The Effects of Shoe Heel Heights on Postural, Acoustical, and Perceptual Measures of Female Singing Performances: A Collective Case Pilot Study

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Abstract

Voice professionals hold varying opinions about whether shoe heel heights affect vocal performance, but to date no empirical study has addressed this matter. The purpose of this investigation was to determine the effects, if any, of three shoe heel heights (low [< 0.5 in.], medium [1.0 - 2.5 in.] and high [> 2.5 in.]) on postural (head position, lumbar lordosis and knee flexion), acoustical (LTAS, formant frequency profiles), and perceptual (singer surveys) measures of prepared arias sung by individual female voice majors ($N = 5$) in a semi-naturalistic audition environment. Among primary results: (a) each participant showed postural changes in head position, lumbar lordosis and knee flexion in three different heel heights; (b) long term average spectra (0 – 10 kHz) comparisons showed significant differences in four out of five participants, (c) participants exhibited idiosyncratic shifts in formant frequencies (F1 – F4) of selected vowels associated with changes in shoe heel height, (d) three singers believed that shoe heel height could impact how comfortable a singer feels in a performance, but no participant specifically mentioned that heel height might affect vocal production, and (e) four out of five singers preferred a medium heel (1.0 – 2.5 in.) for singing. The researcher discussed data in terms of limitations of this study, applications to vocal pedagogy and postural research, and directions for future research.

Introduction

Various professional forums reflect diverse opinion among voice teachers about the types of shoes women should wear when singing in a performance or audition. Eichhorn-Young (2010), for instance, advises students to wear heels, asserting, “Flats make you look like you have stove pipes for legs and generally make you stand like a duck," (lines 16-17). On the other hand, del Santo (2005) says, "Ladies should wear a pair of pumps with a heel of comfortable height. (Remember that posture affects your voice!) Avoid open-toed sandals or boots with thick heavy heels” (lines 72-74).

Numerous investigations have indicated detrimental effects of high heels, especially on gait (e.g., Merrifield, 1971). Studies have also shown that high heels can cause multiple types of injuries to the knees and back (e.g., Kerrigan et al., 2005; Lee, Jeong, & Freivalds, 2001; Bird & Payne, 1999). Women wearing high heels have an increased likelihood of ankle sprains or breaks (e.g., Ebbeling, Hamill, & Crussemeyer, 1994) and an increased likelihood of a slip or fall (e.g., Manning & Jones, 1995). Studies even show that high heels may lead to an increased cost of American healthcare (e.g., Thompson & Coughlin, 1994) and increased heart rate and oxygen consumption (e.g., Ebbeling et al., 1994; Mathews & Wooten, 1963).

Several studies (e.g., Corrigan, Moore & Stephens, 1993; Shimizu & Andrew, 1999; Gerber et al., 2012; Mika A. et al., 2011) have indicated that the mean center of gravity and pressure moves forward and medially as heel height increases. Opila, Wagner, Schiowitz & Chen (1988) asserted that the body compensated for this increase in heel height, as it would have compensated for any outside force or load applied to the human skeleton (such as a backpack), by either contracting the lower back muscles (erector spinae) or the abdominal wall muscles. According to Mika A. et al. (2011), the ability to compensate decreased with age.

A few studies have found an increase in lumbar lordosis (LL), or a greater curving of the lumbar spine, with an increase in heel height (e.g., Pezzan, João, Ribiero, & Manfio, 2011; Lee, et al., 2001). Each of these studies, however, used questionable methods or measured only a specific age group. Other studies have shown that participants wearing higher heels, as compared to lower heels, exhibited (a) no change in LL (e.g., de Lateur, Giaconi, Questad, Ko, and Lehmann, 1991), (b) a mixture of increased and decreased LL in different participants (e.g., Snow & Williams, 1994) or (c) a decrease in LL (e.g., Russell, Muhlenkamp, Hoiriis, & DeSimone, 2012; Bendix, Sorensen & Klausen, 1984). Opila-Correia (1990) measured female participants (*N* = 14) and found that varying experience levels of wearing heels showed no significant effect on LL. After dividing the women into different age groups of younger (*n* = 7) and older (*n* = 7) participants, the researcher found that the older group had (a) more posterior pelvic tilt, (b) decreased degree of LL, and (c) greater anterior movement of the upper trunk. The younger group performed in the opposite way.

Perhaps the most well respected study in the field, concerning heel height, lumbar lordosis and knee flexion (KF), Opila et al. (1988) found that wearing high heels resulted in an energy-costly knee flexion and a concurrent posterior movement of gravity requiring contraction of the quadriceps. The cervical, thoracic, and lumbar spines as well as the trunk, knee and ankle exhibited posterior movement, which in turn caused a significant backward tilting of the pelvis and a significant decrease in lumbar lordosis. Stefanyshyn, Benno, Nigg, Fisher, O'Flynn, and Liu (2000) found that participants (*N* = 13) standing in high heels showed a greater knee bending with increased heel height, which resulted in an increase in an EMG muscle activity measurement in the rectus femoris. This movement accounted for the forward change of the center of mass and attempted to control for the increase in KF. Similarly, Mika et al. (2012), found that when participants wore stiletto type footwear (a) leg muscle activity increased significantly, (b) bending of the knees increased, and (c) restricted range of motion of the ankle and knee during gait. No studies to date have exclusively examined the effects of high heels on head position, although studies with the primary purpose of investigating other effects of heel height have found that high heels caused a posterior movement of the head in comparison to the line of gravity (e.g., Opila et al., 1988).

Numerous vocal pedagogues have offered conversant advice on posture and its effect on singing (e.g., Miller, 1986; Austin, 2012; Rubin, 2004; Arboleda & Frederick, 2008). However, few empirical studies have addressed the potential effects of posture on acoustical, physical, and perceptual aspects of singing. Sundberg, Leanderson, von Euler, and Knutsson (1991) studied changes in the subglottal pressure of baritones (*N* = 2) between supine and upright positions and found that the breathing system efficiently compensated for drastic changes in posture.

