmonics (www.miquel.com)

energy lost at the glottis during phonation. For example, if the vocal cords are fully adducted, little energy will be lost during phonation, and harmonic amplitude will be large. If, however, the vocal cords are somewhat abducted during phonation, more energy will be lost in the form of freely exhaled air, and harmonic amplitudes will attenuate at a greater rate than if the vocal cords were fully adducted.

3.4 Formant frequencies

During phonation, oscillation of the vocal cords creates frequencies that resonate within the vocal tract. Furthermore, like all solid objects (Blevins, 1979), the vocal tract has natural resonant frequencies. The frequencies caused by oscillating vocal folds may interact with the natural frequencies of the vocal tract. Particular frequencies of vocal cord oscillation will synchronize with the natural frequencies of the vocal tract, enhancing resonance at these frequencies. The frequencies of prominent resonation in the vocal tract are known as formant frequencies. Formant frequencies are dependent upon the shape of the vocal tract (Titze, 1994). Specific formant frequencies can be estimated by equations that analogize the vocal tract to a tube open at one end. Although not the primary focus of this thesis, formant frequencies play a large role in vocalizations and speaker perceptions (Feinberg et al., 2005; Smith, Walters and Patterson, 2007; Puts, 2007; van Dommelen and Moxness, 1995).

Chapter 4: Basic Anatomy of the Human Ear and Auditory Processing

Yost (2001) describes the anatomy of the ear in great depth. This chapter contains a brief description of the anatomical structures of the ear relevant for speech processing. The human ear can be separated into three distinct sections: the outer ear, the middle ear, and the inner ear (Figure 6). Each section will be briefly described here.

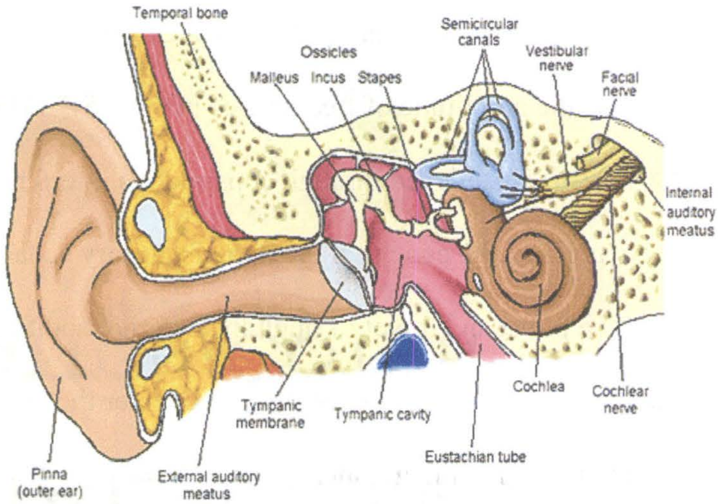

Figure 4.1 – The human ear. The ear is functionally divided into the outer, middle, and inner ear (www.hearingprofessionals.co.nz)

4.1 The Outer Ear

The outer ear is the most lateral portion of the ear, and is the most exposed to the external environment. The outer ear terminates laterally in the pinna, a cartilaginous structure without any significant or controllable muscles (Yost, 2001). The pinna has several bumps and grooves, and is useful for directing sound waves towards medial portions of the ear, somewhat analogous to a satellite. The pinna converges to a small opening in the outer ear, called the concha. The concha, in turn, leads to a smaller opening, the external auditory meatus. The meatus connects the lateral portions of the outer ear to the external auditory canal. The canal is a tube-like structure that is conducive to sound propagation. It has been shown that the pinna, concha, and external auditory meatus collectively increase the amplitude of frequencies in the 1.5-7 kHz range by 10-15 dB (Yost, 2001). This is achieved through constructive interference with the natural frequencies of the concha and external auditory canal. Sound waves are funneled from the pinna and travel through the external auditory meatus and down the external auditory canal, where they encounter the lateral boundary of the middle ear, the tympanic membrane.

4.2 The Middle Ear

The middle ear is laterally bound by the tympanic membrane, or eardrum. The membrane is tightly drawn across a cone-shaped area that leads to the medial portions of the inner ear (Figure 7). Aside from sound propagation through the middle ear, the tympanic membrane also serves to protect the middle ear from the external environment (Yost, 2001). The tympanic membrane connects to the three ossicles, or ear bones. The tympanic membrane

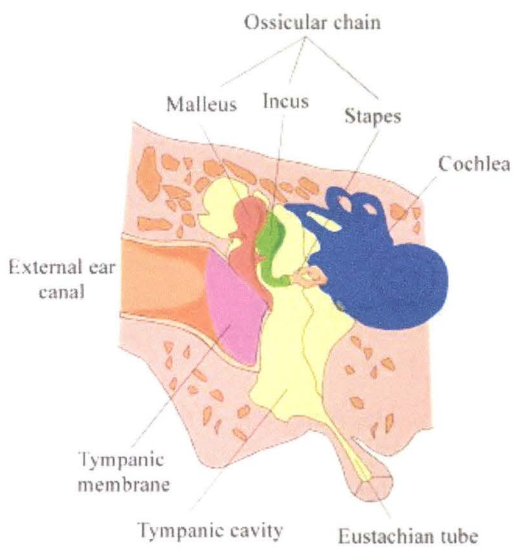

Figure 4.2 The middle ear, highlighting the tympanic membrane and ossicles (www.thinkquest.org).

is directly attached to the malleus, the most lateral ossicle. The malleus connects to the incus, which is medially connected to the stapes. All together, this ossicular chain spans the entire middle ear, which is about 2 cubic centimeters in volume (Yost, 2001). The medial portion of the stapes connects to the lateral boundary of the inner ear, the oval window. When sound waves hit the tympanic membrane, the membrane vibrates, which in turn vibrates the three ossicles and the round window. Sound is therefore transmitted through the middle ear through mechanical vibration.

4.3 The Inner Ear

The stapes connects the middle ear to the most lateral portion of the inner ear, the oval window. The inner ear transforms sound into an electrochemical signal that is processed by the auditory cortex (Yost, 2001). The inner ear contains three fluid-filled structures important for balance and hearing: the semicircular canals, the vestibule, and the cochlea. The stapes sends a signal to the inner ear by vibrating the oval window, which disrupts fluids within the inner ear structures. The two most lateral structures of the inner ear, the semicircular canals and the vestibule, are mostly involved in maintaining balance, and will not be discussed here in depth. When disrupted, however, a chain reaction through the inner ear eventually disturbs fluid in the medial portion of the inner ear, the cochlea. The cochlea is a spiral, shell-shaped structure that contains the primary auditory organ of the inner ear (Yost, 2001). The cochlea is about 35 mm and coils about 2 5/8 times. The cochlea is connected to the lateral portion of the inner ear by the round window, and terminates at a convergence point, called the apex. The inner cochlea is quite complex, thus only the relevant structures will be described here. The length of the inner cochlea can be divided into three sections, superior to inferior: scala vestibuli, scala media, and scala tympani (Figure 8). Scala media, the middle portion of the inner cochlea, contains a fluid called endolymph, and is separated from the scala tympani by the basilar membrane. The basilar membrane has a cellular layer known as the Organ of Corti, which contains inner and outer hair cells. When the stapes vibrates the oval window of the inner ear, it disrupts the fluid in the cochlea, called the endolymph. The motion of the endolymph disrupts the hair cells of the Organ of Corti, which is part of the basilar membrane. The hair cells then transcribe sound from mechanical vibrations to an electrochemical signal to be processed in the auditory cortex.

