The Effect of Task Type on Speaking Fundamental Frequency in Women

by

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Abstract

Speaking fundamental frequency (SF_0) is an acoustic measure that is frequently used by voice clinicians to assess the severity of vocal pathology and to monitor progress in treatment. However, there is little agreement on what task should be used to measure SF_0, and various tasks are commonly used. Twenty-one young women with no vocal pathology were recorded performing 6 tasks commonly used to assess SF_0. A significant difference in SF_0 was found among tasks. The reading passage and spontaneous speech tasks were significantly different than the counting from 1-10 task, sustained /a/, sustained /i/ after counting 1-3 task, and the 20th percentile of the F_0 range. These results support development of procedural standards for acoustic measurement of voice.

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Introduction

Speaking fundamental frequency is "the average fundamental frequency in connected speech" (Boone, McFarlane, Von Berg, & Zraick, 2010, p. 150). Fundamental frequency (F_0) is directly related to the rate of vibration of the vocal folds, and is measured in Hertz (Hz). The term "fundamental frequency" is also sometimes used interchangeably with speaking fundamental frequency (Colton & Casper, 1990, p. 184). In this paper "speaking fundamental frequency" (SF_0) will be used to refer to the mean or modal F_0 of a given vocal production or sample of speech. The term "habitual pitch" will be used to refer to the perceptual equivalent of SF_0 (Boone et al., 2010).

A substantial amount of research has documented normal SF_0 in men, women, and children at various ages. Under normal circumstances, SF_0 in children drops gradually until it reaches adult levels. Research on the SF_0 of children reports values ranging from 220 to 300 Hz (Bennett, 1983; Fairbanks, Herbert, & Hammond, 1949; Fairbanks, Wiley & Lassman, 1949). At puberty SF_0 decreases to adult levels, which for men is about 128 Hz between the ages of 20 and 29 years (Aronson, 1980). The SF_0 of women in the same age range is about 224 Hz (Stoicheff, 1981). The SF_0 of adults gradually increases with age in men, and decreases at menopause in women (Benjamin, 1986; Duffy, 1970; Harnsberger, Shrivastav, Brown, Rothman, & Hollien, 2008; Harries, Hawkins, Hacking, & Hughes, 1998; Hollien & Shipp, 1972; McGlone & Hollien, 1963; Mysak, 1959; Russell, Penny, & Pemberton, 1995; Stoicheff, 1981). The SF_0 of individuals may also vary over time and between dialects (Altenberg & Ferrand, 2006; Coleman & Markham, 1991). Some studies have suggested that race may influence SF_0, but evidence is equivocal (Andrianopoulos, Darrow, & Chen, 2001; Hollien & Malcik, 1962; Hudson & Holbrook, 1982; Wheat & Hudson, 1988; Xue & Mueller, 1996). Change in SF_0 is also associated with various functional and organic vocal pathologies (Hirano, 1989; Murry & Doherty, 1980).

Measures of SF_0 are commonly taken in voice evaluations (Behrman, 2005; Hirano, 1989). However, there is not a standardized protocol for taking these measures. Tasks used for eliciting SF_0 may include reading a standard passage such as Fairbanks' (1960) "Rainbow Passage," producing a spontaneous connected speech sample, counting, sustaining a vowel such as /a/, /i/, or /u/, and sustaining a vowel within a phrase. Some research suggests that different tasks may result in significantly different outcomes (Baker, Weinrich, Bevington, Schroth, & Schroeder, 2008; Britto & Doyle, 1990; Chen, Kimelman, & Micco, 2009; Horii, 1975; Hudson & Holbrook, 1982; Hunter, 2009; Murry, Brown, & Morris, 1995; Mysak, 1959; Ramig & Ringel, 1983; Zraick, Birdwell, & Smith-Olinde, 2005; Zraick, Skaggs, & Montague, 2000).

Since change in SF_0 is associated with some vocal pathologies, some have argued that each person has an F_0 level that is more efficiently produced given the physical characteristics of the individual's speech mechanism (Boone, 1971; Fairbanks, 1940). This ideal F_0 is referred to as "optimal," "optimum," "natural," or "best" pitch. It has also been speculated that if an individual uses an SF_0 that is higher or lower than his or her optimal pitch then vocal pathology may ensue. However, research on optimal pitch is inconclusive. Some research has suggested that optimal pitch is an effective treatment target for patients with a variety of dysphonias (Cooper, 1974). Conversely, other studies have suggested that optimal pitch may not be an effective treatment target, or at least that altering SF_0 may not be necessary to effectively treat dysphonia (Hufnagle & Hufnagle, 1984; Roy & Hendarto, 2005). Even if an optimal pitch exists for each individual, traditional methods for estimating it may not be valid (Britto & Doyle, 1990; Linke, 1973). The issue of identifying optimal pitch is made difficult by the complexity of measuring vocal acoustic efficiency. It is not yet clear how to estimate optimal pitch, or whether or not an acoustically efficient pitch necessarily correlates with long-term vocal health (Titze, 1992). Various methods have been used to estimate optimal pitch, including taking the frequency 25% of the way from the bottom of the F_0 range including falsetto, or asking the patient to produce the utterance “um-hum” or “uh-huh,” as if agreeing with someone (Cooper, 1974; Fairbanks, 1960). However, these traditional methods for estimating optimal pitch have been questioned (Britto & Doyle, 1990; Linke, 1973). Much research is still necessary to answer the questions surrounding optimal pitch.

Research suggests that different elicitation tasks may result in significantly different SF_0 values. The effect of task on SF_0 has potential importance in clinical practice and research. If there is a significant difference between SF_0 values collected using different methods, clinicians and researchers should be aware of any significant difference before choosing a task to elicit SF_0 or before comparing SF_0 data collected using different methods. However, the results of studies evaluating the effect of task on SF_0 are inconsistent. Additional study is necessary to identify possible differences in SF_0 when measured using different tasks.

Review of the Literature

Speaking Fundamental Frequency

SF_0 in children. The SF_0s of male and female children range from approximately 220 to 300 Hz and are comparable until puberty. The reported SF_0 values vary, possibly due to different tasks used to measure SF_0 in different studies. SF_0 gradually decreases and then drops to adult levels at puberty (Aronson, 1980). Several research studies document the normal SF_0 levels of children. Two studies conducted by Fairbanks, Herbert et al. (1949) and Fairbanks, Wiley et al. (1949) examined SF_0 in 7-year-old and 8-year-old girls and boys. All participants in both studies were recorded reading a passage. Only the second and third paragraphs, which comprised 52 words, were analyzed out of the four-paragraph passage. The group of 7-year-old girls exhibited an SF_0 of 281 Hz and the group of 8-year-old girls an SF_0 of 288 Hz. The group of 7-year-old boys exhibited an SF_0 of 294 Hz and the group of 8-year-old boys an SF_0 of 297 Hz. No significant difference in SF_0 was found either between the boys and girls or between the 7-year-old and 8-year-old groups.

McGlone and McGlone (1972) measured the SF_0 of 10 girls between the ages of 5 years, 1 month and 6 years, 10 months. SF_0 was elicited by asking each child to name 20 pictures. However, only 11 pictures elicited the same response from all the children and were used to measure SF_0. The mean SF_0 for all the girls was found to be 248.8 Hz. The mean SF_0 value from this study may be lower than the mean SF_0 values found in the studies by Fairbanks, Herbert et al. (1949) and Fairbanks, Wiley et al. (1949) because picture naming was used rather than a reading passage to elicit SF_0, or because only 11 words were elicited rather than a 52-word passage.

Sorensen (1989) measured SF_0 in 30 children between the ages of 6 and 10 years. The children were divided into groups according to whether they were 6, 7, 8, 9, or 10 years old. All the children read pages 36 and 37 from the first-grade reader *Fun With Our Family* by Robinson, Monroe, and Artley (1962), produced 30 seconds of spontaneous speech with a picture stimulus, and sustained the vowels /i/, /ɪ/, /ɛ/, /æ/, /ʌ/, /ɑ/, and /u/ for approximately 5 seconds each. All the tasks were explained and demonstrated by the investigator, and results from all the tasks were averaged to obtain SF_0 values for each group of children. The boys had mean SF_0 values of 269, 295, 254, 242, and 248 Hz, whereas the girls had mean SF_0 values of 308, 279, 268, 283, and 269 Hz for the 5 age groups, respectively. The mean SF_0 values from these tasks did not show a significant difference between boys and girls of the same age. There was no significant difference found among the SF_0 values of the age groups, indicating no significant effect of age on SF_0 in children. These results are consistent with the results from Fairbanks, Herbert et al. (1949) and Fairbanks, Wiley et al. (1949), which indicated no significant differences between male and female children or among children at different ages.

Bennett (1983) studied longitudinal changes in the SF_0 of 25 girls and boys who were between the ages of 8 and 11 years. Over a 3-year period four yearly measurements were taken in which the children repeated the sentence “There is a sheet of paper in my coat pocket.” Results revealed an average decrease of SF_0 every 12 months of 12 Hz. At the ages of 8:2, 9:2, 10:2, and 11:2, the girls had average SF_0s of 235, 222, 228, and 221 Hz, and the boys had average SF_0s of 234, 226, 224, and 216 Hz, respectively. The age-related changes in SF_0 were significant for both the girls and boys, whereas the difference between girls and boys was not significant. The values for the 8-year-olds in this study are lower than the values for the 8-year-olds in the studies by Fairbanks, Herbert et al. (1949), Fairbanks, Wiley et al. (1949), and Sorensen (1989). This difference in outcome may be related to differences in data collection. Fairbanks, Herbert et al. and Fairbanks, Wiley et al. calculated SF_0 from reading a 52-word passage, McGlone and McGlone (1972) calculated SF_0 from picture naming, and Sorensen (1989) calculated SF_0 from three different tasks. In contrast, Bennett (1983) calculated SF_0 from an imitative sentence.

SF_0 at puberty. In addition to SF_0 dropping gradually in relation to chronological age, the SF_0 of female adolescents drops slightly in relation to menarche. Duffy (1970) examined the SF_0 characteristics of 24 girls aged 11, 13, and 15 years. The 11-year-old girls were premenarcheal, the 15-year-old girls were postmenarcheal, and the 13-year-old girls were mixed. All participants were recorded reading part of the "Rainbow Passage" (Fairbanks, 1960, p. 127). The 11-year-old girls had a mean SF_0 of 287 Hz, the premenarcheal 13-year-old girls had a mean SF_0 of 260 Hz, the postmenarcheal 13-year-old girls had a mean SF_0 of 245 Hz, and the 15-year-old girls had a mean SF_0 of 237 Hz. The authors suggest that the difference in SF_0 found between the premenarcheal and postmenarcheal 13-year-old girls indicates that change in SF_0 was more significantly related to menarche than it was to the 2 years of chronological age or general physical growth.

Williams, Larson, and Price (1996) compared SF_0 in 33 female adolescents between the ages of 11 and 15 years. Sixteen of the participants were postmenarcheal and 17 were premenarcheal. SF_0 was measured from a 150-syllable reading passage and a 30-second spontaneous speech sample about a topic chosen by the participant. The premenarcheal group had mean SF_0s of 218.3 Hz during spontaneous speech and 225.3 Hz during reading. The postmenarcheal group had mean SF_0s of 206.3 Hz during spontaneous speech and 214.8 Hz during reading. Although the postmenarcheal group had lower SF_0 values than the premenarcheal group for both tasks, the differences in SF_0 were not statistically significant either between the tasks or between the premenarcheal and postmenarcheal groups. The authors speculate that the lack of a statistically significant difference may be due to the study's small sample size.

The SF_0 of male children drops rapidly as the vocal folds lengthen once puberty is reached. Curry (1940) measured male adolescent voice change in six pre-adolescent 10-year-old boys, six adolescent 14-year-old boys, and six post-adolescent 18-year-old boys. SF_0 was derived from reading the first paragraph of the "Rainbow Passage." The analysis resulted in mean SF_0s of 269.7, 241.5, and 137.1 Hz for the pre-adolescent, adolescent, and post-adolescent groups. Curry concluded that the majority of male adolescent voice change occurs between the ages of 14 and 18 years.

Harries et al. (1998) measured by ultrasound the vocal fold length of 26 boys who were experiencing puberty between the ages of 13 and 14 years. SF_0 was measured from recordings of the participants reading "Arthur the Rat" and the "Rainbow Passage." Measurements were taken a total of 4 times at intervals of 3 months for a period of one year. A relationship was found between the increasing length of the vocal folds and decreasing SF_0, both of which shifted gradually throughout puberty. However, there was also a sudden drop in SF_0 not parallel with the length of the vocal folds. Since this drop was not accompanied by a change in length, the authors speculate that this drop may be caused by a developmental change in the structure and mass of the vocal folds.