Speech language pathology research has shown the relationship between disordered voice and posture. Bruno et al. (2009) studied voice-disordered patients (*N* = 25) who underwent voice training. Participants showed significant improvements of voice quality after training, which the researchers found corresponded with a more aligned posture. Kooijman et al. (2005) studied the relationship of posture and muscular tension in teachers with persistent voice complaints. The researchers found a positive significant correlation between scores on a posture inventory and scores on the Voice Handicap Index (VHI) and the Dysphonia Severity Index (DSI). Results also showed that anteroposition of the head, or forward thrust of the neck and head (found in 70% of participants), proved to be one of the most common predictors for a low DSI score.

Studies conducted in orthodontics and with sleep apnea patients, where head position and its relationship to craniofacial and craniocervical elements is essential, have found that head position can have an effect on the vocal tract. Studies have shown that a superior, upward tilting movement of the head and chin correlated with an increase of pharyngeal airway space and a superior movement of the hyoid bone (Pae,1994; Hellsing, 1989; Tong, Sakakibara, Xia, & Suetsugu, 2000). Muto et al. (2002) found that a 10º change in the craniocervical inclination caused a 4 mm increase in pharyngeal airway space. Muto and Kanazawa (1994) found that this movement of the head was necessary for maximal mouth opening.

Paseman, Casper, Colton, and Kelley (2004) tested the effect of horizontal head movement on the glottic closure of patients (*N* = 10) with unilateral vocal fold paralysis and found no effect. However, studies measuring the effects of vertical head movements have found differences. In a head repositioning experiment based on Alexander Technique, Jones (1972) manually pulled up on the base of the head of one female singer while taking acoustic analysis and found improved spectrographic analysis with regard to the integrity of vocal partials.

Miller et al. (2012) employed magnetic resonance imaging (MRI) with supine, nonsinging participants (*N* = 10) and found positive correlations between the configuration of craniocervical posture and vocal structures. A straighter cervical curvature in one participant corresponded with (a) increased distance between the hyoid bone and the cranial base, (b) widened oropharyngeal airway at the uvula, (c) narrowed opening of the laryngeal tube, and (d) posterior tongue position. A different participant with increased craniocervical angles (elevated head position) exhibited (a) increased lordosis of the cervical spine, (b) decreased distance between the hyoid bone and cranial base, (c) narrowed oropharyngeal airway at the uvula tip, and (d) widened opening of the laryngeal tube. Luck and Toiviainen (2007) conducted a pilot study exploring the effect of 14 kinematic postural elements on four timbre-related audio features of singers (*N* = 15). The researchers found that head and upper body positioning produced the greatest effects on voice quality. For instance, when a singer had the head positioned down, spectral irregularity (noisiness of the signal) increased. When a singer had the head tilted up, an increase in perceived loudness existed, which the researchers hypothesized came from a freeing up of the vocal apparatus permitting greater air flow.

Di Carlo (1998) compared x-rays of 36 participants (*n* = 12 professional singers, *n* =12 beginning singers, *n* = 12 naïve singers) at rest and as they sang French cardinal vowels in low, medium, and high ranges. At rest x-rays indicated cervical spine abnormalities in all professional singers. DiCarlo also found that while ascending in pitch during the singing tasks, all professional singers (a) increased the buccal opening substantially, (b) raised the head, (c) lengthened the neck, (d) shifted the cervical spine backwards, and (e) exhibited an inversion of the cervical curvature. Di Carlo theorized that the amount of jaw opening determined the raising of the head and backward shift of the cervical spine. Di Carlo also reasoned that cervical inversion could occur in order for the singer to create a pharyngeal widening and the forward tilt needed in the thyroid cartilage to navigate the upper range pitches.

No previous study has examined explicitly the potential effects of lumbar lordosis or knee flexion on singing, or the impact of varying shoe heel heights on singer performances. Moreover, voice teachers routinely offer advice about wearing particular types of shoes for performances. Thus, given findings of previous research about the effects of high heels on posture and the effects of posture on singing, a case study approach utilizing a variety of measures (postural, acoustical, and perceptual) would seem to be a prudent first step in launching a line of research that considers shoe heel heights while singing.

The purpose of this investigation was to determine the effects, if any, of three shoe heel heights (low [< 0.5 inches], medium [1.0 - 2.5 inches] and high [> 2.5 inches]) on postural (head position, lumbar lordosis and knee flexion), acoustical (LTAS, formant frequency profiles), and perceptual (singer surveys) measures of prepared arias sung by individual female voice majors (*N* = 5) in a semi-naturalistic audition environment.

The following research questions guided this investigation:

1. What effects, if any, do varying shoe heel heights have on postural behaviors of individual female singers (*N* = 5) with regard to: (a) head position (HP) as measured by three angles between postural markers positioned on C7, tragus and nasion; (b) lumbar lordosis (LL) as measured by the approximate angle between L1, L4 and S2; and (c) knee flexion (KF) as measured by the angle between the lateral malleous, lateral joint line and lateral lower thigh?
2. What effects, if any, do varying shoe heel heights have on participants' long-term average spectra (LTAS) and formant frequency profiles?
3. What do participant comments indicate about their perceptions of comfort level while singing in varying heel heights?

Method and Procedures

Participants

Participating singers (*N* = 5), recruited from a single teacher’s voice studio at a large Midwestern university, included all female voice performance majors who identified themselves as soprano voice types. Participants ranged from 18 (*n* = 1) to 24 (*n* = 1) years of age (*M* = 22 years). Two participants were in their first year of university voice study, two participants were in their junior years, and one participant was a master's level graduate student (Table 1).

With IRB (Institutional Review Board) approval, participants were informed beforehand that the purpose of the study was “varied measures of vocal sound and appearance during a voice audition process.” They were not informed, however, about the independent variable (heel height) of particular interest.