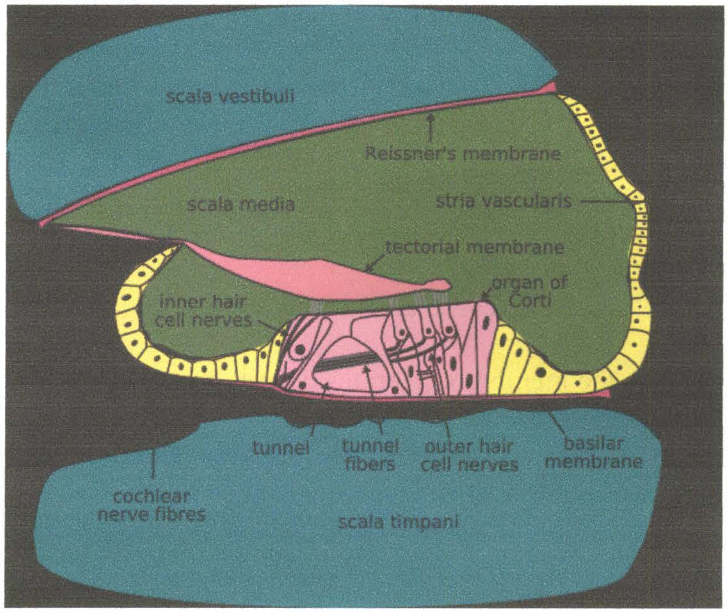

Figure 4.3 – A cross-section of the cochlea. The Organ of Corti is a cellular layer of the basilar membrane and contains the hair cells (www.web-books.com).

The human ear is divided into three distinct parts. The outer ear collects sounds waves and propagates them to the inner ear. Sound is then transcribed from waves to mechanical vibrations of the bony structures of the middle ear. Once the vibrations of the bony structures reach the oval window, the sound is transcribed from mechanical vibration to motion of the fluids within the inner ear. These fluids disturb hair cells within the cochlea. This transcribes sound into an electrochemical signal to be processed by the auditory cortex.

4.4 Auditory processing

Auditory signal processing is a complex topic, and is only described here to an extent relevant to this thesis. After sound is transduced through the outer, middle, and inner ear, a mechanical disturbance of the round window of the cochlea occurs (Yost, 2001). The disturbance eventually sets endolymph in the cochlea into motion, vibrating the basilar membrane and disrupting the hair cells of the Organ of Corti. The hair cells start an electrochemical signal that is transduced to afferent fibers of the central auditory system. There are many afferent fibers for every hair cell. The afferent fibers of hair cells travel to the central auditory system. The processing involved at this point in sound transduction is very complicated and beyond the scope of this thesis, however to put it simply, the central auditory system sorts and processes sound signals and sends them to the auditory cortex for further processing.

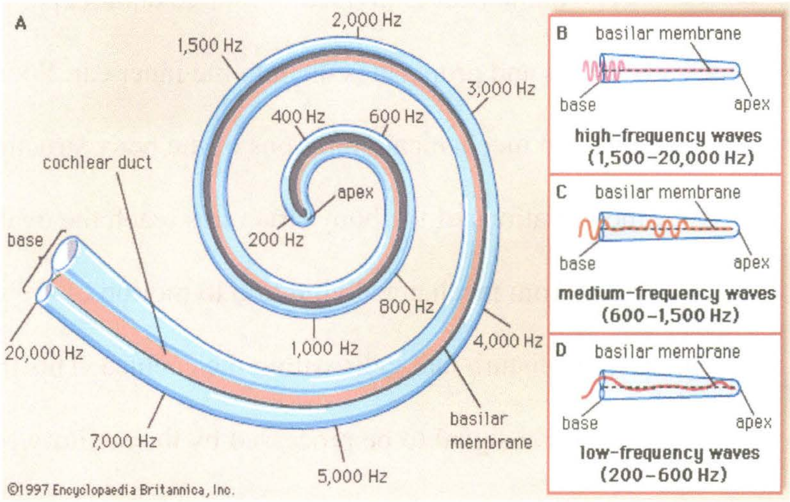

Figure 4.4 – The basilar membrane showing tonotopic organization. The membrane vibrates most to higher frequencies at the basilar end, and to lower frequencies at the apical end (www.hearingcentral.com).

Hair cells are tonotopically arranged along the basilar membrane (Romani, Williamson, and Kaufman, 1982; Pantev et al., 1995), and respond differently to different frequencies (Figure 9). The basilar membrane is stiffer toward the round window, and is vibrated only by higher frequency sounds. The membrane is more compliant towards the apex, and can be vibrated by lower frequency sounds. The afferent fibers of the hair cells in these regions lead to the central auditory system, which in turn is also tonotopically arranged. Human hearing range is generally about 20-20 000 Hz (Blauert, 1997). Most human speech frequencies, however, are quite low relative to the range of audible frequencies. In accordance to Weber's law (Fechner, 1966), larger frequency differences are needed to produce perceptible changes at high frequencies than at low frequencies. Adult human voice frequencies are generally at the low end of the audible frequency range, thus small differences in human voices are more easily discriminated than small differences of higher-pitched noises. The enhanced ability to detect differences in human voices may be advantageous, as it allows for discrimination of voice frequencies between individuals and phonemes.

This chapter contains a very brief overview of the anatomical structures and processes involved in hearing. It is by no mean comprehensive, but describes only the concepts relevant to this thesis. For a full description of auditory anatomy and processing, see Yost (2001).

Chapter 5: Psychophysics and perceived voice traits

5.1 – The necessity of understanding pitch discrimination thresholds

Fundamental frequency is the best-studied vocal parameter affecting vocal attractiveness. It is important, then, for researchers studying this phenomenon to understand limitations to vocal pitch discrimination. The just-noticeable difference for pitch discrimination (how large a difference in pitch must be before human detection) must be understood before studying the effects of pitch on speaker perceptions.