Hollien, Green, and Massey (1994) conducted a 5-year longitudinal study of 48 boys between the ages of 10 and 11 years at the beginning of the study. Either once or twice a month, SF_0 was measured from reading the "Rainbow Passage." The investigators identified the onset of adolescent voice change as the SF_0 value which was followed by a decrease in SF_0 at a rate of at least one semitone per month for at least six months. All of the participants met this criterion, except for three boys who had not started to experience voice change when the study ended. Once voice change had begun, no increases in SF_0 of more than one semitone were noted until the end of adolescent voice change. The end of adolescent voice change was identified as the lowest SF_0 value before a period of stabilization. The data of the 34 boys who completed voice change by the end of the study were then organized into preadolescent, adolescent, and postadolescent categories based on these criteria for the onset and end of adolescent voice change. When they were preadolescent the boys had a mean age of 12 years, 2 months and a mean SF_0 of 233.1 Hz. When adolescent the boys had a mean age of 13 years, 7 months and a mean SF_0 of 173.8 Hz, and when postadolescent the boys had a mean age of 14 years, 10 months and a mean SF_0 of 121.6 Hz. The mean age of onset of voice change was 13 years, 5 months, and the mean duration of adolescent voice change was 18 months. Because the onset of adolescent voice change and the decrease in SF_0 were found to be easily identifiable, the authors suggest that SF_0 may be a useful method for defining progression through male adolescence.

SF_0 in women. After puberty, research suggests that SF_0 in women remains relatively stable from adolescence until it lowers at the completion of menopause. The SF_0 of premenopausal women is approximately 224 Hz, and in postmenopausal women it is approximately 200 Hz (Stoicheff, 1981). However, normative data on SF_0 varies, possibly because of research variables such as the type of task used to elicit SF_0. Stoicheff (1981) studied

SF_0 in 111 women in 6 age groups: between 20 and 29 years, 30 and 39 years, 40 and 49 years, 50 and 59 years, 60 and 69 years, and 70 and 82 years. SF_0 was calculated from reading the first paragraph of the “Rainbow Passage.” The mean SF_0s of the 6 groups were 224, 213, 221, 199, 200, and 202 Hz. Analysis of the results indicated that SF_0 was relatively stable both in the participants between 20 and 49 years of age and in the participants between 50 and 82 years of age. There was also a significant decrease in SF_0 from the younger to the older group. Because of this pattern the author reorganized the participants into three groups: premenopausal women, women experiencing menopause, and postmenopausal women. Analysis of these data revealed that the SF_0 of both the premenopausal women and women undergoing menopause were significantly different than that of the postmenopausal women, suggesting that the observed decrease in SF_0 during the 50s is directly related to the completion of menopause, rather than chronological age.

The change in SF_0 accompanying menopause may be related to physiological changes in the larynx associated with menopause. Abitbol, Abitbol, and Abitbol (1999) used televideoendoscopy and stroboscopy to assess the voices of 100 women who were experiencing menopause. Observation of the images indicated that, when compared with premenopausal women, the vocal folds were less supple, had a thinner mucosa, and had decreased vibratory amplitude.

Higgins and Saxman (1991) studied SF_0 in 10 women between the ages of 20 and 31 years and 11 women older than 69 years. They measured SF_0 from the sustained vowel /æ/, and found that the young women had a mean SF_0 of 235.17 Hz, and the older women had a mean SF_0 of 211.06 Hz. The difference between the young and older women was statistically significant.

These results are consistent with the results from Stoicheff (1981), who found a significant difference between young and older women.

Russell et al. (1995) performed a longitudinal study of SF_0 in 15 Australian women who were originally recorded in 1945 when they were between the ages of 18 and 25 years. These women were located and re-recorded 48 years later in 1993 when they were between the ages of 65 and 68 years. The participants read the same two sentences originally recorded in 1945, and SF_0 was measured from the entire recording of both sentences. The sentences were, "He felt in his pocket and was glad to find his latch key and his money, for with these a man commands the world," and "The Scotch dialect is rich in reproach against the winter wind; they are all words that carry a shiver with them." The mean SF_0 from 1945 was 229.0 Hz and the mean SF_0 from 1993 was 181.2 Hz . The SF_0 in 1993 was significantly lower than the SF_0 in 1945.

Raj, Gupta, Chowdhury, and Chadha (2009) studied changes in SF_0 in postmenopausal women. Participants included 35 females between the ages of 20 and 30 years, and 20 postmenopausal females who had experienced menopause within 5 years previous to the study. The mean SF_0 for the premenopausal women was found to be 231.49 Hz, and for the postmenopausal participants in the study, it was noted that there was a significant decrease in F_0 to 204.98 Hz. This observed decrease after menopause is consistent with the research by Stoicheff (1981), Higgins and Saxman (1991), and Russell et al. (1995) et al. which also indicated a decrease in SF_0 after menopause.

A study conducted by Benjamin (1986) compared the SF_0 of older females between the ages of 69 and 82 years of age with younger females between the ages of 21 and 32 years. Each participant read the “Rainbow Passage” in a normal conversational voice and sustained the vowel /a/ for 7 seconds while holding vocal intensity constant. For the older women, they found an SF_0 of 180 Hz, and for the younger women, 197 Hz. The results from Russell et al. (1995) and Benjamin (1986) are consistent with those from the study by Stoicheff (1981), which indicate that SF_0 values are lower for postmenopausal women.

McGlone and Hollien (1963) studied the SF_0 of 10 female participants between the ages of 65 and 79, and 10 female participants between the ages of 80 and 94 years. Participants were recorded reading the first paragraph of the “Rainbow Passage” after at least 2 practice trials. Analysis of the recordings revealed that the first group had an average SF_0 of 196.6 Hz, and the second group had an average SF_0 of 199.8 Hz. The difference between the two groups was not significant. These results are consistent with those from Stoicheff (1981), which suggested that SF_0 is relatively stable after the completion of menopause.

SF_0 throughout the menstrual cycle. The vocal folds may experience physiologic changes associated with the menstrual cycle. Abitbol et al. (1999) studied the effect of premenstrual syndrome on the voice in 97 female professional singers between the ages of 23 and 36 years. All the participants reported symptoms of premenstrual dysphonia. Televideoendoscopy was used to examine the vocal folds during the ovulatory and premenstrual phases for 3 menstrual cycles. Vocal fold edema was observed during the premenstrual phase in all the participants, as well as a thickened mucus and decreased suppleness of the vocal folds. Other observations included decreased amplitude, decreased supraglottic and subglottic glandular secretion resulting in dryness of the larynx, submucosal vocal fold hematoma, voice fatigue, posterior chink, bilateral vocal fold nodules, and asymmetric vocal fold vibration. They also found that premenstrual syndrome was associated with edema in Reinke’s space and decreased tone in all striated muscle. These results indicate that there may be various vocal changes associated with premenstrual syndrome, which have the potential to result in change in

SF_0. For example, edema in Reinke's space could result in decreased SF_0 during the premenstrual phase.

However, several studies have not found significant differences in SF_0 among various phases of the menstrual cycle. Chae, Choi, Kang, Choi, and Jin (2001) measured SF_0 during the follicular phase and premenstrual phase of 28 female participants between 21 and 30 years of age. Sixteen of the participants were experiencing premenstrual syndrome. The time of ovulation for each participant was determined by daily measurements of basal body temperature, and SF_0 was measured during both the follicular and premenstrual phases from the vowel /a/ sustained for 5 seconds. The mean SF_0 during the follicular phase was 240.82 Hz, and during the premenstrual phase it was 238.32 Hz. There was no significant difference found in SF_0 between the follicular and premenstrual phases.

Raj et al. (2009) studied acoustic changes associated with various phases of the menstrual cycle. Participants included 35 females between the ages of 20 and 30 years with regular menstrual cycles. SF_0 was elicited on the first day of each phase of the menstrual cycle. SF_0 was found to be 231.09 Hz in the menstrual phase, 231.42 Hz in the follicular phase, 231.48 Hz in the ovulatory phase, 229.52 Hz in the luteal phase, and 233.95 Hz in the premenstrual phase. Similar to the study by Chae et al. (2001), no significant change in SF_0 was found among the phases.

Meurer, Garcez, von Eye Corleta, and Capp (2009) compared the voices of 23 female adolescents during the follicular and luteal phases of the menstrual cycle in adolescent women. All the participants were native speakers of Brazilian Portuguese between the ages of 15 and 17 years. All the participants had regular menstrual cycles, did not use oral contraceptives, and did not have previous voice training. SF_0 was measured from recordings of the sustained vowel /a/ and the sentence "irei a Gramado nas férias de inverno" (i.e., I will go to Gramado during my winter holidays). Participants were allowed to repeat the sentence if they wanted to practice. For the follicular phase, they found a mean SF_0 of 189.1 Hz, and for the luteal phase, a mean SF_0 of 196.1 Hz. Overall the participants demonstrated a mean SF_0 of 192.6 Hz. Consistent with the studies by Chae et al. (2001) and Raj et al. (2009), no significant difference was found between the mean SF_0s during the follicular and luteal phases of the menstrual cycle. The outcomes of these studies indicate that there may not be a significant hormonal influence on SF_0 during the menstrual cycle.

SF_0 in men. The SF_0 of men is about 100 Hz lower than the SF_0 of women after puberty. Aronson (1980) reported that the SF_0 of men between the ages of 20 and 29 years is about 128 Hz, and that the SF_0 of women in the same age range is about 227 Hz, indicating a difference of about 100 Hz. The SF_0 of men continues to decrease slightly after puberty, and then increases gradually with age, resulting in a significantly higher SF_0 (Brown, Morris, Hollien, & Howell 1991; Harnsberger et al., 2008; Hollien & Shipp, 1972; Mysak, 1959).

Hollien and Jackson (1973) investigated SF_0 in 157 male university students between the ages of 17.9 and 25.8 years. All participants spoke a Southern American dialect of English. The tasks included reading the passage “Apology for Idlers” by R. L. Stevenson, which takes approximately 3 minutes to read, and a 3-minute spontaneous speech sample about “What I Like to do Most on Vacation,” “The Most Interesting Thing That Has Ever Happened to Me,” “My Favorite Sport,” or “What I Like Best About My Program of Study.” The mean SF_0 for all the participants was 129.4 Hz for the reading passage and 123.3 Hz for the spontaneous speech sample.

Hollien and Shipp (1972) documented SF_0 in 175 men aged from 20 to 89 years. The participants were divided into 7 age groups of 25 men each between the ages of 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89 years. The participants were recorded reading the first paragraph of the "Rainbow Passage." The 7 age groups exhibited mean SF_0s of 120, 112, 107, 118, 112, 132, and 146 Hz, respectively. The 30-year-old men had a significantly lower mean SF_0 than the 20-year-old men, and the 50-, 70-, and 80-year-old men each had significantly higher mean SF_0s than the age group adjacently younger. These data suggest that the SF_0 of men decreases gradually until the age of approximately 40 years, and then increases gradually with age.

Mysak (1959) analyzed the SF_0 of older men. Participants included 12 men between the ages of 65 and 79 years and 12 men between the ages of 80 and 92 years. Recordings were made of each participant reading the first paragraph of the "Rainbow Passage" and providing a spontaneous conversational speech sample about the stimulus topic "What I like to do most in the summertime." For the "Rainbow Passage," Mysak found mean SF_0s of 124.3 Hz for the group of men between 65 and 79 years old and 141.0 Hz for the group of men between 80 and 92 years old. For the continuous speech sample, SF_0s of 120.2 and 136.5 Hz for the two groups were found. The difference between the two groups was significant.

Harnsberger et al. (2008) examined the voices of younger and older men. Sixteen older men ranging in age from 74 to 88 years and 14 younger men ranging in age from 21 to 29 years were recorded reading the "Rainbow Passage." Analysis of the recordings of the second sentence of the passage revealed that the older men had a mean SF_0 of 144 Hz, which was significantly higher than the SF_0 of 107 Hz demonstrated by the younger men. The results of the study by Harnsberger et al. are consistent with the results from Hollien and Shipp (1972) and Mysak (1959), which also suggested that SF_0 in men increases with age. Hollien and Shipp speculate that the higher SF_0 observed in older men is the effect of changes in vocal-fold mass. Gradual change in vocal-fold mass may be a result of wear from years of phonation. Specifically, they speculate that the increase in SF_0 is a result of typical physiologic aging, such as muscle atrophy, lowered vocal-fold thickness, or increased vocal-fold stiffness.