Each singer agreed to bring to the recording session the following selection of self-owned audition clothing and accessories in which she felt comfortable:

- two dresses (any sleeve length, open-necked, form fitting, above the knee) or two skirts and corresponding tops (any sleeve length, open-necked tops, form fitting, above the knee skirts)
- four pairs of shoes including flats (less than 0.5 inches) mid-height shoes (1.0 - 2.5 inches) and the highest heels each singer owned (2.5 inches plus), avoiding platform or wedge styles and opting for stiletto type heels
- a variety of accessories (rings, necklaces, earrings, broaches, bracelets, etc.) The researcher also instructed each participant to bring anything else she would typically bring to an audition (water, audition notebook of scores, headshot or resume, etc.).

Sung Excerpts

The researcher consulted each singer prior to the study in order to choose an individual aria excerpt appropriate for this investigation. Selection criteria included: (a) an aria the singer would use in an audition, (b) an aria the singer had self-reportedly learned well but was not so ingrained as to incorporate muscle memory patterns, (c) an aria excerpt with a time length of 1.5 - 2.5 minutes to prevent singer fatigue but to have a long enough sample for LTAS analysis, and (d) an excerpt that displayed pitch range and vocal technique. No controls for language or style were deemed necessary.

Room Set-Up and Preliminary Performance

Recording occurred in a University research room arranged to semi-replicate a room in which a singer might audition. A leveled blue tape line positioned on the wall in front of the participants served as a suggested focal point in order to control for postural sway (Opila et al., 1988). After singers found a comfortable stance, the researcher marked the position of each foot so that each singer stance remained consistent between takes. Upon entering the research room, all participants verbally confirmed themselves to be in adequate vocal and physical health for undertaking an audition. Participants spent 3-5 minutes warming up in the research room until each participant verbally confirmed she was comfortable singing in the room. In order to become accustomed to the room and procedures, each singer sang the audition selection once in the outfit originally worn to the research room before continuing with the study.

Performance Protocol

Following these initial procedures, the researcher chose a dress or skirt/top combination from the array of options brought by each participant. Participants then privately changed into the selected dress or skirt/top combination. During this time, the researcher placed the three heel heights and accessory choices into three groups on the table, labeled “Outfits 1, 2 and 3.” The chosen combinations matched the style of the accessory to the shoe, so that a dressy accessory was put with the highest, dressiest heel, in order to detract attention from the heels as the independent variable. Each participant wore her hair up and out of her face for easy viewing of postural markers. Each participant sang the audition aria twice in each outfit, and therefore in each heel height, which resulted in a total of six recordings. The researcher randomized the order to account for any possible order effect. The researcher instructed each participant to find a focal point anywhere along the leveled, blue tapeline, and to avoid excessive gesturing (in order to minimize postural sway for postural measurements). Each participant heard a starting pitch played on the keyboard. Thereafter, she began singing at her own comfortable tempo.

Postural Markers and Analyses

To facilitate postural analyses, each participant wore three types of postural alignment markers (head, lumbar lordosis, knee flexion). These markers remained in the same place for each participant throughout her recording session.

Head position

The researcher adhered three head position markers: (a) a PomPom (white, 25.4 mm, with an Avery Hole Reinforcement label [florescent pink, . diameter] to the approximate location of the C7 vertebra; (b) an Avery Hole Reinforcement label (white, . diameter, with a symmetrical open circle in the middle facilitating exact measurement) adhered to the right tragus; and (c) one PomPom (white, 4 mm, with a black point drawn on the right lateral side) adhered to the nasion (bridge of the nose). Following Cuccia and Carola (2009), three angles constituted measurements for head position. An increase in angle 1 (Na-Tr-Vert) indicated a superior chin movement while a decrease indicated an inferior chin movement. An increase in angle 2 (C7-Tr-Vert) indicated an anterior movement of the neck while a decrease in angle 2 indicated a posterior movement of the neck. Angle 3 (C7-Tr-Na) indicated the overall craniocervical posture and disclosed the sum of angles 1 and 2 (Figure 1).

Lumbar lordosis

Many postural researchers view radiographs as the most effective measurement of lumbar lordosis (Mayer, Tencer, Kristoferson, & Mooney, 1984). However, to avoid exposing participants to radiation, various other measures have been used, including (a) photographic measurement using a plumb line (Ferreira, Duarte, Maldonado, Bersanetti, & Marques, 2011), (b) tape measure (Burdett, Brown & Fall, 1986; Fitzgerald Wynveen, Rheault & Rothschild, 1983), (c) parallelogram goniometer and standard goniometer (Fitzgerald et al., 1983), (d) flexible ruler (Bryan, Mosner, Shippee & Stull, 1989; Hart & Rose, 1986), and (e) inclinometer or gravity goniometer (Mayer et al., 1984).

These other methods require the midsection to be exposed. Due to the impractical nature of the midsection being exposed while singing an audition, the researcher created a postural marker (Figure 1). It incorporated a 9 x 2 in. piece of black ribbon affixed with three PomPom markers (white, 25.4 mm, with a black point drawn on the right lateral side) spaced 3.0 in. apart. Three elastic bands (white, 3/7 in. X 2 yd) pulled in the clothing sufficiently and further stabilized the postural marker to simulate the approximate location of L1, L4 and S2 lumbar vertebrae. Participants confirmed that the elastic bands were tight enough to ensure a consistent position of the markers but loose enough to avoid any perceived negative impact on singing (Figure 1).

Whittle and Levine (1997) described three methods of measuring the angle of lumbar lordosis with three postural markers adhered to the skin of each participant. The method chosen for this study measured the angle between an extension of the connected, straight line between S2 and L4, and the line connecting L4 and L1. A smaller angle would indicate a decrease in lumbar lordosis (i.e. the spine is more straightened) whereas a greater angle would indicate an increase in lumbar lordosis (i.e., the spine is more curved) (Figure 1).

Knee flexion

The researcher adhered three Avery Hole Reinforcement labels (white, . diameter) to approximate locations of the lateral malleous, lateral joint line and the lateral lower thigh. An increased angle of knee flexion would indicate a tendency for the knees to be hyperextended or locked, while a decreased angle would indicate a more bent knee posture (Figure 1).