5.2 – Vocal pitch discrimination

In psychophysical studies of absolute pitch discrimination, the just-noticeable difference is usually defined as the difference in pitch that will produce a perceptible difference 75% of the time (Stevens, 1951). This just-noticeable difference is dependent on individual hearing ability, as well as the technology and methods used in testing. In general, just-noticeable differences for pitch discrimination are greater at the higher frequencies, in accordance with Weber's law (Fechner, 1966). Flanagan and Saslow (1957) used an electronic vowel synthesizer to test vocal fundamental frequency discrimination. They found just-noticeable-differences between 0.28-0.48 Hz for vowel sounds at 80 and 120 Hz. Klatt (1973) found a similar result in using a digitally simulated speech synthesizer. Just-noticeable differences of 0.3-0.5 Hz were found for constant-frequency vowel sounds with an initial frequency of 120 Hz. More recently, Smith et al. (2005) determined a just-noticeable difference in pitch for vowel sounds at several initial frequencies and formant frequency patterns. They found just-noticeable differences in voice pitch under 2% for spoken vowel sounds above 100 Hz. Puts et al. (2007) also attempted to determine just-noticeable differences in voice pitch. They reported a just-noticeable difference of 1.2 semitones, however this was the point at which 50% of participants were able to perceive a difference between two voices, which, to the best of my knowledge, is not an established method of determining just-noticeable differences. The content of voice clips was also not specified, making it hard to compare to previous experiments of voice pitch discrimination.

There is some variance in just-noticeable differences in voice pitch found in previous experiments. It is therefore important to determine the just-noticeable difference in pitch as tailored to specific methods and technologies before attempting to determine just-noticeable differences for perceived traits.

5.3 – Just-noticeable differences of perceived traits – Smith et al., (2005)

Voice characteristics affect listener's perceptions of the speaker. Voice pitch is used as a cue not only for attractiveness, but also for perceptions of body size (van Dommelen and Moxness, 1995; Fitch, 1997; Collins, 2000; Smith et al., 2005; Feinberg et al., 2005; Bruckert, 2006), age (Horri and Ryan, 1975; Smith and Patterson, 2005; Feinberg et al., 2005; Bruckert, 2006), masculinity (Feinberg et al., 2005), dominance (Tusing and Dillard, 2000; Puts, 2006; Puts, 2007), and internal personality attributes (Wilson, 1984; Miyake and Zuckerman, 1993;.Zuckerman and Miyake, 1993; Zuckerman, Miyake and Elkin, 1995).

The relative impact of vocal parameters on perceptions of the speaker has been assessed in several studies (Zuckerman and Miyake, 1993; Feinberg et al., 2005; Bruckert, 2006; Puts, 2007, Smith and Patterson, 2005), however, only one study has determined actual just-noticeable differences in perceived traits. Smith et al., (2005) found just-noticeable differences in perceived speaker size through combined and isolated manipulations of pitch and formant frequencies of both single-vowel and speech-like stimuli. They showed that formant spectrum manipulations in speech of about 8% are required to produce just-noticeable differences in perceived body size at pitches of 40 and 160 Hz. The just-noticeable difference rose to 18% when the pitch was 640 Hz.

Since voice pitch has been established as an important parameter affecting perceptions of several mate-choice relevant attributions (Feinberg et al., 2005; Bruckert, 2006; Puts, 2007, Smith and Patterson, 2005), methods similar to the ones used by Smith et al., (2005) could be used to determine the just-noticeable differences for these attributions.

Chapter 6:

Psychophysical Properties of Perceived Vocal Attractiveness

Based on Pitch Manipulations

Introduction:

Studies suggest voice pitch alters perceived vocal attractiveness (see Feinberg, 2008 for review). Voice pitch negatively correlates with pubertal and adult levels of testosterone (Beckford, 1985; Harries et al., 1997; Dabbs and Mallinger, 1999). Testosterone can act as an immunosuppressant, thus high quantities are costly to maintain (Folstad and Karter, 1992; Thornhill and Gangestad, 1999; Chen, 2004). Men that produce testosterone displays, such as low voice pitch, demonstrate the quality to overcome the handicap of high testosterone (Zahavi, 1975; Hamilton and Zuk, 1982). Furthermore, testosterone displays can be used in male-male competition for mates as a means of intimidating or combating same-sex rivals (Darwin, 1871; Andersson, 1994). High-pitched voices among women may be indicative of high estrogen levels (Abitbol, Abitbol, Abitbol, 1999; Alonso and Rosenfield, 2002), which positively correlate with women's abilities to conceive (Lipson and Ellison, 1996; Baird et al., 1999). It has been shown that, on average, women prefer men with lower-pitched voices, while men prefer high-pitched women's voices (see Feinberg, 2008 for review).

Although findings on preferences for voice pitch between studies have been fairly consistent, there are some discrepancies in the literature (see Feinberg, 2008, for review). One experiment on women's vocal preferences across the menstrual cycle demonstrated that women only prefer low-pitched men's voices during ovulation, and only in a short-term relationship context (Puts, 2005). By contrast, many other experiments have demonstrated that women prefer low-pitched men's voices across all phases of the menstrual cycle, regardless of relationship context (Feinberg et al., 2005a; Feinberg et al., 2006; Feinberg et al., 2008a; Apicella and Feinberg, 2009). One study has found that voices experimentally lowered in pitch were not more attractive than average-pitched voices (Riding, Lonsdale, and Brown, 2006), although it should be noted that high-pitched voices were significantly less attractive than were average and low-pitched voices

It is possible that methodological differences might account for discrepancies in the field. The degree of pitch manipulation has varied widely across separate studies. Studies on vocal attractiveness have used pitch manipulations of ±20 Hz (Feinberg et al., 2005a, Feinberg et al., 2006; Feinberg et al., 2008a, Feinberg et al., 2008b), ±0.5 equivalent rectangular bandwidths (Jones et al., 2008, Vukovic et al.; 2008; Apicella and Feinberg, 2009), ±two semitones (Puts, 2005), and ± 30% of the original voice pitch (Riding, Lonsdale, and Brown, 2006) (Table 1).

Table 6.1- List of pitch manipulations used in previous studies

Pitch Manipulation	Used in	Pitch range at 120 Hz
±20 Hz	Feinberg et al., (2005) Feinberg et al., (2006) Feinberg et al., (2008a) Feinberg et al., (2008b)	100-140 Hz
±0.5 ERB	Jones et al., (2008) Vukovic et al., (2008) Apicella and Feinberg, (2009)	~100-140 Hz
±2 semitones	Puts (2005)	113-127 Hz
±30%	Riding, Lonsdale, and Brown (2006)	84-156 Hz

Given the disparities in the strength of pitch differences in previous voice preference research, and the variety of results, it is necessary to establish perceptual thresholds for various vocal attributions. Determining a just-noticeable difference in vocal attractiveness based on pitch manipulations would allow researchers to avoid the seemingly arbitrary manipulations used previously.