Not all studies confirm the increase in SF_0 observed in older men, however. Brown et al. (1991) examined SF_0 in 45 men in three age groups: 20-35, 40-55, and 65-85 years. The participants were recorded reading the first paragraph of the "Rainbow Passage." The three age groups had mean SF_0s of 118, 100, and 127 Hz. Although the older men had higher SF_0 values than the young men, the difference in SF_0 was not significant across the age groups.

Higgins and Saxman (1991) studied SF_0 in 10 men between the ages of 20 and 31 years and 10 men older than 69 years. They measured SF_0 from the sustained vowel /æ/, and found that the younger men had a mean SF_0 of 121.99 Hz, and the older men had a mean SF_0 of 132.02 Hz. Although the older men had a higher SF_0 than the young men, the difference between the young and older men was not statistically significant. This outcome is similar to that of Brown et al. (1991), who did not find a statistically significant age-related difference between older and younger men.

The effect of singing training on SF_0. Professional singing training may alter the normal age-related changes in SF_0. Studies have not found a significant age-related difference in the SF_0 of professional singers comparable to the difference observed between the SF_0s of younger and older nonsingers. Brown et al. (1991) compared SF_0 in 60 professional singers and 94 nonsingers in three different age groups: 20-35, 40-55, and 65-85 years of age. The professional singers were further divided into the groups soprano, alto, tenor, and baritone/bass. Ten females and 10 males were included in each age group of professional singers. Fifteen participants were included in each age group of male nonsingers. There were 20 participants included in the younger age group of the female nonsingers, 10 participants in the middle-aged group, and 19 participants in the older group. The participants were recorded reading the first paragraph of the "Rainbow Passage." The sopranos had mean SF_0s of 224, 218, and 214 Hz, and the altos had mean SF_0s of 206, 191, and 188 Hz in the younger, middle-aged, and older groups, respectively. The female nonsingers exhibited mean SF_0s of 192, 195, and 175 Hz in the three age groups. The tenors had mean SF_0s of 137, 138, and 136 Hz, and the baritones/basses had mean SF_0s of 126, 119, and 121 Hz in the three age groups. The male nonsingers had mean SF_0s of 118, 100, and 127 Hz in the three age groups. Sopranos and tenors had significantly higher SF_0 levels than their nonsinger counterparts, except in the case of the older males. Interestingly, altos and baritones/basses also tended to have a higher SF_0 than their nonsinger counterparts, but this difference was only significant for the middle-aged males. Consistent with previous research documenting lowered SF_0 in older women, the older female nonsingers had significantly lower SF_0 levels than the younger female nonsinger groups, and the elderly male nonsingers had higher SF_0 levels than the younger male nonsinger groups. However, there was no significant age-related difference in SF_0 for either the male or female professional singers. The results of this study suggest that professional singing training may minimize the normal age-related changes in SF_0.

Morris, Brown, Hicks, and Howell (1995) examined the vocal characteristics of both male nonsingers and male professional singers. All the participants were divided into 3 groups according to age, and the singers were further grouped according to whether they were tenor or bass/baritone. Young participants between the ages of 20 and 35 years included 18 nonsingers, 5 tenors, and 9 bass/baritones. Middle-aged participants between the ages of 40 and 55 years included 14 nonsingers, 5 tenors, and 6 bass/baritones. Older participants over the age of 65 years included 18 nonsingers, 5 tenors, and 4 bass/baritones. Each participant read the first paragraph of the "Rainbow Passage." There was no significant difference between the mean SF_0s of the young singers and nonsingers. However, the mean SF_0s of the middle-aged and elderly singers were significantly higher than their nonsinger counterparts. Additionally, the mean SF_0 of the middle-aged nonsingers was significantly lower than the mean SF_0s of the young or elderly nonsingers. The mean SF_0s of the tenors did not differ significantly among the age groups, but the mean SF_0 of the young bass/baritones was significantly lower than the middle-aged or elderly bass/baritones. These results are consistent with the results from Brown et al. (1991), which showed that professional singers do not experience normal age-related changes in SF_0. The authors speculate that professional singing training may disrupt normal age-related changes in the voice by conditioning and maintaining the laryngeal musculature.

Two studies have found no significant difference in SF_0 between groups of younger and older professional singers (Brown et al., 1991; Morris et al., 1995). One exception was the significant difference in SF_0 found between younger and older bass/baritone men, whose SF_0 decreased with age, showing a trend opposite that found in male nonsingers (Morris et al., 1995). It remains unclear why professional singing training appears to affect the normal age-related changes in SF_0. However, it has been speculated that professional singing training maintains and conditions the laryngeal musculature, thus averting age-related changes in the voice (Morris et al., 1995).

The effect of race on SF_0. It has been speculated that physical differences between speakers of different races may result in acoustic differences in vocal characteristics such as SF_0. Supporting this hypothesis, several studies of African-Americans have found low SF_0 values when compared to results of other studies for Caucasians of similar age (Hollien & Malcik, 1962; Hudson & Holbrook, 1982; Wheat & Hudson, 1988; Xue & Mueller, 1996). However, other studies comparing groups of African-American and Caucasian participants have not found a significant difference between these race groups (Andrianopoulos, Darrow, & Chen, 2001; Moran, McCloskey, & Cady, 1995; Morris, 1997; Sapienza, 1997). One study found a significantly higher SF_0 in Chinese speakers of Mandarin (Andrianopoulos et al., 2001). However, it is not clear whether this difference was due to race or dialect, or an interaction of both race and dialect.

Several studies have found lower SF_0s in African-American speakers when compared with values reported for Caucasian speakers in other studies. Wheat and Hudson (1988) measured SF_0 in spontaneous speech in 100 African-American children who were 6 years old. The boys had a mean SF_0 of 219.50 Hz, and the girls had a mean SF_0 of 211.30 Hz. These SF_0 values are lower than for white children in the studies previously cited (Bennett, 1983; Fairbanks, Herbert et al., 1949; Fairbanks, Wiley et al., 1949; McGlone and McGlone, 1972; Sorensen, 1989). In a study with participant groups and procedures similar to those in Curry (1940), Hollien and Malcik (1962) measured adolescent voice change in 18 African-American boys, and also found lower SF_0 values than the Caucasian counterparts in Curry (1940) in all age groups. Hudson and Holbrook (1982) measured SF_0 in spontaneous speech in 200 African-American men and women between the ages of 18 and 29 years. The mean SF_0s of 108.05 Hz for the men and 188.85 Hz for the women are lower than reported values for Caucasian participants of similar age in several other studies (Benjamin, 1986; Brown et al., 1991; Higgins & Saxman, 1991; Hollien & Jackson, 1973; Hollien & Shipp, 1972; Russell et al., 1995; Stoicheff, 1981). Xue and Mueller (1996) found that SF_0 in African-American nursing home residents between the ages of 65 and 94 years were lower than values reported for older Caucasian women (Benjamin, 1986; Higgins & Saxman, 1991; McGlone & Hollien, 1963; Stoicheff, 1981; Russell et al., 1995). However, it should be noted that Hudson and Holbrook, Wheat and Hudson (1988), and Xue and Mueller (1996) measured SF_0 from spontaneous speech, whereas many of the comparable studies cited with Caucasian participants measured SF_0 from other tasks, such as reading passages and sustained vowels.

Although these studies suggest that African-American speakers may have a lower overall SF_0 than Caucasian speakers, several other studies comparing groups of African-American and Caucasian participants within the same study have not found a significant difference between these race groups (Andrianopoulos et al., 2001; Moran et al., 1995; Morris, 1997; Sapienza, 1997). One study (Morris, 1997) found no significant difference in SF_0 measured from a reading passage between 45 African-American boys and 45 Caucasian boys between 8 and 10 years old. Sapienza (1997) measured SF_0 from sustained vowels in 20 African-American adults and 20 Caucasian adults between the ages of 18 and 28 years. The African-American and Caucasian men had mean SF_0s of 123.95 and 124.53 Hz, and the African-American and Caucasian women had mean SF_0s of 223.10 and 214.90 Hz. There was no significant difference in SF_0 between the race groups. Moran et al. (1995) examined acoustic characteristics of the voices of African-American and Caucasian men between the ages of 65 and 86 years. SF_0 as measured from the first paragraph of the "Rainbow Passage" was 117 Hz for the African-American men and 121 Hz for the Caucasian men. The difference in SF_0 between the races was not found to be statistically significant. The results of these studies suggest that the SF_0s of African-American and Caucasian speakers may not be significantly different.

One study compared the SF_0 of 4 different cultural groups (Andrianopoulos et al., 2001). The 4 groups were comprised of Caucasian and African-American speakers of standard American English, native Indian speakers of Hindi, and native speakers of Mandarin Chinese.

Acoustic measures were taken from the sustained vowels /a/, /i/, and /u/ produced by all the participants. Analysis of the results indicated that the SF_0 values of both the Chinese women and Chinese men were statistically significantly higher than the SF_0 values of the other groups. The results of this study suggest that race or dialect may affect SF_0 when measured from sustained vowels. However, it is not clear from these results whether race, dialect, or both race and dialect affect SF_0, or whether race or dialect affect SF_0 when measured from other types of speaking samples, such as reading or spontaneous speech. Nevertheless, the research cited comparing groups of African-American and Caucasian participants within the same study has not found a significant difference between African-American and Caucasian speakers (Andrianopoulos et al., 2001; Moran et al., 1995; Morris, 1997; Sapienza, 1997).

Intrasubject variation in SF_0 over time. There is a certain amount of normal variability that occurs in an individual's SF_0 over time. Since pre- and post-treatment measures of SF_0 are commonly compared, normal intrasubject variability in SF_0 over time warrants consideration. Coleman and Markham (1991) studied normal SF_0 variation in a group of 11 female graduate students and a group of 6 newscasters (two female, four male) from national and local television broadcasts. The newscasters were chosen to represent speakers with trained speaking voices. The graduate students were recorded at least every 3 days for 30 days, and the newscasters were recorded at least 6 times over a period of 2 weeks. The study also examined recordings of the sermons of a televised minister over a period of 7 years, and recordings of a male folk story teller over a period of 10 years. The graduate students were recorded reading the second paragraph of the "Rainbow Passage," and results indicated that the average change in SF_0 over the 30-day period was 2.74 semitones, with a maximum variation of 4.26 semitones, and a minimum of 1.54 semitones. Analysis of two-minute samples from the broadcasts of the newscasters revealed an average SF_0 variation over two weeks of 2.63 semitones, with a maximum of 3.2 semitones, and a minimum of 1.4 semitones. Analysis of two-minute samples from the sermons of the televised minister over 7 years revealed a total SF_0 range of 6.84 semitones, with a small standard deviation of 1.83 semitones. Analysis of two-minute samples from recordings of the story teller revealed an SF_0 range of 8.45 semitones, with a standard deviation of 2.75 semitones. The authors interpret these data to suggest that speakers can be expected to exhibit an SF_0 within 3 semitones of their true SF_0 in a sample 90% of the time.

Intrasubject variation in SF_0 between dialects. Bilingual speakers sometimes shift SF_0 between languages, suggesting that dialect may influence SF_0. Altenberg and Ferrand (2006) examined SF_0 in monolingual and bilingual women. Participants were composed of 3 groups: 10 monolingual female speakers of English between the ages of 19 and 24 years, 9 bilingual female speakers of English and Russian between the ages of 18 and 21 years, and 9 bilingual female speakers of English and Cantonese between the ages of 18 and 24 years. Eight of the 9 bilingual speakers of English and Russian considered Russian to be their native language, and 3 of the bilingual speakers of English and Cantonese considered both languages to be their native languages, while the remaining 6 considered English their native language. All the speakers of English and Cantonese felt more competent in English. All participants were recorded speaking spontaneously about their summer vacation in both languages in randomized order. The bilingual speakers of English and Russian had mean SF_0s of 208.20 Hz in Russian and 190.12 Hz in English. Their mean SF_0 in Russian was significantly higher than in English. The bilingual speakers of English and Cantonese had mean SF_0s of 174.79 Hz in Cantonese and 182.31 Hz in English. No significant difference was found between their mean SF_0s in English and Cantonese. There was no significant difference among the SF_0s of the three groups in English. It is important to note that, unlike the speakers of English and Russian, the speakers of English and Cantonese all felt more comfortable in English than Cantonese. This may have caused the lack of a significant difference between languages, since it is possible that the SF_0 of a dominant language may influence the SF_0 used in a language in which the speaker is less proficient. Regardless, the significant difference found between languages in the speakers of English and Russian suggests that SF_0 can be influenced by dialect.