Video recording

Two digital Zoom Handy Video Q3 cameras recorded participants in .mov format to assist with postural marker analyses. One camera viewed the shoulders and above for head position analysis, while another camera viewed the lumbar region for lumbar lordosis measurement. One digital RCA Small Wonder EZ2000 recorded participants in .avi format and viewed the upper thigh to the feet for knee flexion analysis.

Cameras were re-positioned, as needed, prior to each participant's recording session in order to view all postural markers and accommodate individual body sizes. Once repositioned, however, all cameras remained stationary throughout that particular session. The researcher transferred all video recordings digitally to a MacBook Pro computer for analysis using QuickTime (version 10.1) and VLC media player (version 1.1.12) software.

Procedure

For postural analysis, the researcher chose three vowels on varying pitches from each participant’s aria (the same vowels used for acoustical analysis) and created a still picture screenshot at the midpoint of each vowel at a juncture where there was no visible participant sway or exaggerated atypical movements. The researcher then viewed and measured each screenshot.

The researcher used Onde Rulers, an on-screen ruler program with a protractor (version 1.12.21) for all angle measurement of postural analysis. Prior comparison between on-screen protractor values and manual protractor values confirmed that each protractor yielded the same measurements. The on-screen protractor was chosen because of its convenience. To account for any atypical postural sway, the average angle degree measures from the two performances in each shoe height condition were used to report results.

Audio Recording

All performances were recorded with an AKG C 420III cardioid condenser head-mounted microphone positioned 5 cm from the left side of the participants' lip corner, out of the direct air stream (Titze & Winholtz,1993). The microphone connected to a Tascam US-122MKII Audio/MIDI interface as a pre-amplifier. Recording input level remained consistent for each participant. Signals were recorded in .wav format with a 44.1 kHz (32 bit) sampling rate onto a MacBook Pro Computer equipped with Audacity software (version 1.3.14-beta).

Acoustical Analyses

LTAS. The researcher used long term average spectra data acquired from KayPentax Computerized Speech Lab (CSL) Model 4500 software to analyze each participant recording. The researcher analyzed this data using a window size of 512 points with no pre-emphasis or smoothing, a Hamming window and a bandwidth of 86.13 Hz. Averaging of LTAS data from two performances within each heel height (low average, medium average, high average) controlled for possible one-time variations.

Formant frequency profiles. Praat software (Boersma & Weenink, 2010) was employed for formant extraction and formant frequency profile (F1 - F4) analyses. Praat computed linear predictive coefficients through the Burg algorithm integrated into the program and applied a Gaussian-like window. Pratt software gives the location of each formant frequency (Hz). The researcher took the midpoint of a steady state vowel, plus .10 s on either side of the midpoint, for a total selection of .20 s of each of the three vowels chosen per participant aria. The researcher averaged these obtained data points taken over .20 s to ensure a more complete picture and to account for possible changes in vibrato per participant. The researcher also averaged both takes in each shoe heel height to obtain overall mean formant frequency differences between heel heights. After obtaining these frequencies, the researcher then calculated, in cents, the difference between formant frequencies in different heel heights. Cents constitutes a logarithmic measurement of the distance between two frequencies (Hz), where a semitone is equal to 100 cents.

Survey Instruments

Prior to exiting the research room, each singer completed a survey soliciting demographic information and responses to a series of Likert-type scale items and open-ended questions concerning audition clothing choices, outfit selection, performance in the study, and preference when choosing outfits for an audition.

Results

Participants sang different arias and wore their own shoes of different heel heights, which negates the ability to compare across participants. However, results from this collective case study will be presented by research question with both overall observations and individual remarks.

Research Question One: Postural Data

Table 2 presents postural data for all participants. Each participant responded differently in overall adjustments to posture as heel height increased. Some participants decreased head position angles while also decreasing both lumbar lordosis and knee flexion angles (Carol, Betty). Elisa decreased head position measurements but instead remained in an overall similar alignment for both lumbar lordosis and knee flexion. Dorothy also decreased angle 1 head position measurements but had the greatest increase in her lumbar lordosis measurements and a slight increase in knee flexion. Ann showed a decrease in head position measurements from low to medium heels but a slight increase from low to high heels. Ann also had virtually no change in lumbar lordosis measurements (0.17°) and an increase in knee flexion measurements from low to medium heels.

When disaggregated by heel height, participants displayed different degrees of change. Some participants had the greatest difference (positive or negative as measured in degrees) in postural measurements between low and medium heel height and this difference only increased as they wore the highest heels, however, other participants did not show a great difference between low and medium heels but more difference once they added the highest heel. For the purposes of reporting these results, the difference between low and high heels will be of primary interest as it shows the widest range of change for each participant.

Head Position

Four out of five participants decreased angle 1 head position measurements, which indicated that they lowered the chin when singing in high heels versus low heels. Only one participant (Ann) increased head position angle 1 measurements, very slightly at 0.50°. Angle 2, which measured the degree of anterior and posterior neck and head movement, displayed a smaller amount of change. Four out of five participants decreased angle 2 measurements when singing in high heels versus low heels, which designated a posterior movement of the neck. Betty slightly increased the angle 2 measurement (0.33°). Angle 3 is a sum of angles 1 and 2 and represented the overall head position change. Four out of five participants decreased overall head position measurements from low to high heels with a range of decrease from -5.84° to -2.83°. Ann slightly increased her overall head position measurement (0.33°).

Lumbar Lordosis

With the exception of Dorothy, most participants only displayed slight changes in lumbar lordosis measurements with the addition of high heels. Dorothy had the largest degree of change as she increased the amount of lumbar curve by 13.84°. Ann also exhibited a slight increase in lumbar lordosis of 0.17°. Both Carol and Betty had a greater straightening of the lumbar curve at -1.33° and -3.17° respectively. Elisa remained the same from low to high heels.