Previous psychophysical studies have found just-noticeable differences in voice pitch (as opposed to pure tones). Both Flanagan and Saslow (1957) and Klatt (1973) used electronic vowel synthesizers to produce various voice pitches and have found fairly consistent just-noticeable differences of ~0.5 Hz (Flanagan and Saslow, 1957; Klatt, 1973). More recent studies have found just-noticeable differences in voice pitch of 2% (Smith et al., 2005). It is possible to apply the same psychophysics paradigms to find thresholds for perceived vocal traits. Such techniques have recently been employed to find just-noticeable differences in perceived size based on formant manipulations at different pitches (Smith et al., 2005).

As mentioned above, other studies have shown that men generally prefer high-pitched women's voices, while women prefer low-pitched men's voices (see Feinberg, 2008 for review). Feinberg et al. (2008b) demonstrated that men preferred women's voices with raised pitch at low, average, and high initial frequencies. This finding revealed that men's vocal preferences are not geared toward average pitch; rather that men have a preference for higher than average pitch. To the best of our knowledge, however, preferences for voices outside the natural adult range of frequencies have not been assessed. It is therefore unknown whether the general trends in attractiveness are consistent above and below the natural range of adult pitch. It is conceivable that preferences for voice pitch reach a limit at the upper or lower limits of women's and men's natural frequencies, as voices outside this range may be indicative of pathology or something unnatural (Sorensen and Horii, 1982; Gilbert and Weismer, 1974). A psychophysical study on voice attractiveness using stimuli both within and outside the natural range of frequencies would reveal if pitch preferences remain consistent beyond normal voice pitches.

Here I will determine just-noticeable differences in vocal attractiveness based on voice pitch manipulations. In Experiment 1, just-noticeable differences for voice pitch were determined to allow for comparisons to thresholds of other attributions. The goal of Experiment 2 was to find just-noticeable differences in vocal attractiveness of men's and women's voices. Furthermore, it examined potential limitations of vocal preferences outside the natural range of adult frequencies.

Experiment 1: Voice pitch discrimination

The purpose of Experiment 1 was to establish just-noticeable differences in pitch. Although several studies have found just-noticeable differences for voice pitch (Flanagan and Saslow, 1957; Klatt, 1973; Smith et al., 2005), it is important to establish pitch discrimination with our own instruments and conditions for comparison to other attributions. Experiment 1 was a basic psychophysics experiment done in a similar manner to that of Smith et al. (2005).

Methods

Stimulus creation: An initial male and female voice was created from an average of 32 male and 32 female voices, separately, using STRAIGHT (Kawahara and Matsui, 2003). Briefly, this procedure entails automatic pitch extraction, and demarcating key temporospectral features (e.g. formant frequencies and vowel onset and offset) on spectrograms of the sound. These temporospectral features are then aligned in time and space, and then pitch, amplitude, time, and formant frequencies are then averaged. Voices were averaged in pairs, iteratively, until one base voice of each sex (2 total) were created from an average of 32 voices. This procedure was done to reduce any acoustic outliers present in any single voice. Like in face research, the average of 32 voices is representative of the common characteristics of these groups (Benson and Perrett, 1993). The final pitches of the averaged voices were 111 Hz for the male voice and 212 Hz for the female voice. Voices were monopthong vowels sounds to reduce formant transitions (as in Feinberg et al, 2008b).

Frequency manipulation: Acoustic analysis and manipulation of the initial voices was done using Praat (Boersma and Weenik, 2009). The initial voices were manipulated using the pitch-synchronous overlap add (PSOLA) method (Charpentier and Moulines, 1989, ™ France telecom). The Pitch-Synchronous Overlap Add method selectively manipulates pitch and corresponding harmonics independent of time and formant frequencies, and has been used successfully in many studies on voice preferences and other mate-choice relevant contexts in humans (eg. Feinberg et al., 2005; Feinberg et al., 2006; Feinberg et al., 2008b; Jones et al., 2008; Vukovic et al., 2008), and other mammalian species (Reby et al., 2005; Fitch and Fritz, 2006). Harmonic content was matched across voices. A range of voices was made in 2 Hz intervals: the range for men's voices was 60-180 Hz, and the range of women's voices was 160-300 Hz. Praat's pitch parameters were set at a minimum 50 Hz and maximum 300Hz for men's voices, and a minimum 100 Hz and maximum 600 Hz for women's voices. Window length was determined automatically by Praat.

Participants and procedures: Participants were university students (n=8, 4 men, 4 women, mean age: 22.25 years, SD: 1.16). They were asked to compare voices and rate which one had the higher pitch. A 2 alternative forced-choice paradigm was designed with the method of constant stimuli (Gescheider, 1997), in which participants were asked to pick the voice with the higher-pitch (see Smith et al., 2005). Male participants listened to all possible pairs from the female voice range, and females listened to all possible pairs from the male voice range. Males listened to 51 blocks of 50 voice pairs and 1 block of 6 voice pairs, while women listened to 37 blocks of 50 voice pairs and 1 block of 42 voice pairs. Each block took approximately 15 minutes to complete, and participants completed a maximum of six blocks per day. The frequencies of all voices were randomized within and between blocks. In all, males listened to 2485 voice pairs, and females listened to 1830 voice pairs.

Results

Psychometric functions were created for each participant by plotting a cumulative normal distribution of the proportion of correct responses made as a function of the Weber fraction (the frequency difference between two voices in a pair divided by the frequency of the lower-pitched voice) in between pairs of voices (Gescheider, 1997). The just-noticeable difference was defined as the

Weber fraction at which the correct voice was chosen 75% of the time (Stevens, 1951). Each participant's data was fitted with a binary logit or probit model. The lower asymptotes of each model was set to either 0 or 0.5 on the y-axis. These models would represent data in which small values on the x-axis could produce incorrect responses more than 50% of the time, and data in which small Weber fractions could produce incorrect responses a maximum of 50% of the time. Any biases in choosing one side of the screen were accounted for in the models. Models with the highest chi-square values were chosen to represent the data. We calculated overall just-noticeable difference for pitch discrimination by averaging all eight participants' individual just-noticeable differences. The average just-noticeable difference for pitch discrimination was 4.1% (SD: 1.9%, all confidence intervals between (CI) $-2.7\% < CI < 18.3\%$). The test models were significantly different than the intercept-only models (all $\chi^2 > 158$, all $p < 0.0001$). Analysis of deviance calculated goodness of fit (all $D < 1198.4$, all $D/df < 0.483$). There was no significant difference between men's and women's thresholds (Welch two-sample t-test: $t(5.9) = -0.5421$, $p = 0.6075$).