Hanley (1951) examined the effect of dialect on SF_0 in 27 men. Nine men spoke a General American dialect, 11 spoke a Southern American dialect, and 7 spoke an Eastern American dialect. The participants were recorded reading the first paragraph of the “Rainbow Passage” and producing a two-minute speech about either “My favorite sport” or “My hobby.” The first sentence of the “Rainbow Passage” was not included in the analysis, and only the middle portion of the spontaneous speech sample was analyzed. The General American group had mean SF_0s of 119.4 Hz for the reading and 111.4 Hz for the spontaneous speech. The Southern American group had 134.6 and 136.2 Hz, and the Eastern American group had 122.2 and 117.2 Hz for the reading and spontaneous speech, respectively. The mean SF_0 of the Southern American group was higher than the SF_0s of the General American or Eastern American groups, but the difference was only significant when measured from spontaneous speech. This study, as well as the study by Altenberg and Ferrand (2006), suggests that SF_0 may sometimes be influenced by dialect.

SF_0 in the pathologic voice. Abnormally low or high SF_0 is associated with various vocal pathologies. In one of the largest collections of data on voice pathologies available, Hirano (1989) studied acoustic characteristics of the voices of 40 normal adults and 1,563 adult voice patients at the Department of Otolaryngology and Head and Neck Surgery, Kurume University

Hospital, Japan. SF_0 was measured from sustained phonation for a comfortable length of time, usually 2-5 seconds. Pathologies included acute laryngitis, chronic laryngitis, subepithelial bleeding, vocal-fold nodule, vocal-fold polyp, Reinke's edema, sulcus vocalis, vocal-fold cyst, granuloma, papilloma, epithelial hyperplasia, glottic carcinoma T1a, glottic carcinoma T1b, glottic carcinoma T2, glottic carcinoma T3 and T4, supraglottic carcinoma, unilateral vocal-fold paralysis, bilateral vocal-fold paralysis, laryngeal trauma, hyperfunctional dysphonia, hypofunctional dysphonia, and mutational dysphonia. Results indicated that SF_0 was significantly higher for the male participants with glottic carcinoma, supraglottic carcinoma, sulcus dysphonia and mutational dysphonia. The increases in SF_0 associated with sulcus dysphonia and the carcinomas may be due to increased stiffness of the vocal fold cover. Mutational dysphonia caused a high SF_0 because these participants phonated in falsetto. SF_0 was significantly lower for male participants with acute laryngitis and Reinke's edema. This decrease in SF_0 associated with acute laryngitis and Reinke's edema may be due to increased mass and decreased stiffness of the vocal fold cover. SF_0 was significantly lower for female participants with nodules, granuloma, supraglottic carcinoma, unilateral vocal-fold paralysis, acute and chronic laryngitis, polyp, Reinke's edema, sulcus vocalis, cyst, bilateral vocal-fold paralysis, and hyper- and hypofunctional dysphonia. The authors indicated that the decrease in SF_0 for the female pathological voice samples may be explained by the fact that typical Japanese women tend to use a head voice at a relatively high pitch, which would be difficult to achieve with most vocal pathologies. The highest physiological tone, F_0 range of phonation, SPL for the loudest tone, and SPL range of phonation were also found to be significantly low in many of the disease groups. However, SF_0 and lowest physiological tone increased significantly after surgery in the participants with Reinke's edema. In participants with carcinoma, hemilaryngectomy caused a decrease in both SF_0 and the highest physiological tone. In light of the results of this study, the authors recommend measuring SF_0 in order to assess the severity of disorders and the effects of treatments.

Murry and Doherty (1980) analyzed the vocal acoustic characteristics of 5 normal men between the ages of 55 and 71 years and 5 men with laryngeal cancer between the ages of 61 and 69 years, in order to determine whether or not acoustic measurements could be used to clinically differentiate between speakers with no pathology and speakers with laryngeal cancer. Each participant sustained the vowel /a/ for at least 2 seconds and read the "Rainbow Passage." Analysis of the recordings of the third sentence of the passage revealed a mean SF_0 of 122.9 Hz for the normal men and a mean SF_0 of 113.8 Hz for the men with laryngeal cancer. Analysis of the sustained vowel /a/ revealed an SF_0 of 115.3 Hz for the normal men and an SF_0 of 112.0 Hz for the men with cancer. The difference was significant between mean SF_0 in the normal and laryngeal cancer participants when calculated from the sentence, but the difference was not significant between the mean SF_0s of the sustained vowels. These results suggest that laryngeal cancer is associated with lowered SF_0 in men.

However, not all research confirms the connection between altered SF_0 and vocal pathology. Murry (1978) investigated the relationship between pathologic and normal SF_0 in 80 male participants between the ages of 28 and 77 years. The participants included 20 males with vocal-fold paralysis for over a year, 20 with benign mass lesions, 20 with laryngeal cancer, and 20 with no vocal pathology. The vocal fold paralysis included unilateral paralysis due to trauma, postcarotid endarterectomy, neurological disease, and nonspecific causes. The benign mass lesions included vocal nodules, vocal polyps, contact ulcers, and granuloma. The laryngeal cancer included glottal cancer confined to the vocal folds, glottal cancer requiring total laryngectomy of the vocal folds and surrounding area, and supraglottal cancer. All participants read the first paragraph of the "Rainbow Passage" and the third sentence was used to measure SF_0. The groups with vocal-fold paralysis, benign mass lesions, laryngeal cancer, and the normal control group had mean SF_0 values of 127, 133, 133, and 122 Hz. Although both SF_0 range in semitones and standard deviation of SF_0 were lower in the participants with paralysis than in the normal participants, no significant differences in SF_0 were found between the normal participants and the three groups of participants with vocal pathology, suggesting that vocal paralysis, benign mass lesions, and laryngeal cancer may not result in an altered SF_0.

Summary. This review has cited research documenting that normal SF_0 levels are approximately 220 to 300 Hz in children, 224 Hz in women, and 128 Hz in men (Aronson, 1980; Fairbanks, Herbert et al., 1949; Fairbanks, Wiley et al., 1949; Russell et al., 1995; Sorensen, 1989; Stoicheff, 1981). The SF_0 of girls and boys decreases to adult levels at puberty. Duffy (1970) found that a significant drop in SF_0 accompanied menarche in female adolescents. Similarly, adolescent males show a rapid decrease in SF_0 associated with puberty (Harries et al., 1998; Hollien et al., 1994). In adult women SF_0 remains relatively stable until it decreases at menopause (Stoicheff, 1981). The drop in SF_0 accompanying menopause may be related to physiological changes in the larynx associated with menopause observed by Abitbol et al. (1999). In men, SF_0 increases gradually with age (Brown et al., 1991; Harnsberger et al., 2008; Hollien & Shipp, 1972; Mysak, 1959). However, the age-related patterns in SF_0 for both men and women may be altered in professional singers (Morris et al., 1995). Other factors may influence SF_0; for example, some normal variability occurs in an individual's SF_0 over time (Coleman & Markham, 1991). Additionally, two studies suggest that dialect may influence SF_0 within an individual speaker (Altenberg & Ferrand, 2006; Hanley, 1951), although several studies have not found a significant difference in SF_0 based on race (Andrianopoulos, Darrow, & Chen, 2001; Moran, McCloskey, & Cady, 1995; Morris, 1997; Sapienza, 1997). Several studies indicate that SF_0 may be affected by many organic and functional vocal pathologies (Hirano, 1989; Murry & Doherty, 1980).

Measuring Speaking Fundamental Frequency

Prevalence of SF_0 measurement. Surveys indicate that speaking fundamental frequency (SF_0) is one of the most common measures taken by voice specialists, and that it is widely used for monitoring progress in treatment and evaluating the severity of dysphonia. Hirano (1989) conducted a survey to assess the frequency of use and usefulness of various clinical voice evaluation measurements according to voice clinicians throughout the world. The researchers obtained 276 responses from laryngologists, phoniatricians and speech pathologists throughout Europe, Africa, America, Asia, and Oceania. Results of this survey indicated that measurements of F_0 range and SF_0 were taken "frequently" or "always" by about half of the respondents. Overall, 76% of respondents considered measurements of SF_0 to be useful for monitoring change, 57% considered it useful to evaluate the degree of dysphonia, 40% considered it useful for research, 28% considered it useful for diagnosing and evaluating degree of disease, and 22% considered it useful for developing a prognosis. These results indicate that SF_0 is a relatively common measurement taken by voice clinicians and is widely considered clinically useful for clinical and research purposes.

A more recent survey by Behrman (2005) examined how likely American speech-language pathologists would be to use certain diagnostic tools, such as acoustic, aerodynamic and electroglottographic assessments, stroboscopy, and patient self-perception scales, in the case of a patient referred for muscle tension dysphonia. Participants were limited to speech-language pathologists with access to acoustic instrumentation and with at least 3 years of experience conducting stroboscopic examinations or experience reviewing them with an otolaryngologist. Participants were asked to rate the importance of each diagnostic tool in defining the overall therapy goal, defining specific therapy session goals, educating the patient about voice production, helping the patient achieve a target production, providing reinforcement to the patient, and measuring treatment outcome. Seventy-five percent of the 53 respondents reported that they were likely to use acoustic measures, although responses were diverse regarding the importance of acoustic measures for specific purposes. Forty-one of 53 respondents considered acoustic measures important for providing reinforcement to the patient and for treatment outcomes assessment, 23 respondents considered acoustic data important for educating the patient, and 27 respondents considered it important for helping the patient achieve a target production. Results indicated that measures of F_0 are significantly more common than intensity or spectral measures. Ninety-four percent of the respondents commonly measure mean speaking F_0, 77% commonly measure habitual frequency range, and 41% commonly measure physiologic frequency range. The results of this survey indicate that measures of SF_0 are still one of the more common measures taken in a voice evaluation.

The effect of task on SF_0. In spite of the prevalence of SF_0 measurement in voice evaluations, there is little agreement on what task should be used to elicit these measures. Tasks used for eliciting SF_0 vary among voice clinicians and researchers and may include reading a standard phonetically-balanced passage such as Fairbanks' (1960) "Rainbow Passage," obtaining a spontaneous connected speech sample, counting, sustaining a vowel such as /a/, /i/, or /u/, and sustaining a vowel within a phrase. However, studies indicate that different tasks result in significantly different calculated SF_0 values (Baker et al., 2008; Britto & Doyle, 1990; Chen et al., 2009; Fitch, 1990; Horii, 1975; Hudson & Holbrook, 1982; Hunter, 2009; Murry et al., 1995; Mysak, 1959; Ramig & Ringel, 1983; Zraick et al., 2005; Zraick et al., 2000).

In the study by Mysak (1959) mentioned previously, a significant difference was found between SF_0s derived from reading the first paragraph of the "Rainbow Passage" and a continuous speech sample for 2 groups of older men, comprising 12 men aged from 65 to 79 years and 12 men aged from 80 to 92 years. For the standard passage, Mysak found mean SF_0s of 124.3 Hz for the first group and 141.0 Hz for the second group. For the continuous speech sample, he found mean SF_0s of 120.2 and 136.5 Hz for the two groups, which are significantly lower SF_0 values than from the reading sample.

Ramig and Ringel (1983) studied acoustic vocal characteristics of 48 male participants in 3 age groups, including young men between the ages of 26 and 35 years, middle-aged men between the ages of 46 and 56 years, and older men between the ages of 62 and 75 years. Acoustic measures were taken from recordings of each participant reading a standard passage and producing 30 seconds of spontaneous speech from a picture stimulus. For the reading passage, the young men had a mean SF_0 of 121.93 Hz, the middle-aged men had a mean SF_0 of 118.36 Hz, and older men had a mean SF_0 of 125.98 Hz. For the spontaneous speech sample, the young men had a mean SF_0 of 118.30 Hz, the middle-aged men had a mean SF_0 of 111.90 Hz, and older men had a mean SF_0 of 120.61 Hz. Mean SF_0 was significantly higher when derived from reading a passage than when derived from a spontaneous speech sample regardless of age.

Hudson and Holbrook (1982) studied the effect of task on SF_0 in 200 black young adults (100 male, 100 female) between ages 18 and 29 years. Modal F_0 was derived from recordings of the participants reading the "Rainbow Passage," and the middle 40 seconds of a 120-second spontaneous connected speech sample. The modal F_0 of the males averaged was 108 Hz for the spontaneous speech task and 110 Hz for the reading task. The modal F_0 of the females averaged was 189 Hz for the spontaneous speech task and 193 Hz for the reading task. For both sexes, the modal F_0s for spontaneous speech were significantly lower than for reading. These results are consistent with those from Mysak (1959) and Ramig and Ringel (1983).