Knee Flexion

Elisa, Carol and Betty all exhibited a greater bending of the knees with the addition of higher heels as compared to low heels with Carol having the highest degree of change (-5.00°). Dorothy had a slight straightening of the knees (0.33°) when adding high heels. The researcher had to discard Ann's knee flexion measurements in high heels due to an obstruction in viewing the postural markers, however, Ann showed a slight increase in knee flexion, or more straightening of the knees from low to medium heels.

Research Question Two: Acoustical Data

The following considerations will aid interpretation of results from acoustical measures. According to Howard and Angus (2006), 1 dB constitutes a just noticeable difference in the energy of complex sound. Thus, LTAS spectra that indicate differences of 1 dB or greater in signal amplitude will be of particular interest.

LTAS

Table 3 presents LTAS data for all participants. Entire spectrum (0-10 kHz)
LTAS comparisons of mean signal amplitude for each participant showed small differences. Dorothy and Ann slightly increased in mean signal amplitude with an increase in heel height. Betty decreased in mean signal amplitude as heel height increased. Elisa showed a small increase in mean signal amplitude from low to medium heels, but an even smaller decrease from medium to high heels which overall equaled a small increase from low to high heels. Carol reacted in the opposite way and exhibited a small decrease from low to medium heels, a small increase from medium to high heels, which equaled an overall diminutive decrease from low to high heels. A one-way repeated measures analysis of variance (ANOVA) of low, medium and high heel LTAS for each participant found a significant effect ($p < .05$) for four out of five participants. Fifteen follow-up paired *t*-tests (two-tailed) addressed specific differences between heel heights. Results indicated significant differences ($p < .0033$ with Bonferroni correction) between (a) low and medium heels in two out of five participants, (b) medium and high heels in four out of five participants and (c) low and high heels in four out of five participants.

While these mean relative dB readings did not indicate ± 1 dB differences, changes in individual partials did exhibit ± 1 dB differences, according to heel height, in four out of five participants. Two participants increased the majority of partials from low to medium heels while three participants decreased. From medium to high heels, two participants decreased the majority of partials and three participants increased the majority of partials. Overall, from low to high heels, three participants increased the majority of partials while two participants decreased the majority of partials. Betty, the only participant that did not exhibit significant differences between heel heights ($p = .16$), increased and decreased partials similarly between conditions, i.e., from low to high heels, Betty increased 69 individual partials and decreased 48. Although participants responded differently with small changes on individual partials, small differences on large groups of partials could possibly contribute to an overall timbre change.

Formant frequency profiles

Table 4 presents formant frequency data for all participants. Participants exhibited idiosyncratic shifts in formant frequencies. These formant frequency changes could indicate perceived timbre differences. Overall, Elisa's performances indicated changes in formant frequencies ranging from 1 to 220 cents differences between shoe heel heights. Elisa demonstrated very small cent deviations on the vowel /ɑ/ from the word "sky" when increasing heel height. However, the /ɑ/ vowel in the word "wide" (scored at B4) exhibited a 220 cents increase in F2 frequency from low to medium heels, and greater cents deviations in F1- F3 as a whole than the /ɑ/ vowel in the word "sky" (scored at F#5). On the /ɛ/ vowel, Elisa raised the frequency of F1 with increased heel heights, but lowered the frequency of all other formants (F2, F3, F4).

Dorothy's performances indicated changes in formant frequencies in a range of 12 to 269 cents as shoe heel height increased. Dorothy uniformly increased F1 and F2 formant frequencies as heel height increased. The /ɑ/ vowel showed an increase F4) for both low to medium heel and low to high heel performances. A decrease in F3 frequency occurred on the /ʊ/ vowel in both low to performance comparisons. A decrease in F3 frequency in the /e/ vowel occurred in the low to high heel performance comparison.

Carol displayed changes in formant frequencies in a range of 3 to 124 cents between sung trials in different shoe heel heights. Carol tended to lower formant frequencies as heel height increased and most changes occurred in F1, F2 and F4. On the /i/ vowel in low to medium heels, Carol demonstrated a large dampening of F2 and F4 which was exaggerated as heel height increased from low to high on this vowel. Overall, higher heels contributed to greater changes in formant frequencies than medium heel height shoes.

Betty's overall measurements indicated changes in formant frequencies in a range of 1 to 226 cents between conditions in the three shoe heel heights. From low to medium heels, Betty tended to raise the F1, F2, and F3 formant frequencies and lower F4. When analyzed from low to high heels, the vowel /e/ in the word "me" showed an increase in all four formant frequencies and a large increase of 226 cents in F2.

Ann's performances displayed changes in formant frequencies in a range of 0 to 272 cents between the three trials in different heel heights. Ann tended to lower the formant frequencies as heel height increased, especially on the open vowels /ɑ/ and /o/. F3 and F4 a
important changes in /ɑ/ and /e/. On the v
formant 52 cents, however, from low to high, the third formant decreased by -66 cents. The vowel /o/ displayed the most deviation in cents between all formant frequencies (*N* = 4), however, the analysis of the vowel /e/ increased in F1, F2 and F4 from low to high heels.

Research Question Three: Perceptual Data

All participants completed a survey consisting of seven, Likert-type scale items anchored by *strongly disagree* (1) and *strongly agree* (5). Participants largely agreed that they perceived themselves to be vocally healthy, physically healthy, and comfortable singing in the room. The survey asked each participant (a) in which outfit she felt she sang best, and (b) why the singer chose that specific outfit. All participants wrote comments about heel height without being prompted. Ann, Carol, Dorothy and Elisa expressed preference for the medium height heel while Betty preferred the highest heel. Participant comments on high heels included, "It's how I'm most used to singing," and "The heels were too high and threw my balance off a bit." Commentary on low heels included, "Comfortable shoes, but no heel and I like to wear heels for auditions” and “Flats make me feel too relaxed and drowsy.” The medium heels possessed the most positive comments including, “The shoes are very sturdy,” and “Most comfortable shoes, have a heel but not too high.”