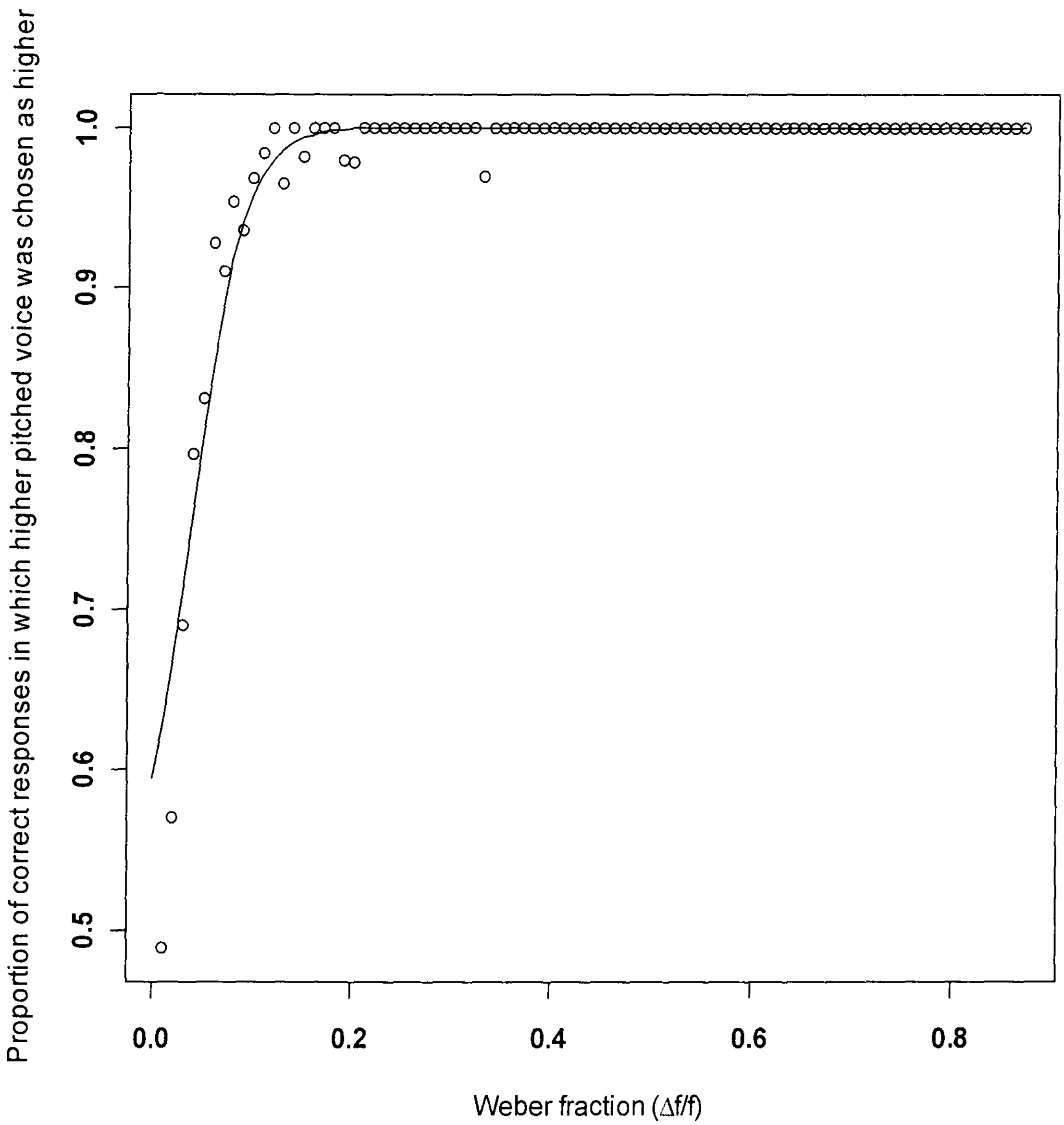

Figure 1. A psychometric function for a typical participant showing the proportion of correct responses as a function of the Weber fraction between two voices. The proportion of correct responses increased with the Weber fraction.

Discussion

We found a just-noticeable difference for pitch discrimination of 4.1%. The just-noticeable difference was calculated by averaging all participant's just noticeable differences, both men's and women's, as there were no significant differences between sexes. The just-noticeable difference found here is comparable to the recent just-noticeable difference of 2% found using computer software (Smith et al., 2005). The just-noticeable difference in pitch discrimination will be useful to compare to the just-noticeable differences in voice attractiveness found in Experiment 2.

Experiment 2: Vocal attractiveness

The purpose of Experiment 2 was to establish a just-noticeable difference in vocal attractiveness based on manipulations of pitch. We also assessed the attractiveness of voices outside the natural range of adult frequencies. It is possible that voice pitch preferences are maintained below or above natural frequencies. In many species, preferences for quality indicators increase selection pressure for particular traits to the point that supernormal stimuli are preferred (Fisher, 1999; Andersson 1994). Here we tested whether or not there are limits for voice pitch preferences.

Methods

Studies demonstrate high agreement among raters when making judgments of attractiveness (see Feinberg et al., 2005; Collins, 2000; Collins & Missing, 2003), thus in Experiment 2 four men and four women (n=8, heterosexual, mean age: 22.34 years, SD: 1.30) completed a psychophysical study on voice preferences. Participants were presented with pairs of voices and were asked to indicate their preference by choosing the voice they thought was more attractive. All other stimuli and procedures were identical to those used in Experiment 1.

Results

Psychometric functions were created as in Experiment 1. The just-noticeable difference was defined as the Weber fraction at which participants showed a preference for a higher or lower-pitched voice 75% of the time. Individual just-noticeable differences were averaged together to find the overall just-noticeable difference.

Men showed a monotonic preference for high-pitched voices across the entire range of women's frequencies. The overall just-noticeable difference for men rating women's voices was 18.1% (SD: 8.6% all CI: 2.7%<CI<49.5%). The test models were significantly different than the intercept-only models (all $\chi^2 >$ 155.8, all $p<0.0001$). Analysis of goodness of fit was calculated (all D<2435.6, all

D/df<0.98). Men showed preferences for high-pitched voices even above the natural range of women's frequencies.

Women's preferences for men's voices were not monotonic. Women preferred low-pitched voices beyond the natural lower end of men's voices (~96 Hz). Below this, however, women showed preferences for raised pitch. Since preferences were not monotonic across the range of voices, a single just-noticeable difference for the entire range of frequencies could not be calculated. Instead, a just-noticeable difference was calculated from voices above 110 Hz. The 110 Hz value was chosen to exclude any residual preferences for raised pitch found at the lower male voices. Preferences showed a monotonic trend for low-pitched voices in this range, allowing a just-noticeable difference to be calculated. The just-noticeable difference for women rating men's voices above 110 Hz was 8.8% (SD:2.7%, all CI: -7.7%<CI<56.3%). The test models were significantly different than the intercept-only models (all χ^2>30.65, all p<0.0001). Analysis of goodness of fit was calculated (all D<580.65, all D/df<0.928).