Schultz-Coulon (1975) examined the effect of task on SF_0 in 10 male trained singers, 14 female trained singers, 24 female healthy nonsingers, 11 male healthy nonsingers, and 20 women and 8 men with hyperfunctional dysphonia. All participants were between the ages of 20 and 55 years. SF_0 was measured by obtaining reading, counting, and spontaneous speech samples. The men from all three groups had mean SF_0 values of 117 Hz for the reading, 110 Hz for the counting, and 107 Hz for the spontaneous speech. The women from all three groups had mean SF_0 values of 208 Hz for the reading, 198 Hz for the counting, and 191 Hz for the spontaneous speech. Similar to the results of Mysak (1959), Ramig and Ringel (1983), and Hudson and Holbrook (1982), the results indicated that SF_0 was significantly higher when measured from reading than from counting or spontaneous speech.

Not all studies indicate significant differences between spontaneous speech and reading samples, but many indicate significantly higher values associated with sustained phonation (Britto & Doyle, 1990; Fitch, 1990; Murry et al., 1995; Sorensen, 1989; Zraick et al., 2000). Zraick et al. (2000) examined the effect of task on SF_0 in 12 adult premenopausal females between the ages of 19 and 48 years, 12 adult males between the ages of 20 and 50 years, and 12 male and female children between the ages of 5 and 10 years. The SF_0 of each participant was calculated from each of the following tasks at a “comfortable” pitch and loudness: (1) counting from 1 to 10, (2) reading 10 seconds of the "Grandfather Passage,” (3) producing spontaneous speech for 10 seconds, (4) sustaining the vowel /a/for 8 seconds, (5) producing the utterance "um-hum" with a closed mouth, as if he or she were agreeing with someone, (6) sustaining the vowel /i/ for 1 second after counting from 1 to 3, and (7) producing "uh-huh" with an open mouth. Seven participants (2 adult females, 2 adult males, and 3 children) were immediately retested, and within-subject reliability was found to be high for all tasks. There was no significant difference among tasks for the children and men participants, but there was a significant difference among tasks for the women. For each of the 7 tasks, the 12 children exhibited mean SF_0s of 215.21, 228.45, 224.31, 224.59, 226.19, 224.32, and 214.64 Hz. The 12 men had mean SF_0s of 121.05, 135.97, 127.76, 124.02, 127.29, 120.79, and 121.41 Hz, and the women had mean SF_0s of 186.78, 192.26, 187.64, 201.30, 199.55, 205.47, and 187.11 Hz for the 7 tasks, respectively. For the women, the SF_0 from the sustained /i/ after counting from 1 to 3 were significantly higher than from counting from 1 to 10, reading the "Grandfather Passage," spontaneous speech, and producing "uh-huh." Producing "um-hum" resulted in a significantly higher SF_0 than counting from 1 to 10 and spontaneous speech. Also, the SF_0 from sustaining the vowel /a/ was significantly higher than from spontaneous speech. The results of this study suggest that many of the tasks used for eliciting SF_0 may result in significantly different values for women.

Murry et al. (1995) examined the variability in SF_0 associated with task type in two age groups of normal male and female speakers and a group with vocal-fold paralysis. In this study, younger (20-35 yrs) and older (59-73 yrs) normal men and women sustained the vowel /a/ for 10 seconds, read the first paragraph of the "Rainbow Passage," and spoke spontaneously for 30 seconds with picture prompts in the morning, early afternoon, and late afternoon on three different days. The 9 younger male participants demonstrated a mean SF_0 of 123 Hz for the sustained vowel, 137 Hz for the reading sample, and 136 Hz for the speech sample. The 6 older male participants demonstrated mean SF_0s of 142 Hz , 139 Hz , and 134 Hz for the 3 tasks, respectively. The 10 younger female participants demonstrated mean SF_0s of 209, 195, and 189 Hz, for the sustained vowel, reading, and speech samples, while the 7 older female participants demonstrated mean SF_0s of 189, 170, and 175 Hz for the 3 tasks, respectively. The younger males' sustained phonation sample was significantly lower than their reading or spontaneous samples, but the younger and older females and older males produced sustained phonation with a higher SF_0 than they did during the reading or spontaneous samples. However, the sustained vowel was significantly higher only in the case of the older females. The vocal-fold-paralysis group in the study by Murry et al. (1995) produced a sustained vowel /a/ and read the first paragraph of the "Rainbow Passage" twice on the same day. Seven women with vocal-fold paralysis demonstrated higher mean SF_0s for the sustained vowel than for the speech sample "of a long round arch" from within the reading passage. The difference between the sustained vowel and speech samples for the women with vocal-fold paralysis was greater than for the normal older women. The women with paralysis had mean SF_0s of 219.9 and 211.6 Hz for the sustained vowel from both sample times, and 183.5 and 181.3 Hz for the speech sample from both sample times. These results indicate greater within-day sampling variability in mean SF_0 for sustained vowels than for connected speech, as well as different results from the different task types for both the normal and pathologic participants. In the groups examined in this study, variability in sample type was found to be greater than the variability associated with repeated sampling of the same sample type.

Britto and Doyle (1990) found similar results to Murry et al. (1995). The SF_0s of 20 males and 20 females between 20 and 30 years of age were calculated from 1 minute samples of spontaneous conversational speech, reading the "Rainbow Passage," and sustained phonation of

/a/ following “one, two, three.” The men produced mean SF_0s of 115.9, 114.6, and 124.4 Hz, and the women produced mean SF_0s of 199.0, 198.6, and 218.4 Hz for the spontaneous speech sample, reading sample, and sustained phonation, respectively. For both men and women, SF_0 was lowest when calculated from the reading sample, and highest when calculated from a sustained vowel. SF_0 was greater when calculated from the sustained vowel, but the difference between SF_0 obtained from the reading sample and from the conversational speech sample was not significant. Similarly to the study mentioned earlier by Brown et al. (1991) which compared female professional singers and nonsingers, no significant difference was found between the SF_0 values calculated for the reading and spontaneous samples .

Fitch (1990) used three different tasks to measure SF_0 in 6 men and 6 women between 21 and 26 years of age. The tasks included reading the middle 4 sentences of the first paragraph of the “Rainbow Passage,” producing a 3-minute spontaneous speech sample, and sustaining the vowels /i/, /u/, /a/, and /æ/. The questions “What do you do when you get home from work/school?” or “What did you do yesterday?” were used to elicit the spontaneous speech sample. All participants were retested using the same procedures 7-10 days after the first test date. The male participants had mean SF_0s of 112.9, 109.1, and 132.6 Hz for the reading, spontaneous speech, and sustained vowels, respectively, and when retested with the same tasks they had mean SF_0s of 112.9, 111.0, and 140.0 Hz. The female participants had mean SF_0s of 206.4, 210.3, and 259.4 Hz for the three tasks, and when retested had mean SF_0s of 210.1, 209.9, and 265.0 Hz. Although there was no significant difference between any of the test-retest SF_0 values, there was a lower test-retest correlation for the sustained vowels than for the reading and spontaneous speech samples. Also, the sustained vowel yielded significantly higher SF_0 values than the reading or spontaneous speech samples. These results are consistent with the studies by

Britto and Doyle (1990), Brown et al. (1991), and Murry et al. (1995), who also found higher SF_0 values for sustained phonation than for reading or spontaneous speech.

Willis and Kenny (2007) studied the effect of task on SF_0 in 20 adolescent girls between the ages of 12.6-13.7 years and 20 adolescent boys between the ages of 12.0-13.7 years. Fifty-five percent of the boys and 60% of the girls included in this study had past singing training. All the participants read the 180-word passage, “Arthur, the Young Rat” and counted backwards from 20 to 1. The boys had a mean SF_0 of 198 Hz for the reading and 189 Hz for the counting task, and the girls had a mean SF_0 of 259 Hz for the reading and 235 Hz for the counting task. For both boys and girls, the SF_0 values for reading were higher than those for counting. This outcome is similar to the outcome of the study by Schultz-Coulon (1975), who found that SF_0 was significantly higher when measured from reading than from counting. However, the difference between tasks was not significant for the boys, whereas it was significant for the girls. These results suggest that counting backwards may result in significantly different SF_0 values than reading a standardized passage in adolescent females, but not in adolescent males.

Baker et al. (2008) found that task type may also affect SF_0 in children. Forty-eight children aged from 5 years, 0 months to 7 years, 11 months were recorded completing 4 tasks: (a) sustaining the vowel /a/ for 5 sec, (b) sustaining the vowel /a/ for 5 sec at the end of the phrase “I need a mo(p)”, (c) repeating the sentence “Bob wants a ball”, and (d) counting from 1 to 10. They found a mean SF_0 of 240.46 Hz for the sustained vowel, a mean SF_0 of 236.55 Hz for the sustained vowel within a phrase, a mean SF_0 of 235.66 Hz for the repeated sentence, and a mean SF_0 of 246.51 Hz for the counting task. The difference in SF_0 among the four tasks was found to be statistically significant. The mean SF_0 derived from the counting task was significantly greater than from the sustained vowel within a phrase and from the repeated sentence task. The authors speculate that the counting task may have resulted in a higher SF_0 because it was not imitative, unlike the other tasks performed in this study.

In the study mentioned earlier by Sorensen (1989), the SF_0 of 30 children between the ages of 6 and 10 years was measured using three tasks. All the children read two pages from a first-grade level reader, produced 30 seconds of spontaneous speech with a picture stimulus, and sustained the vowels /i, ɪ, ɛ, æ, u, ʌ, ɑ/ for about 5 seconds. The boys had mean SF_0 values of 254 Hz for the reading, 242 Hz for the spontaneous speech, and 275, 268, 258, 251, 284, 263, and 258 Hz for each of the sustained vowels. The girls had mean SF_0 values of 275 Hz for the reading, 260 Hz for the spontaneous speech, and 291, 287, 276, 273, 298, 285, and 287 Hz for each of the sustained vowels. For both the male and female children, the SF_0 values from the spontaneous speech were significantly lower than the reading and sustained vowels.

Chen et al. (2009) did not find a significant difference between different tasks in children, although they did find a significant difference between SF_0 measured in traditional structured tasks and in free play, suggesting that the measurements taken in the structured tasks may not be representative of the children's SF_0 in everyday contexts. The SF_0s of 10 preschool children (8 female, 2 male) between the ages of 2 years, 7 months and 5 years, 11 months were measured during free play and traditional structured activities. The structured activities were (1) sustaining the vowel /a/ for 6 seconds at the end of counting to three, (2) sustaining the vowel /i/ for 6 seconds at the end of counting to three, (3) a 2-3 minute spontaneous connected speech sample elicited through story retell following reading of a story book, (4) a 2-3 minute spontaneous connected speech sample about a topic such as the child's favorite movie. For the spontaneous connected speech samples, the middle 60 seconds was used from each sample for analysis. The child was also recorded for 5 minutes during free play with peers. Mean SF_0 for free play was

418 Hz. Mean SF_0 for the sustained phonation tasks were 334 Hz for sustained /a/ and 358 Hz for sustained /i/. Mean SF_0 for the story retell and conversational tasks were 297 and 307 Hz. No significant differences were found among the structured tasks, but SF_0 measured during free play was an average of 94 Hz higher, which was significantly different than SF_0 measured in traditional structured speech activities.

In another recent study, Hunter (2009) evaluated the effect of task type on SF_0 in one male child, age 5 years 7 months. The child performed the same structured tasks used by Baker et al. (2008), and additionally was recorded all day for 4 days. Similar to the results from Chen et al. (2009), no significant differences were found among the structured tasks. However, the SF_0 from the all-day recording of the child's speech for 4 days (376 Hz) was significantly higher than the mean SF_0 from the structured tasks (257.6 Hz). However, the author pointed out that the SF_0 from the unstructured speech was skewed by high-frequency vocalizations such as screams and whining.

The effect of sample length on SF_0. In addition to variance in task type used to calculate SF_0, there is also variance in the length of sample voice clinicians use to calculate SF_0. For example, standardized passages, such as the "Rainbow Passage," are sometimes analyzed in whole or in part. Often only one sentence or phrase is analyzed from the reading of a standardized passage. Spontaneous speech and counting samples used to take acoustic measures obviously may vary in length. Clinicians should therefore be aware of variability associated with sample length.