Only two participants mentioned receiving advice from voice teachers and other voice professionals concerning heels and singing. Betty commented that she had been told to always wear high heels and preferably nude colored shoes, because they make a singer’s legs look longer. Elisa wrote that she had been advised to wear medium height heels. All other comments consisted of advice about hair, makeup, style and length of dress, type of audition, etc.

When asked if they believed that what they wear could affect vocal production, all participants answered “yes.” Three participants specifically mentioned shoes, however these comments addressed comfort rather than vocal production, such as, “regarding shoes, only wear what you can stand in for 20 plus minutes.” Other participant comments included avoiding too tight clothing around the waist, wearing something to encourage professionalism and mental focus, and wearing something that is comfortable.

Discussion

This pilot study inaugurates a line of research exploring potential effects of different shoe heel heights on singer performance, a heretofore under-investigated phenomenon. Primary results of this investigation suggest (a) different shoe heel heights appear to contribute to postural changes in participants' head position, lumbar lordosis, and knee flexion; (b) four out of five participants exhibit significant differences according to shoe heel height in LTAS measurements; (c) formant frequency profiles of selected vowels vary idiosyncratically according to shoe heel height, but consistently display appreciable cents deviations; and (d) most participants appear aware of shoe heel height as a potential matter of comfort and appearance, but not as a matter that might affect vocal performance. These results are limited to the particular participants in this collective case study and also limited by the particular dependent measures and procedures employed. Nonetheless, they raise matters of interest for vocal pedagogues and for future research.

Given overall findings from this study, one might reasonably speculate that shoe heel height, while apparently contributing to results of postural alignment and acoustical measures, does not operate in isolation from other factors, such as (a) years of vocal singing experience that might inform a singer's ability to compensate for postural misalignment, (b) vowel formation habits, and (c) current vocal technique. With respect to postural alignment, it is widely accepted by postural experts that any increase in heel height could cause some sort of compensation in the body (Opila et al., 1988; Klausen, 1965). It is unclear, however, whether this compensation could impact the larynx. Future studies might well explore whether singers with varying technical levels and experience performing in high heels create compensatory changes in phonation or respiration.

The present study incorporates a semi-naturalistic "audition" environment with attention to overall apparel choices in order to draw attention away from a primary interest in shoe heel height. By so doing, however, participants wore their own shoes and sang different arias. Future investigations could control for these potentially confounding variables by (a) having singers perform the same aria (which would permit across participant comparisons and enable formant frequency extraction of the same vowels on the same sung pitches) and (b) ensuring exact, rather than approximate, shoe heel height differences. The latter research decision could call participants' attention to shoe heel height as the independent variable of interest, but results from the present collective case study suggest that a full scale experimental study with more participants is a next step in this line of research.

Results of postural alignment measures with the participants in this study appear particularly intriguing. In low to high heel comparisons, two singers decreased lumbar lordosis, one singer remained the same, and two singers increased lumbar lordosis. Such findings may indicate that results of previous strictly postural studies (e.g., Opila et al., 1998; Opila-Correia, 1990; Russell et al., 2012) may not always transfer to singers. More research is needed to determine potential effects of lumbar lordosis changes on vocal solo performance.

Knee flexion is a measure heretofore unconsidered by voice researchers. Postural researchers have found that participants bend the knee as heel height increases (Stefanyshyn et al., 2000; Opila, 1988). Results of this study indicate that from low to high heels, three participants evidence a greater bending of the knee, while one participant showed a slightly greater straightening of the knees. Singers may not demonstrate the same knee flexion tendencies as non-singers. Future studies might well consider this possibility.

It is important to note that one change in a postural measurement could affect the entire alignment needed for singing. For instance, a decrease in lumbar lordosis could correlate with a collapsed sternum, which could impact breathing. It is important to consider the entire picture when discussing postural changes and the field needs more research to understand the potentially complex interrelation of all postural measurements in singers. This study contributes to the research literature by offering replicable, non-invasive postural alignment measures that enable examination of posture with participants still fully clothed. Future studies can refine these measures and also compare such indirect measures to results obtained with radiography.

Luck and Toiviainen (2007) found that head position affected voice quality and that a downward head position caused spectral irregularity and noise. Miller et al. (2012) showed that a straighter cervical curvature resulted in a posterior tongue position. The data from this study indicate that four out of five participants decreased the angle of head flexion as heel height increased. Based on the studies above, one might speculate that decreased head flexion angles could result in increased tongue tension and spectral irregularity during singing. Increased head position in singers might also correspond with a higher larynx position due to the inferior movement of the hyoid bone (Pae et al., 1994; Hellsing, 1989; Tong et al., 2000). More research is needed on potential effects of head position on singing performance. Likewise, more research is needed on potential effects of shoe heel heights on singers' head positions while performing.

Singer perceptions continue to be important in considering which heel height may be advantageous for singing. The only participant (Betty) who preferred the highest heel was the only participant who did not show statistically significant differences in LTAS measurements between heel heights. Future research may consider the possibility that how a singer views and perceives a heel height condition as being helpful or detrimental may impact the participant’s ability to sing efficiently in these higher heels. Nonetheless, practical opinions of singers, casting directors, costumers, etc. will be important in determining if and how suggested heel heights can be implemented.

Voice teachers routinely advise their female students on performance apparel, including what type of shoes to wear. More studies, such as the present one, may help teachers and singers alike to make more informed decisions about shoe heel heights. It is doubtful that shoe heel height alone can make the difference between a stellar vocal performance and a mediocre one

Yet singing, by nature, is a highly nuanced and inter-related phenomenon. Continued research that contributes to understanding more fully how shoe heel height may interact in nuanced ways with singer's vocal production appears warranted.