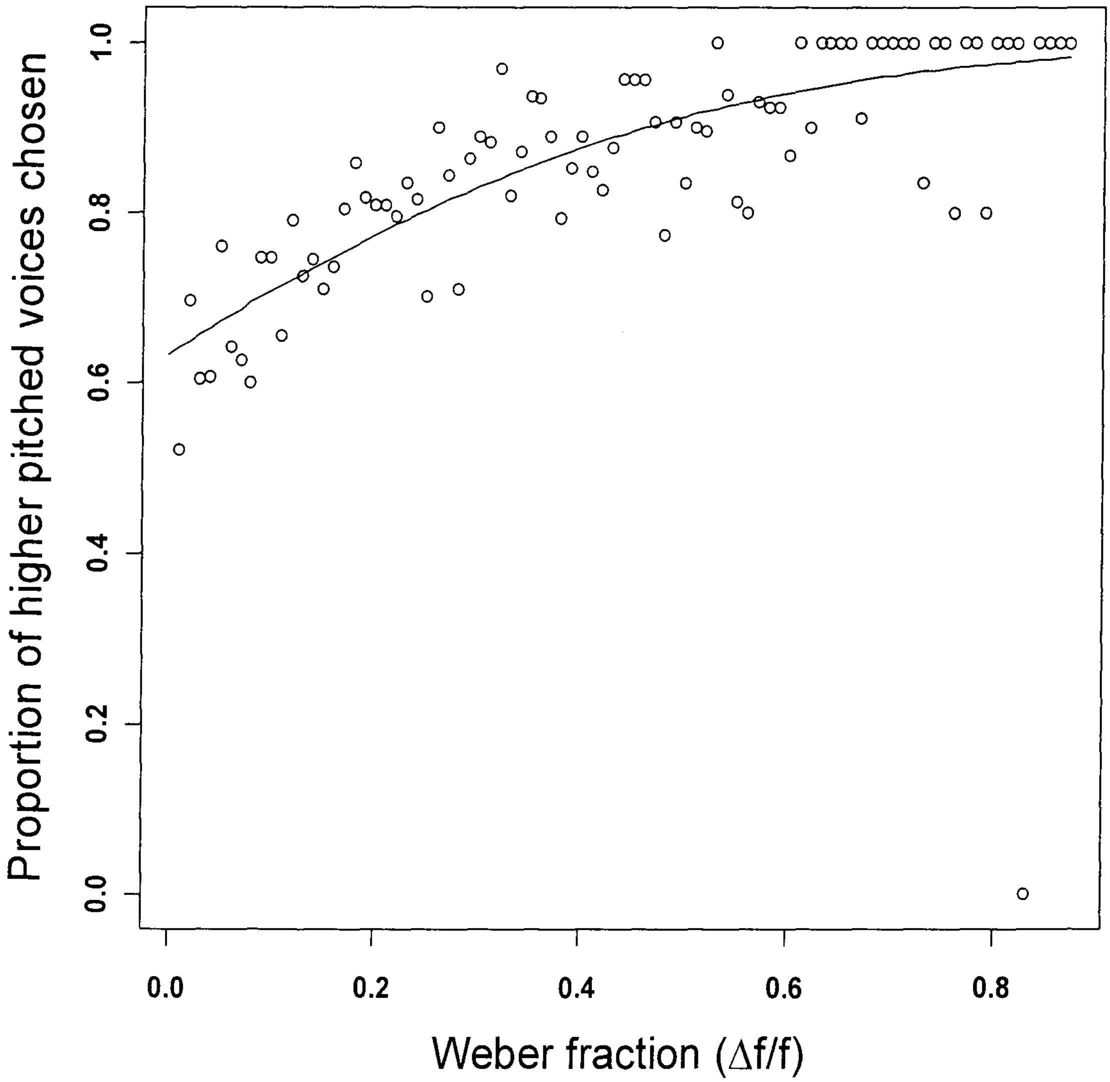

Figure 2. A psychometric function for a typical male participant showing the proportion of higher-pitched voices chosen as a function of the Weber fraction between two voices. The proportion of higher-pitched voices chosen increased with the Weber fraction.

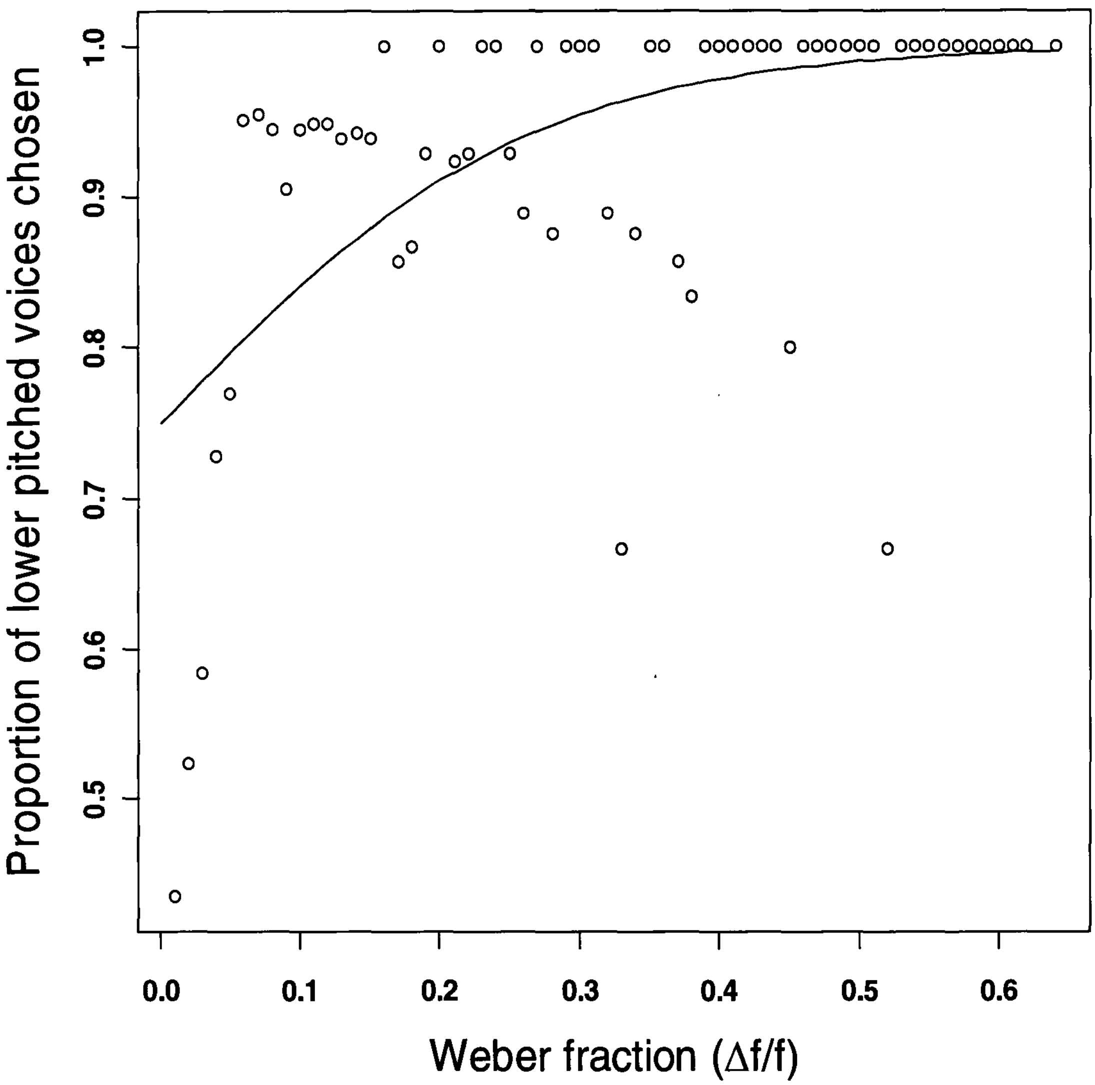

Figure 3. A psychometric function for a typical female participant showing the proportion of lower-pitched voices chosen as a function of the Weber fraction between two voices for men's voices above 110 Hz. The proportion of lower-pitched voices chosen increased with the Weber fraction.