Horii (1975) examined the effect of sample length on SF_0 and standard deviation of F_0. Ten adults were recorded reading the entire "Rainbow Passage," which comprises 331 words and takes about 2 minutes to read. Each recording was then analyzed in segments of 3.6, 7.2, 14.4, 28.8, 57.6, 72.0, and 90.0 seconds. Results indicated that the standard deviation of SF_0 decreases steadily from 7 Hz to 1 Hz from the sample length of 3.6 seconds to the sample length of about 60 seconds, at which point the decrease in standard deviation slows. A second experiment was performed to assess measurement of SF_0 through samples selected by linguistic unit (i.e., by sentence) instead of number of seconds. In this experiment, 65 adult males between 26 and 79 years of age were recorded reading the first paragraph of the "Rainbow Passage." Analysis of these recordings resulted in a mean SF_0 of 112.5 Hz, a mean standard deviation of 2.41 semitones, and a mean median F_0 of 110.7 Hz. The standard error in estimating SF_0 of the paragraph from the SF_0 of the second sentence was 3.0 Hz, implying that the SF_0 of a whole paragraph can be estimated by the SF_0 of the second sentence within 3.0 Hz two-thirds of the time. Comparison of the first and second experiment indicates that analyzing a sentence within a recording rather than an arbitrary segment of the same duration results in a significantly more accurate estimate of the SF_0 of the entire passage. The difference decreases, however, as sample length increases. These results suggest that if it is necessary to measure SF_0 from only one sentence, it is better to analyze a sentence within a recorded passage rather than an arbitrary selection of the same duration from within a passage. However, the author recommends that measuring SF_0 through single sentences be avoided due to the relatively large standard of error.

Zraick et al. (2005) also studied the effect of sample length on SF_0. Thirty nonsmoking females between 18 and 30 years of age were recorded 3 times counting for 60 seconds at their most comfortable pitch and loudness. The counting task was chosen because of its low linguistic demand and low difficulty. Mean SF_0 was calculated across the 3 trials for each speaker for 5 different time periods within each sample: 0-1, 0-5, 0-15, 0-30, and 0-60 s. The 30 participants had mean SF_0 values of 222.47, 213.51, 212.73, 210.00, and 207.98 Hz for the 5 periods, respectively. It was found that the mean SF_0 for the 1-sec and the 60-sec periods were significantly different from each of the other periods. The authors noted that the differences in SF_0 among time periods may have been caused by frequency changes associated with monosyllabic and polysyllabic numbers. However, the significant difference found between the 30-second sample and the 60-second sample suggests that clinicians should take sample length into account when choosing tasks for eliciting SF_0.

Summary. Acoustic measurement of SF_0 is a common component of voice evaluations, but methods of measuring it vary (Hirano, 1989; Behrman, 2005). The research cited suggests that different assessment methods potentially result in significantly different SF_0 values. Table 1 summarizes studies which evaluate the effect of two or more task types on SF_0. Several studies have found a significant difference between SF_0 measured from reading standard passages such as the "Rainbow Passage" and spontaneous speech samples (Hudson & Holbrook, 1982; Mysak, 1959; Ramig & Ringel, 1983). Other studies have not found a significant difference between reading and spontaneous speech samples, but found a significantly different SF_0 measured from sustained phonation (Britto & Doyle, 1990; Murry et al., 1995; Sorensen, 1989; Zraick et al., 2000). One study found a significant difference among several tasks in women but not in men or children (Zraick et al., 2000). Similarly, Willis and Kenny (2007) found that there was a significant difference between a reading passage and a counting task for female adolescents, but not for male adolescents. Two studies have found that task type may also have an effect on the SF_0 of children (Baker et al., 2008; Sorensen, 1989). In addition, the results of two studies (Horii, 1975; Zraick et al., 2005) have implicated an effect of sample length on SF_0. Clinicians and researchers should be aware of possible differences based on elicitation methods, especially when comparing SF_0 values elicited using different methods.

Table 1. *Summary of studies examining the effect of task type on SF_0*

Study	Participants	Ages[†]	Type of Sample	Mean SF_0[‡]
Mysak (1959)	12 men	65-79	reading passage	124.3*
			spontaneous speech	120.2*
	12 men	80-92	reading passage	141.0*
			spontaneous speech	136.5*
Ramig & Ringel (1983)	48 men	26-35	reading passage	121.9*
			spontaneous speech	118.3*
		46-56	reading passage	118.4*
			spontaneous speech	111.9*
		62-75	reading passage	126.0*
			spontaneous speech	120.6*
Hudson & Holbrook (1982)	100 women	18-29	reading passage	193*
			spontaneous speech	189*
	100 men		reading passage	110*
			spontaneous speech	108*
Schultz-Coulon (1975)	58 women	20-55	reading passage	208*
			counting	198
			spontaneous speech	191
	29 men		reading passage	117*
			counting	110
			spontaneous speech	107
Fitch (1990)	6 women	21-26	reading passage	206.4
			spontaneous speech	210.3
			sustained vowels	259.4
	6 men		reading passage	112.9
			spontaneous speech	109.1
			sustained vowels	132.6
Britto & Doyle (1990)	20 women	20-30	reading passage	198.6
			spontaneous speech	199.0
			sust. /a/ after '1 2 3'	218.4
	20 men		reading passage	114.6
			spontaneous speech	115.9
			sust. /a/ after '1 2 3'	124.4
Murry et al. (1995)	10 women	20-35	reading passage	195
			spontaneous speech	189
			sustained /a/	209
	7 women	59-73	reading passage	170
			spontaneous speech	175
			sustained /a/	189*
	9 men	20-35	reading passage	137
			spontaneous speech	136
			sustained /a/	123*
	6 men	59-73	reading passage	139
			spontaneous speech	134
			sustained /a/	142
	7 women (with paralysis)		reading passage	183.5
			sustained /a/	219.9

Table 1. *Summary of studies examining the effect of task type on SF_0 (cont.)*

Study	**Participants**	**Ages**†	**Type of Sample**	**Mean SF_0**‡
Zraick et al. (2000)	12 women	19-48	counting 1-10	186.8
			reading passage	192.3
			spontaneous speech	187.6
			sustained /a/	201.3
			"um-hum"	199.6
			sust. /i/ after '1 2 3'	205.5*
			"uh-huh"	187.1
	12 men	20-50	counting 1-10	121.0
			reading passage	136.0
			spontaneous speech	127.8
			sustained /a/	124.0
			"um-hum"	127.3
			sust. /i/ after '1 2 3'	120.8
			"uh-huh"	121.4
	12 children	5-10	counting 1-10	215.2
			reading passage	228.5
			spontaneous speech	224.3
			sustained /a/	224.6
			"um-hum"	226.2
			sust. /i/ after '1 2 3'	224.3
			"uh-huh"	214.6
Willis & Kenny (2007)	20 girls	12-13	reading passage	259*
			counting backwards	235*
	20 boys		reading passage	198
			counting backwards	189
Baker et al. (2008)	48 children	5-7	sustained /a/	240.5
			sust. /a/ after phrase	236.6
			repeated sentence	235.7
			counting 1-10	246.5*
Hunter (2009)	1 boy	5	sustained /a/	263.4
			sust. /a/ after phrase	260.1
			repeated sentence	252.0
			counting 1-10	241.7
Sorensen (1989)	15 girls	6-10	reading passage	275
			spontaneous speech	260*
			sustained vowels	285
	15 boys		reading passage	254
			spontaneous speech	242*
			sustained vowels	265

* SF_0 of task is significantly different than the SF_0 values of at least 50% of the other tasks measured in the participant group.
† in years
‡ in Hertz

The Concept of Optimal Pitch

Literature concerning voice treatment often speaks of "optimal," "optimum," "natural," or "best" pitch. The more recent term "vocal efficiency" is also related to the concept of optimal pitch (Titze, 1992). Fairbanks (1940, p. 166) proposed that every person has a "natural pitch level" most efficient for speaking, and that this efficient pitch level is determined by the physical characteristics of the individual's speech mechanism.

Boone (1971) defined optimal pitch as a pitch level or range of pitches that can be produced efficiently with the least energy or effort by the muscles of the larynx. He speculates that optimal pitch is therefore directly dependent on the natural length and mass of the thyroarytenoid muscle. Nevertheless, the concept of optimal pitch has been seriously questioned (Minifie, 1983).

It was historically thought that using an SF_0 that is higher or lower than optimal pitch may cause or contribute to some vocal pathologies. Supporting this idea, research by Cooper (1974) suggests that targeting pitch in therapy may be effective for treating most types of dysphonia. A total of 155 voice patients were evaluated for SF_0 and hoarseness before and after vocal rehabilitation. The participants included 152 adults between the ages of 15 and 73 years, and 3 male children between the ages of 11 and 13 years. All participants exhibited a variety of functional and organic dysphonias, including nodules, contact ulcer, polyps, polypoid degeneration, keratosis, leukoplakia, bowed vocal folds, paralytic dysphonia, ventricular phonation, spastic dysphonia, incipient spastic dysphonia, hysterical dysphonia, falsetto, and functional misphonia. All participants received vocal rehabilitation that focused on direct adjustment of pitch to an optimal pitch level. All 155 participants were recorded counting to 10 (only "one two three" was analyzed), and the first 27 patients were additionally recorded reading the “Rainbow Passage,” phonating the vowels /i/, /a/, and /u/ for 1-3 seconds 3 times each, saying the phrase “My name is _____” 3 times, and saying “um-hum” 3 times. Only the phrase “The rainbow is a division of white light” was analyzed from the reading passage. The “um-hum” task was only performed pretreatment and was used to identify each individual’s optimal pitch. Results indicated that 150 of the 155 participants demonstrated a pretreatment SF_0 lower than their measured optimal pitch, and that the 27 participants all had hoarseness to varying degrees. After therapy directly addressing optimal pitch, 128 participants were re-evaluated for hoarseness 3 months to 7 years after rehabilitation and were rated either excellent, good, or fair on the following variables: pain, discomfort, or irritation during and after speaking; automaticity of correct pitch, tone focus, quality, volume, breath support, and rate; inflammation or lesions on vocal folds; and approximation of vocal folds during phonation. Ninety-eight percent of the 128 participants re-evaluated remained excellent or good. Because of the good results of therapy, the author concluded that inappropriate pitch is a major contributing factor in most types of dysphonia and that optimal pitch as estimated using the “um-hum” technique is an effective therapy target.

However, many believe it is misleading to consider inappropriate pitch as the major contributing factor in most types of dysphonia, because many patients with vocal pathologies exhibit an SF_0 comparable to normal speakers without vocal pathology (Mueller, 1975). A study by Roy and Hendarto (2005) suggests that directly addressing SF_0 in therapy may not be necessary to improve voice in patients with functional dysphonia (FD), even when successful treatment resulted in a shift in SF_0. In this study, 40 women diagnosed with FD between 26 and 79 years of age were treated successfully in a single therapy session with manual circumlaryngeal techniques, which do not directly address inappropriate pitch. Participants were recorded reading the first paragraph of the "Rainbow Passage" before and after the session, and the middle portion of the paragraph was used to measure SF_0. There was no significant difference between pretreatment and posttreatment SF_0. However, half of the participants demonstrated a reduction in SF_0 after treatment, and half demonstrated an elevation in SF_0 after successful treatment. Also, 80% of the participants demonstrated a change in SF_0 greater than one semitone. The authors point out that it is possible that some patients may benefit from targeting SF_0, but for most participants in their study, the change in SF_0 that occurred after treatment could not have been easily predicted from the pretreatment data.

Hufnagle and Hufnagle (1984) performed a study to determine whether or not there is a significant change in SF_0 when a voice with dysphonia improves in vocal quality. Participants included 8 female clients between 18 and 26 years of age with dysphonia associated with vocal nodules. SF_0 was elicited before and after therapy by having the participants read the "Rainbow Passage." Therapy comprised advising the patient of factors that contribute to a voice disorder, recommending a period of soft whisper to reduce vocal abuse, and implementing procedures that facilitate proper muscular balance. Results indicated that, although vocal quality significantly improved, SF_0 did not differ significantly after therapy. The authors suggest these results indicate that dysphonia associated with vocal nodules may be best managed by methods other than manipulating pitch. Their conclusion is similar to the conclusion reached by Roy and Hendarto (2005), who suggested that in most cases targeting SF_0 is not necessary to treat FD.

Although many clinicians assume that using an SF_0 different from optimal pitch may cause or contribute to vocal pathology, the results of the research cited are inconclusive. Cooper (1974) found that optimal pitch seemed to be an effective treatment target for patients with a variety of functional and organic dysphonias. On the other hand, the study by Roy and Hendarto

(2005) suggested that optimal pitch may not be an effective treatment target, since change in SF_0 that occurred with treatment in their study was not predictable from the pretreatment data. Similarly, Hufnagle and Hufnagle (1984) found that change in SF_0 was not necessary to improve vocal quality in patients with dysphonia associated with vocal nodules.