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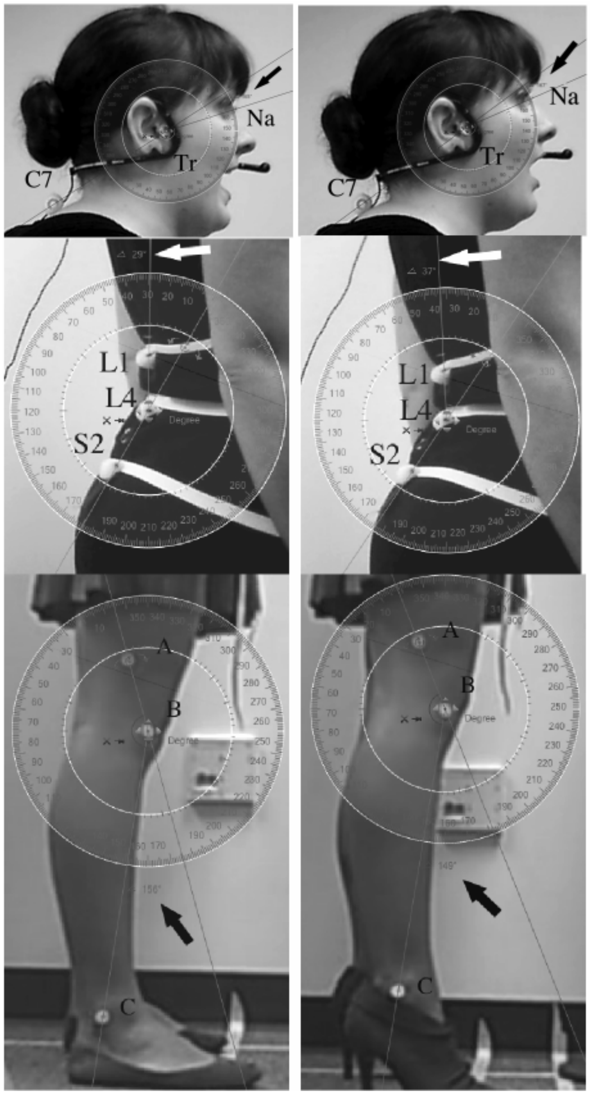

Figure 1. Head position (HP) analysis. Head position measurement of “Dorothy” with Onde Rulers Screen Protractor measured angle 3 between points C7, Tragus (Tr) and Nasion (Na). The photograph on the left measured 165° of HP, while singing the vowel /e/ and the picture on the right demonstrated an increase of only 2° (167°) while singing the vowel /a/.

Lumbar lordosis (LL) analysis. Lumbar lordosis measurement of “Elisa” with Onde Rulers Screen Protractor measured the angle between L1, L4, and S2 vertebrae. The photograph on the left measured 29° of LL and the picture on the right demonstrated an increase in LL at 37°. Knee flexion (KF) analysis. A = Lateral malleous, B = Lateral joint line, C = Lateral lower thigh. Knee flexion measurement of “Carol” with Onde Rulers Screen Protractor measured the angle between points A, B, and C. The photograph on the left measured 156° of KF in low heels and the picture on the right demonstrated a decrease in KF of 149° while wearing high heels.

Table 1

Participant Demographic Information, Heel Heights, Aria Performed and Vowels Analyzed

Participant	Age	Year in School (Years of Voice Study)	Heel Heights (in.)	Aria Performed *Larger Work* (Composer)	Vowels (Pitch) “Word”
Elisa	24	1st Year Master’s	0.50	Laurie’s Song	/E/ (D5) “say”
		(7 years)	2.50	*The Tenderland*	/a/ (B4) “wide”
			4.00	(Copland)	/a/ (F#5) “sky”
Dorothy	21	Senior	0.50	Kommt ein schlanker	/a/ (C5) “braut;”
		(7 years)	2.75	Bursch gezogen	/u/ (A5) “Bursch”
			3.75	*Der Freischütz*	/e/ (G5) “seh’n”
				(von Weber)	
Carol	22	Junior	0.00	Batti, batti o bel Masetto	/i/ (E5) “batti”
		(4 years)	2.50	*Don Giovanni*	/a/ (F#5) “baciar”
			4.25	(Mozart)	/o/ (F5) Masetto
Betty	20	Junior	0.50	Non so piœ cosa son	/i/ (D5) “venti”
		(6 years)	2.00	cosa faccio	/e/ (G5) “se”
			3.75	*Le Nozze di Figaro*	/e/ (E5) “me”
				(Mozart)	
Ann	18	Freshman	1.00	L’ho perduta	/a/ (F5) “sa”
		(3 years)	2.00	*Le Nozze di Figaro*	/o/ (D^{b}5) “non”
			2.50	(Mozart)	/e/ (E5) “Meschinella”

Table 2

Postural Measurements (Degrees) ofHead Position, Lumbar Lordosis and Knee Flexion in Three Heel Heights

	M (degrees)			Difference Between Heel Heights (degrees)		
	Low	Medium	High	Low/Medium	Medium/High	Low/High
HP Angle 1						
Elisa	111.50°	109.17°	109.00°	-2.33°	-0.17°	-2.50°
Dorothy	109.50°	108.50°	105.17°	-1.00°	-3.33°	-4.33°
Carol	109.00°	109.83°	103.67°	0.83°	-6.16°	-5.33°
Betty	105.33°	104.00°	103.83°	-1.33°	-0.17°	-1.50°
Ann	100.33°	99.50°	100.83°	-0.83°	1.33°	0.50°
HP Angle 2						
Elisa	47.33°	46.00°	46.00°	-1.33°	0.00°	-1.33°
Dorothy	56.17°	55.83°	56.50°	-0.34°	0.67°	0.33°
Carol	46.17°	45.50°	45.67°	-0.67°	0.17°	-0.50°
Betty	48.00°	46.83°	46.67°	-1.17°	-0.16°	-1.33°
Ann	54.67°	53.50°	54.50°	-1.17°	1.00°	-0.17°
HP Angle 3						
Elisa	158.83°	155.17°	155.00°	-3.66°	-0.17°	-3.83°
Dorothy	165.67°	164.17°	161.67°	-1.50°	-2.50°	-4.00°
Carol	155.17°	155.33°	149.33°	0.16°	-6.00°	-5.84°
Betty	153.33°	150.83°	150.50°	-2.50°	-0.33°	-2.83°
Ann	155.00°	153.00°	155.33°	-2.00°	2.33°	0.33°
LL Angle						
Elisa	33.33°	31.83°	33.33°	-1.50°	1.50°	0.00°
Dorothy	33.83°	38.50°	47.67°	4.67°	9.17°	13.84°
Carol	12.00°	11.83°	10.67°	-0.17°	-1.16°	-1.33°
Betty	27.00°	25.17°	23.83°	-1.83°	-1.34°	-3.17°
Ann	15.00°	15.50°	15.17°	0.50°	-0.33°	0.17°
KF Angle						
Elisa	142.83°	143.67°	142.67°	0.84°	-1.00°	-0.16°
Dorothy	146.17°	146.83°	146.50°	0.66°	-0.33°	0.33°
Carol	155.17°	154.00°	150.17°	-1.17°	-3.83°	-5.00°
Betty	155.83°	155.50°	152.33°	-0.33°	-3.17°	-3.50°
Ann	154.33°	155.50°	-	1.17°	-	-