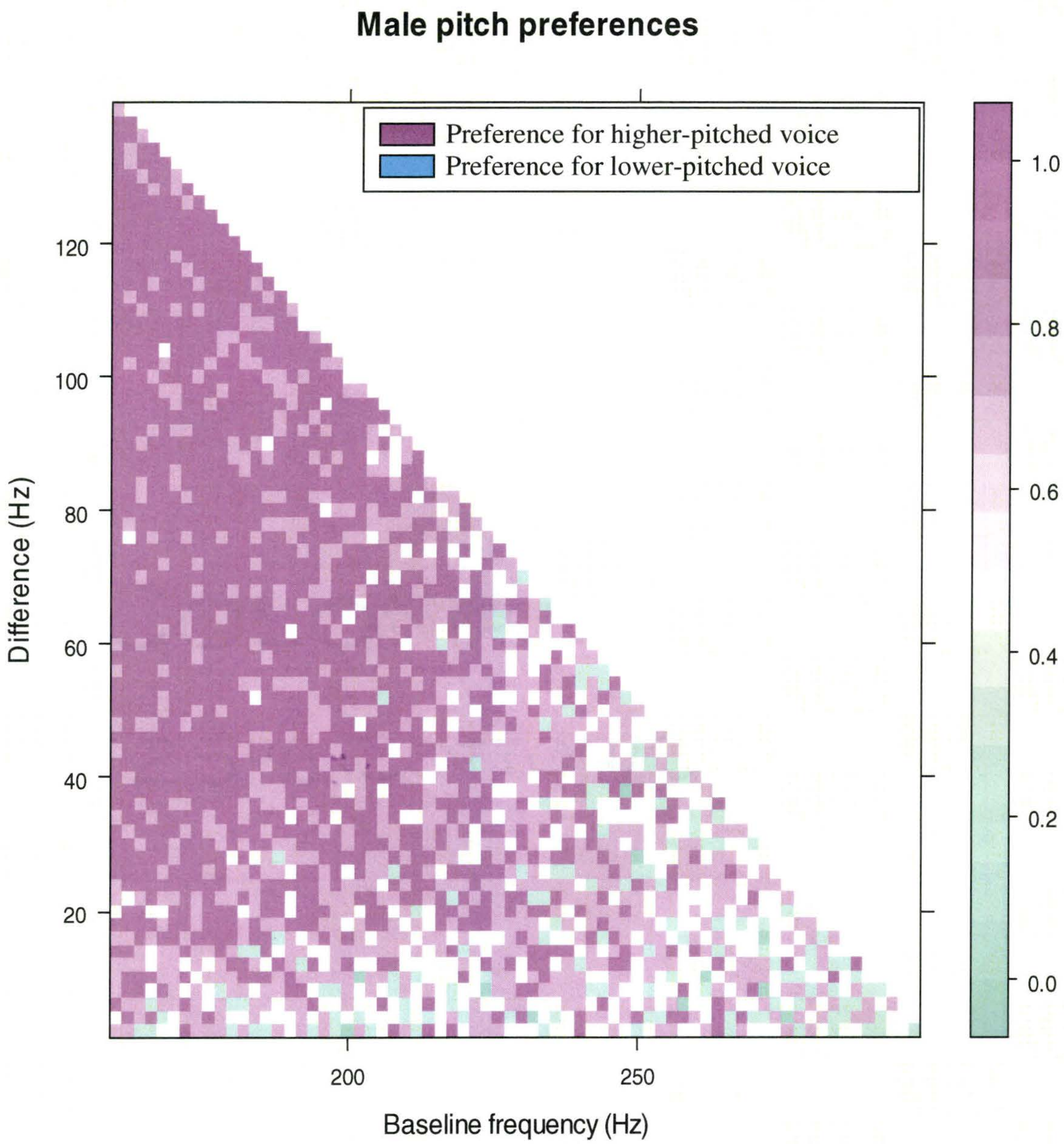

Figure 4. Men's vocal preferences as a function of baseline frequency (Hz) and the difference in between two voices (Hz). Men preferred higher-pitched voices across the range of women's frequencies. Preferences were averaged across all four male participants.