Estimating Optimal Pitch

Several methods have been used to identify an individual's optimal pitch. Fairbanks (1960) recommends calculating optimal pitch by taking the frequency 25% of the way from the bottom of the frequency range including falsetto. Hahn, Lomas, Hargis, and Vandraegen (1957) suggest using the frequency one-third of the way from the bottom of the frequency range excluding falsetto. Boone (1971) suggests that optimal pitch may be identified by asking the patient to yawn and then sigh, or to produce the utterance "uh-huh," as if he or she were agreeing with someone. Similarly, Cooper (1974) recommends finding optimal pitch by asking the patient to say "um-hum."

In a well-known study, Pronovost (1942) promoted the 25-percent method for estimating optimal pitch. Ten common clinical methods for determining optimal pitch were evaluated by comparing the derived frequencies to the actual SF_0 used by 6 adult males judged to have "superior" voices. The SF_0 was measured as the median F_0 from reading the first paragraph of the "Rainbow Passage" as if "to an audience of 25 people". The first and last sentences of the passage were excluded for analysis. The normal F_0 range and the F_0 ranges including falsetto were also measured. The median pitch level for the group was 132.1 Hz. Assuming that the SF_0 used by the participants, who were judged to have "superior" voices, would approximate their true optimal pitch, Pronovost compared the median F_0 used by the participants with the optimal pitch levels calculated by 10 clinical methods for estimating optimal pitch. According to the findings, the following 5 methods were considered to be more accurate and reliable than the other methods for estimating optimal pitch: (a) the 25 percent method, which estimates optimal pitch at the 25-percent point of the F_0 range in semitones including falsetto, (b) the 33 percent method, which estimates optimal pitch at the 33-percent point of the F_0 range excluding falsetto, (c) the 38-percent method, which estimates optimal pitch at the 38-percent point of the F_0 range excluding falsetto, (d) the two tones below the middle tone method, which estimates optimal pitch at two tones below the median note of the F_0 range excluding falsetto, and (e) the five tones method, estimating optimal pitch at five tones above the lowest tone of the F_0 range. These methods were judged by the author to be accurate estimates of optimal pitch because the optimal pitches determined by these methods deviated from the measured median pitch of the participants by less than one tone on average. According to the results of this study the following 5 methods were considered less accurate: (a) the 3.5 tones method, (b) the 8.5 tones method, (c) the 15.5 tones method, (d) the vocalized sigh method, in which the person is instructed to sigh and phonate after taking a deep breath, and (e) the sustained vowel method. Of the methods which were considered most accurate, Pronovost suggested using the 25-percent method since it was the most convenient to use.

However, traditional methods for estimating optimal pitch may not be valid. Britto and Doyle (1990) compared optimal pitch, using Pronovost's 25% method, to the SF_0s used by 20 males and 20 females between 20 and 30 years of age. The SF_0 was calculated from 1 minute of spontaneous conversational speech, reading the "Rainbow Passage," and sustained phonation of /a/ following "one, two, three." The phonational range was also determined by eliciting five sustained phonations of /a/ at lowest F_0 level without vocal fry, and also at the highest F_0 level including falsetto. Results indicated that the participants' SF_0 was between 8- and 10-percent up the phonational range, which is significantly different from the optimal pitch derived using the 25% method. The mean derived optimal pitch was 151.9 Hz for the men, and 250.6 Hz for the women. The SF_0s of the participants were significantly lower than the optimal pitch derived by the 25-percent method recommended by Pronovost (1942), but this may be due to some difficulties in the data collection of this study. Eight speakers (2 male, 6 female) produced a lowest F_0 that was greater than the SF_0 measured by one or more of the three tasks. Although the authors omitted the data from these speakers, it suggests that the phonational ranges calculated in this study should be interpreted with caution. The authors mention that the phonational ranges measured in this study were somewhat smaller than those reported in previous research, and that some of the participants had difficulty with the task used to measure the frequency range.

A study by Linke (1973) attempted to find a relationship between SF_0 levels with perceived vocal effectiveness in 27 young adult female university students. He reasoned that participants who spoke with optimal pitch should be perceived as being more generally effective users of their voice than those who did not use an optimal pitch. The participants were recorded reading a 55-word passage “as if to an audience of 25 persons” (p. 176). A group of 30 graduate students and instructors in speech and speech pathology rated each recording for general vocal effectiveness relative to each other on a scale from 1 to 9. Analysis of the recordings showed that the participants had a mean SF_0 of 201.0 Hz, which was at the 20.5-percent point of the F_0 range in semitones. No significant correlation was found between SF_0 and ratings of general vocal effectiveness. This outcome suggests that SF_0 may not be related to perceived vocal effectiveness in young women.

The difficulties associated with estimating optimal pitch are related to the complexity of determining vocal efficiency. Titze (1992) defines efficiency “as the output obtained for a given amount of input” (p.135). The difficulty of estimating optimal pitch is partially due to the complexity of estimating vocal input and output energy During phonation, glottal resistance limits airflow from the lungs, resulting in an aerodynamic power of about 1 watt. However, the power transferred from the airstream to the vocal folds is estimated to be only about 0.1 watt, much less than the total aerodynamic power of the airflow from the lungs. The power lost in the transfer from the airstream to the vocal folds depends on several variables. For example, the power loss can be reduced by maintaining vocal-fold hydration, which reduces the tissue’s viscosity. Some aerodynamic power is also dissipated through air turbulence in the ventricle, though it is not known how much. Another way in which aerodynamic power is lost is through vibration of the vocal tract wall, both above and below the glottis. It is not known whether a speaker can minimize these losses to maximize vocal acoustic efficiency (Titze, 1992).

According to Titze (1992), there are additional complications in determining an optimal pitch. Even if it were possible to estimate acoustic efficiency in the mechanical sense of output obtained for a given amount of input, it is not clear that it would necessarily correspond with long-term health of the vocal folds and larynx. Since higher frequencies are radiated more effectively than lower frequencies, formulas calculating vocal efficiency tend to favor higher frequencies as well as higher intensities, even when a high-frequency, high-intensity voice requires more vocal strain. A pressed voice may be more acoustically efficient than a breathy voice, but may result in contact stress and trauma to the vocal fold tissue. Clearly, in order to determine optimal pitch, a more complete picture of vocal efficiency and its impact on long-term vocal health is needed.

Although the concept of optimal pitch is still widely considered clinically useful, the basis for this assumption remains unclear and is lacking solid empirical support. Even if there is a pitch range that is more acoustically efficient for the individual, traditional methods for estimating it have been widely called into question (Britto & Doyle, 1990; Linke, 1973). It is not clear how to best estimate optimal pitch, or whether or not optimal pitch correlates with vocal health. The theoretical subject of optimal pitch remains controversial.

Conclusion

This literature review has cited research documenting typical SF_0 values associated with factors such as age and vocal pathology. In children SF_0 gradually decreases until puberty, at which point SF_0 drops to adult levels. SF_0 decreases slightly at menopause in women, and in men it increases gradually with age. Change in SF_0 may also be associated with various functional and organic vocal pathologies. Other research has been cited suggesting that different tasks used to elicit SF_0 may or may not result in significantly different outcomes. However, results have been inconclusive. Since differences in SF_0 based on elicitation task type may affect the validity of comparing SF_0 values measured using different tasks, clinicians and researchers should be aware of any possible differences task type could have on SF_0.

Optimal pitch is an F_0 that is theoretically produced more efficiently by an individual. It is commonly argued that using an SF_0 that is higher or lower than an individual's optimal pitch may result in vocal pathology. However, the concept of optimal pitch and the methods commonly used to estimate it have been widely questioned. The results of research concerning methods for eliciting optimal pitch have been inconclusive. Additionally, the effect of various tasks on the measurement of SF_0 has not yet been firmly established. More research is needed to examine the consistency of results from different tasks used to elicit SF_0.

Justification

Speaking fundamental frequency (SF_0) is a useful measure that is often used to evaluate severity of vocal pathology and monitor progress in treatment (Hirano, 1989; Behrman, 2005). Since change in SF_0 may accompany many types of organic and functional dysphonia, measuring SF_0 is recommended in order to evaluate the severity of disorders and the effects of treatment (Murry & Doherty, 1980; Hirano, 1989). Surveys indicate that SF_0 is one of the most common acoustic measures taken by voice clinicians (Hirano, 1989; Behrman, 2005).

In spite of the importance of SF_0 measurement in voice assessment and treatment, there is little agreement on what methods are best for measuring SF_0. Various tasks may be used for eliciting SF_0 and include reading a standard phonetically-balanced passage such as Fairbanks' (1960) "Rainbow Passage," obtaining a spontaneous connected speech sample, counting, sustaining a vowel such as /a/, /i/, or /u/, and sustaining a vowel within a phrase. Some research indicates that SF_0 may differ significantly when derived from different tasks (Mysak, 1959; Ramig & Ringel, 1983; Hudson & Holbrook, 1982; Zraick et al., 2000; Murry et al., 1995; Britto & Doyle, 1990; Baker et al., 2008; Chen et al., 2009; Hunter, 2009; Horii, 1975; Zraick et al., 2005). Differences, as well as a lack of differences in SF_0 have been reported between a reading passage and a spontaneous speech sample (Mysak, 1959; Ramig & Ringel, 1983; Hudson & Holbrook, 1982). Many studies have indicated significantly different values associated with sustained phonation than with other elicitation methods (Murry et al., 1995; Britto & Doyle, 1990; Zraick et al., 2000).

Although much of the research cited suggests that different tasks may result in significantly different calculated SF_0 values, results are inconsistent. Clinicians and researchers should be aware of any effect of task on SF_0 values, especially when choosing an appropriate task to measure SF_0 or when comparing data collected using different methods. Additional study is therefore necessary to clarify understanding of the effect of task on SF_0. The purpose of this study is to examine whether there is a significant difference among the SF_0 values of women measured from reading, a spontaneous speech sample, counting, the sustained vowel /a/, the sustained vowel /i/ at the end of counting from 1 to 3, and the frequency at 20% of the F_0 range. These tasks were chosen to be evaluated because they are commonly used in research and clinical settings. Women were chosen as participants because research has found more variability in SF_0 associated with task type in women than in men or children (Zraick et al., 2000).

Method

Participants

Participants in this study were limited to women who (a) were at least 19 years of age, (b) had no history of smoking, (c) were not pregnant, ovulating, or postmenopausal, (d) had no vocal training, (e) were not taking any medications (other than oral contraceptives and vitamins), (f) had no history of asthma (other than childhood asthma), (g) had no signs of reflux, (h) had no history of laryngeal pathologies or other laryngeal abnormalities, (i) had no history of any serious respiratory infection or illness, (j) passed a pure tone hearing screening of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz presented at 20 dB, and (k) had no signs of vocal pathology according to a third-party panel of judges. The judges on the panel held current certification in speech-language pathology, doctoral degrees, and expertise in voice disorders. Any participant who did not meet these requirements was not permitted to participate in the study. Twenty-two participants between the ages of 20 and 34 years (M = 22.95; SD = 3.40) were recruited to participate in the study. The data of one participant were excluded from analysis due to possible voice pathology according to the third-party judges, leaving a total of 21 participants who met all the criteria for participation in the study. Table 2 summarizes the characteristics of the 21 participants included in the study for analysis.

Procedure

Participants were recruited through flyers posted in public areas (see Appendix A for the flyer). In addition, participants were recruited by reading a recruitment script at the end of undergraduate and graduate Communication Disorders classes (see Appendix B for the recruitment script used). Any person who expressed interest in participating was given an information sheet outlining the criteria for participation (see Appendix C for screener). The participant was able to indicate on this form if she met the criteria for participation without indicating which of the criteria she did not meet. At this time the participant also had an opportunity to ask any questions regarding the criteria for participation. If the participant met all of the criteria, the investigator scheduled a time to conduct the study procedure. The time was scheduled between 7 and 13 days after the first day of her menstrual cycle in order to increase the likelihood that the participant was not ovulating at the time of the study.