Note. HP = Head position; LL = Lumbar lordosis; KF = Knee flexion. An increase in angle 1 HP (Na-Tr-Vert) indicated a superior chin movement. An increase in angle 2 HP (C7-Tr-Vert) indicated an anterior movement of the neck. Angle 3 HP (C7-Tr-Na) indicated the overall craniocervical posture and is the sum of angles 1 and 2. An increase in LL indicated a greater inward curve in the low back. An increase in KF indicated a greater tendency to lock the knees.

LTAS Relative Energy Differences (dB SPL) and Partial Changes Per Participant According to Shoe Heel Heights

	MEAN LTAS Diff. (dB SPL)	One-Way ANOVA, Significance*	*t*-Test (2-tailed), Significance*	Relative Energy Change (dB SPL)		Number of Partials Changed		
				Max.	Min.	Decreased	Increased	No Change
Elisa								
Low to Med. Heels	0.78		*t*(116) = -37.98,*p* < .0001*	1.36	0.34	0	117	0
Med. to High Heels	-0.16		*t*(116) = -8.84,*p* <.0001*	0.42	-0.57	92	24	1
Low to High Heels	0.62	*F*(1,116)=811.54,*p*<.0001*	*t*(116) = -27.13,*p*<.0001*	1.34	0.00	0	116	1
Dorothy								
Low to Med. Heels	0.01		*t*(1 16) = -.45,*p* = .66	0.67	-0.64	53	64	0
Med. to High Heels	0.13		*t*(116) = -5.41,*p* <.0001*	0.77	-0.45	32	84	1
Low to High Heels	0.14	*F*(1,116) = 18.62,*p*<.0001*	*t*(116) = -5.31,*p*<.0001*	0.65	-0.64	39	77	1
Carol								
Low to Med. Heels	-0.94		*t*(1 16) = 37.60, *p* < .0001*	-0.26	-1.58	117	0	0
Med. to High Heels	0.80		*t*(116) = -21.50,*p* <.0001*	1.62	-0.23	3	114	0
Low to High Heels	-0.14	*F*(1,116) = 574.05,*p*<.0001*	*t*(116) = 5.51,*p*<.0001*	0.42	-0.88	80	37	0
Betty								
Low to Med. Heels	-0.05		*t*(116) = 1.91, *p* = .06	0.61	-0.89	63	52	2
Med. to High Heels	-0.01		*t*(116) = 0.19,*p* = .85	1.21	-0.67	63	53	1
Low to High Heels	-0.06	*F*(1,116) = 1.85,*p* = .16	*t*(116) = 1.67,*p* = .10	0.91	-0.91	69	48	0
Ann								
Low to Med. Heels	0.01		*t*(116)=-0.34,*p*= .73	1.33	-1.02	62	55	0
Med. to High Heels	0.26		*t*(116) = -4.06,*p* <.0001*	2.64	-1.35	34	83	0
Low to HighHeels	0.27	*F*(1,116) = 11.50,*p*<.0001*	*t*(116) = -3.40,*p*<.001*	2.74	-2.01	38	79	0

* *p* < .003 3, two-tailed, Bonferroni Correction

Formant Frequency Differences (Cents) Between Three Heel Heights

	Low to Medium Heel Difference (cents)				Low to High Heel Difference (cents)			
	F1	F2	F3	F4	F1	F2	F3	F4
Elisa								
/E/ (D5) “say”	16	-24	-41	-57	77	-28	-38	-16
/a/(B4)“wide	58	220	17	5	17	65	-14	-18
/a/ (F#5) “sky"	1	-3	15	33	3	2	-6	5
Dorothy								
/a/ (C5) "braut"	114	269	67	121	91	267	77	120
/u/ (A5) "Bursch"	38	37	-71	-22	34	33	-32	82
/e/ (G5) "seh'n"	13	45	25	77	17	25	-51	12
Carol								
/i/(E5)"batti"	38	-110	-19	-60	12	-124	11	-70
/a/ (F#5) “baciar"	-24	-21	-11	-11	-34	-31	11	3
/o/ (F5) "Masetto"	19	20	-9	58	-73	-75	28	85
Betty								
/i/(D5)"venti"	21	149	82	-35	7	-29	-82	-117
/e/ (G5) "se"	6	14	29	-60	-4	8	52	-29
/e/(E5)"me"	22	26	128	-55	1	226	31	26
Ann								
/a/ (F5) "sa"	-15	-8	52	-42	-5	8	-66	-48
/o/ (Db5) "non"	-128	-93	-220	-77	-272	-196	-142	-40
/e/ (E5) "Meschinella"	-32	-23	108	74	36	0	100	41

Note. Cents constitutes a logarithmic measurement of the distance between two frequencies (Hz), where a semitone is equal to 100 cents.