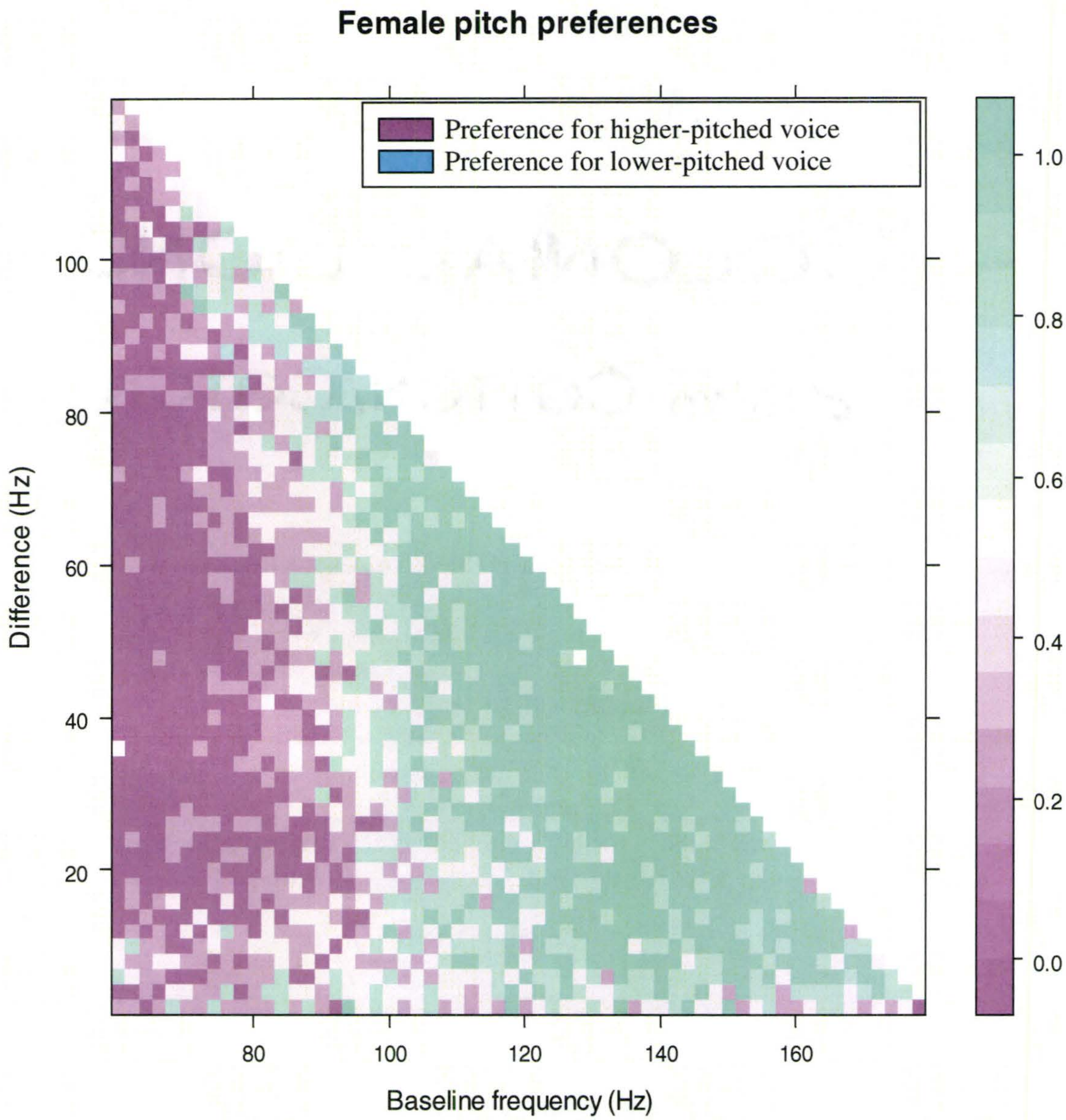

Figure 5. Women's vocal preferences as a function of baseline frequency (Hz) and the difference in between two voices (Hz). Women preferred lower-pitched voices above the natural lower end of men's frequencies (~96 Hz), however, they preferred higher-pitched voices below the natural lower limit. Preferences were averaged across all four female participants.

Discussion:

The just-noticeable differences for vocal attractiveness was over 2x larger for men's voices and over 4x larger for women's voices than the just-noticeable difference for pitch discrimination. This indicates that perceptions of vocal attractiveness require a larger stimulus difference than does pitch discrimination. The perceptual threshold for attractiveness was smaller for men's voices than women's voices.

Men's preferences for high-pitched voices were maintained across the entire range of women's frequencies, while women's preferences for low-pitched voices were inverted below the natural range of men's voices. This suggests that women were averse to voices that are lower than what is naturally produced, whereas men's preferences for high-pitched voices have no such limit.

General Discussion

The just-noticeable differences for vocal attractiveness of 18.1% for women's voices and 8.8% for men's voices were larger than the 4.1% just-noticeable difference in pitch discrimination. Men's preferences for high-pitched voices were consistent outside the range of natural female frequencies. This finding is an extension of those by Feinberg et al. (2008b) who found that voices were more attractive when raised from low, average, and high initial frequencies. Although the range of women's voices used in this sample went well beyond the natural range of women's frequencies (up to 300 Hz), further studies could assess whether there is an upper limit to men's preferences for high-pitched voices.

Interestingly, women showed an aversion to low voice pitch when voices were below the natural range of men's frequencies. By contrast, low-pitched voices were preferred within and above the natural range. Women, then, showed a limit on vocal preferences while men did not. This may be because abnormally deep voices can be indicative of pathology, as in smoker's voice (Sorensen and Horii, 1982; Gilbert and Weismer, 1974), or simply because abnormally low voices could be indicative of overspending of somatic resources on producing a large larynx. It should be noted that although abnormal frequencies were used in the highest female voices, formant frequencies remained unmanipulated, ensuring the voices still sounded adult-like (Smith et al., 2005).

The just-noticeable differences in attractiveness reported here may serve as guidelines for future voice attractiveness studies. Though the individual just-noticeable differences were fairly consistent within each sex, there was some variation. Furthermore, different instruments and methodologies will produce different perceptual thresholds, are exhibited by the variance in pitch discrimination thresholds of recent studies, including our own (Smith et al., 2005). Thus, if the findings of this study are to be used as guidelines for future voice attractiveness studies, it may be prudent to manipulate pitch well above the

18.1% and 8.8% just-noticeable differences for women's and men's voices, respectively.

Recent work on vocal changes across the menstrual cycle has found that 55% of women tested raised their voice pitch by about 13 Hz during ovulation (Bryant and Haselton, 2009). This falls well below the 18.1% just-noticeable difference for women's voice attractiveness found in this study. Interestingly, in Bryant and Haselton (2009), only 55% of people could detect the average 13 Hz change in voice pitch. This suggests that the increase in pitch alone over the menstrual cycle may not produce changes in vocal attractiveness as has been proposed by other studies (Pipitone and Gallup, 2008). It is possible, however, that an integration of other vocal parameters, such as those that indicate mood, would be enough to produce changes in attractiveness over the menstrual cycle. Further studies monitoring the voice across different menstrual cycle phases may bring light to how changes in various vocal parameters are integrated to produce changes in attractiveness.

It should be noted that the just-noticeable differences given here were found with monopthong vowel sounds that were manipulated in pitch alone. Future studies could compare just-noticeable differences for other vocal parameters and attributions to the thresholds given here. Finding just-noticeable differences in attractiveness based on formant frequency manipulations would give a clearer picture of how formant information is integrated into perceptions of attractiveness. Furthermore, just-noticeable differences for attractiveness could be found using combined manipulations of both fundamental and formant frequencies. Comparing thresholds for combined manipulations with thresholds for isolated fundamental and formant frequency manipulations would give information on how the two vocal parameters interact to produce overall perceptions of attractiveness. Another step could be to find the aforementioned just-noticeable differences using neutral and content filled vocalizations. It has recently been discovered that men's preferences for high-pitched voices are strengthened for voices stating interest in the listener (Jones et al., 2008). Thus, just-noticeable differences for attractiveness may be smaller for voices giving statements of interest than for content-neutral sentences.

Pitch is an important vocal parameter associated with vocal attractiveness. The results of this study indicate that the degree of manipulation in pitch required to produce changes in vocal attractiveness is greater than that required for simple pitch discrimination. Men have preferences for high-pitched voices even above the natural range of women's voices, whereas women's preferences for low-pitched voices are inverted below the natural range of men's voices. Finding just-noticeable differences of vocal attractiveness and other attributions through manipulations of various vocal parameters may allow for comparisons of the relative salience of perceived traits in the voice.

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