Table 2. *Participant Demographics*

Participant	Age	OC	DPC	T	H
1	29	+	13	72	48
2	27	+	11	71	49
3	23	-	10	70	51
4	23	-	10	70	52
5	23	-	9	70	51
6	22	+	13	70	51
7	21	-	8	71	49
8	21	+	8	71	51
9	21	-	8	72	52
10	21	-	6	71	54
11	22	+	6	72	52
12	34	+	10	71	49
13	20	-	13	70	49
14	22	+	8	71	51
15	23	-	12	72	51
16	20	+	10	72	49
17	22	+	12	77	40
18	20	-	9	70	45
19	23	-	7	71	44
20	23	+	10	71	27
21	22	-	11	72	47

OC = use of oral contraceptives; DPC = days post cycle; T = room temperature; H = room humidity

At the time of the study, the participant received a consent form to review before beginning the study (see Appendix D for the consent form). After the participant read the consent form, the investigator reviewed the consent form with her and gave her the opportunity to ask questions or to withdraw from the study. If the participant wished to continue in the study, she was asked to initial and sign the consent form with the investigator as witness. By signing the consent form the participant confirmed that she met all the criteria for participation.

Each participant was assigned a participant code to ensure that all information collected was anonymous. The participant was then asked to indicate her age, any use of oral contraceptives, and the first day of her last menstrual cycle (see Appendix E for recording form). The participant was assured at this time that all information would be kept anonymous since the recording form would be identifiable only by a participant number. The participant's consent form was kept separately from the recording form.

In order to ensure that the participant's hearing was within normal limits, a pure tone hearing screening was administered using a portable audiometer supplied by the Auburn University Speech and Hearing Clinic (AUSHC) (see Appendix F for specific instructions given and the recording form). All of AUSHC's portable audiometers are calibrated by the audiology department of AUSHC. Tones of 500, 1000, 2000, and 4000 Hz were presented at 20 dB in a sound-treated booth. The identification number of the audiometer, the participant identification number, and each of the frequencies tested in the right and left ears were recorded. The participant had to pass all frequencies at 20 dB bilaterally in order to continue participation in the study.

In order to screen the participant's voice for signs of vocal pathology, each participant was audio-recorded sustaining the vowels /a/ and /i/ and reading 6 sentences. The microphone was placed at a 45-degree angle, approximately 4 cm away from the mouth. The participant was asked to sustain the vowels /a/ and /i/ for about 3 sec each, then to read the following sentences one at a time: (a) The blue spot is on the key again, (b) How hard did he hit him? (c) We were away a year ago, (d) We eat eggs every Easter, (e) My mama makes lemon jam, and (f) Peter will keep at the peak (see Appendix G for instructions to participant). A third-party panel of judges with expertise in voice disorders listened to the recordings of each participant's voice in order to check for any auditory signs of vocal pathology. These judges held current certification in speech-language pathology, doctoral degrees, and expertise in voice disorders. If any signs of vocal pathology were noted by the judges, the data collected from the participant's voice were not included in the study. One participant exhibited pitch breaks during the sustained vowels, which was indicative of possible vocal pathology according to the judges. The data of this participant were therefore excluded from the study.

The participant's speaking fundamental frequency (SF_0) was then recorded using a Marantz PMD 671 digital recorder. The recorder was set to have a sampling rate of 44 kHz and a quantization rate of 16 bits. The Computerized Speech Laboratory (CSL) Main Program option for the KayPENTAX CSL Model 4500 hardware was then used to analyze the recordings. The microphone was positioned at a constant distance of approximately 4 cm from the participant's mouth. Using the digital recorder, the participants were recorded performing the following 5 tasks: 1) reading the entire phonetically-balanced "Rainbow Passage" (Fairbanks, 1960), 2) a spontaneous speech sample of at least 60 seconds about the topic "What I like to do most in the summertime," 3) counting from 1 to 10, 4) sustaining the vowel /a/ for 8 sec, and 5) counting from 1 to 3 and sustaining the vowel /i/ at the end of the word "three" for 5 sec. The participant's F_0 range was also recorded. Participants were asked to step up from a comfortable pitch to the highest pitch possible, and then step down from a comfortable pitch to the lowest pitch possible without glottal fry. The investigator provided an appropriate model of this task as well as a model of inappropriate glottal fry (see Appendix G for the specific instructions given to the participant; see Appendix H for the recording form). The F_0 range was used to identify the frequency at 20% of the F_0 range. This value has been used to identify SF_0, and was compared with the F_0 values from the other 5 tasks used to measure SF_0. The participant was seated in a chair in a quiet room and instructed to speak at a comfortable pitch and loudness for all tasks. Each task was presented after a rest period of 30 seconds to prevent vocal fatigue. The tasks were presented in randomized order to each participant to prevent any effect of order or possible vocal fatigue (see Appendix G for the specific instructions given to the participant; see Appendix H for the recording form; see Appendix I for the reading passages).

In order to test within-subject consistency, 20% of the participants were randomly selected to be immediately retested. All the tasks used to measure SF_0 were administered a second time in randomized order to these participants. Also, while neither humidity nor temperature were controlled, they were monitored using an Oregon Scientific weather instrument and recorded with each participant's information.

Analysis

The Computerized Speech Lab (CSL) main program was used to measure the mean F_0, or SF_0, of each task. For the tasks of counting from 1 to 10 and sustaining the vowel /a/ for 8 sec, the entire task was used to determine SF_0. Only the first paragraph of the "Rainbow Passage" was analyzed for SF_0, and only the middle 30 seconds of the spontaneous speech sample was analyzed. Only the 5-second sustained vowel portion of the sustained /i/ at the end of the utterance “one, two, three” was analyzed. The F_0 range was measured using CSL and converted to semitones according to this equation:

$$\textit{number of semitones} = 39.863 \text{ X } \log(f_2/f_1)$$

f_1 is the lowest F_0 value in the range and f_2 is the highest F_0 value. Once the semitone range was established, the 20th percentile used for analysis was calculated according to this equation:

$$20\% = 1.0595^{((\text{semitones}/10) \text{ X } 2)} \text{ X } f_1$$

In order to test inter-investigator reliability, the data from 20% of the participants was also measured by a second investigator. In order to test intra-investigator reliability, the data from 20% of the participants was measured a second time by the first investigator.

Results

Fundamental frequency (F_0) data were analyzed using PASW Statistics software. Raw data of the six independent variables were examined visually for skewness and kurtosis. A Kolmogorov-Smirnov test of normality revealed that 3 of the independent variables were not normally distributed, but were skewed to the left. These independent variables included the reading passage (skewness, -1.196; kurtosis, 1.753), spontaneous speech sample (skewness, -0.879; kurtosis, 1.352), and the 20th percentile of the F_0 range (skewness, -1.214; kurtosis, 0.312). The data for the reading passage and the spontaneous speech sample may have been skewed by the low SF_0 values of two participants. In addition, there were two outlier values for the 20th percentile of the F_0 range. The low SF_0 values resulted from glottal fry that appeared more excessively in the reading passage and spontaneous speech. To determine whether there is a significant difference in SF_0 measured from the six different tasks, SF_0 data were analyzed with a one-way analysis of variance (ANOVA). Due to concern over the assumption of normality being violated, a Robust ANOVA was also run to account for this violation. However, the outcome of the more conservative Robust procedure was identical to those of the original analysis; therefore, the results of the original analysis are being reported. For the analysis, there was one within-subjects factor with six levels. Because sphericity could not be assumed, the Greenhouse-Geisser corrected test was used to adjust the degrees of freedom. Table 3 lists the complete ANOVA results. Table 4 lists the summary statistics for the SF_0 outcome data. SF_0 was found to significantly differ among tasks ($F(45.852, 2.293) = 4.68$, $p < .011$, $\eta^2 = .190$).

Table 3. *Within-subjects multivariate analysis of variance results for the effect of task on SF_0.*

Source	*df*	SF_0		
		MS	*F*	*p*
Task	2.293	4606.278	4.681	.011
Error	45.852	984.107		

df = degrees of freedom; *MS* = mean square; *F* = Fisher's *F* ratio; *p* = probability

Table 4. *Summary Statistics.*

Task	SF_0				
	M	*SD*	*Min*	*Max*	*N*
Reading passage	191.240	14.226	156.68	212.79	21
Spontaneous speech sample	186.961	22.721	124.59	223.62	21
Counting 1-10	203.765	19.786	157.27	247.32	21
Sustained /a/	204.079	24.047	167.29	249.86	21
Sustained /i/ after counting 1-3	209.392	16.141	177.43	246.17	21
20^{th} percentile of F_0 range	212.107	37.485	128.59	252.20	21

M = mean; *SD* = standard deviation; *Min* = minimum SF_0; *Max* = maximum SF_0;
N = total number in sample

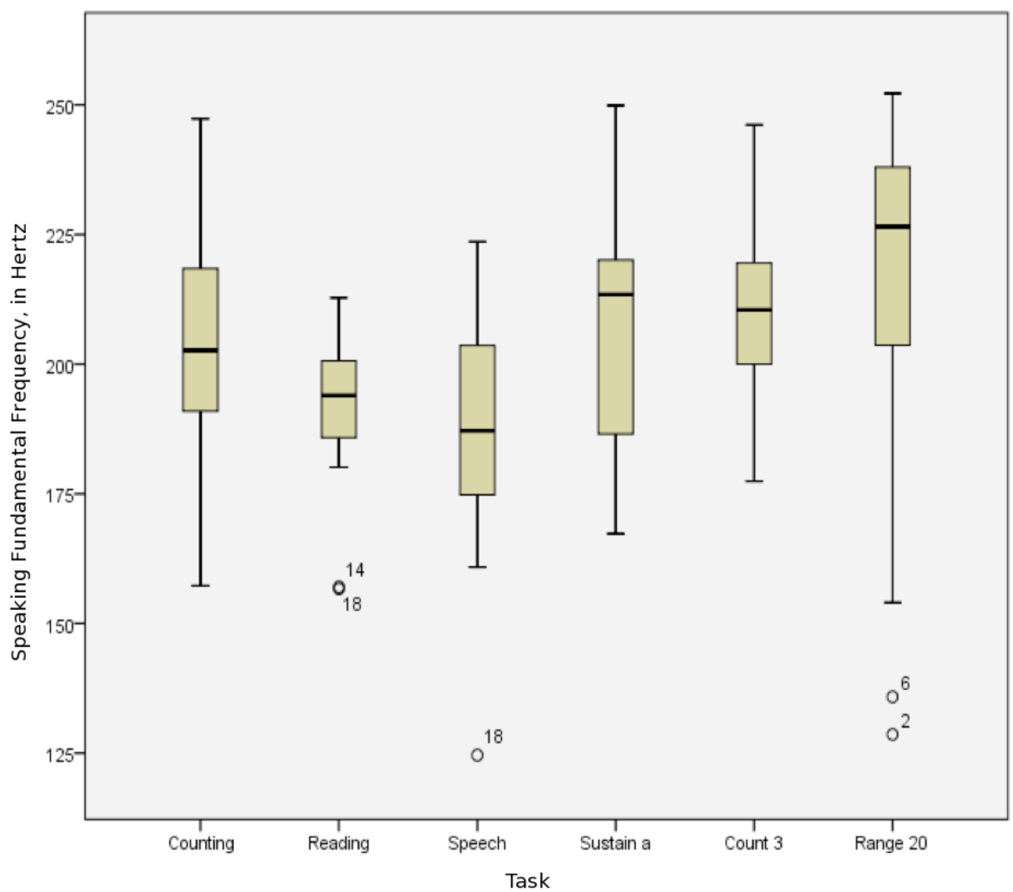
Pairwise comparisons for task were conducted to reveal which tasks differed from one another. Pairwise comparisons for task revealed that the reading passage and spontaneous speech tasks resulted in significantly lower mean SF_0 values than the counting from 1-10, sustained /a/, sustained /i/ after counting 1-3, and the 20^{th} percentile of the F_0 range. Holm's sequential Bonferroni procedure was used to control for Type 1 error across the significant tests at the .05 level of confidence. For this more conservative procedure, each pairwise comparison, beginning with the smallest *p* value, is reevaluated for significance by comparing it to the level of confidence divided by the number of significant *p* values. With this procedure, two of the significant pairwise comparisons lost significance: the difference between the spontaneous speech task and the sustained vowel /a/ task and the difference between the reading passage task and the sustained vowel /a/ task. Table 5 illustrates the results of the pairwise comparisons. Figure 1 presents the distributions of fundamental frequency scores for the six different tasks.

Table 5. p *values for pairwise comparisons between mean SF_0 values of each task.*

	Reading passage	Spontaneous Speech	Counting 1-10	Sustain /a/	Sustain /i/ after counting 1-3	20^{th} percentile of range
Reading passage						
Spontaneous speech	.123					
Counting 1-10	.003*	.000*				
Sustain /a/	.021*	.018*	.965			
Sustain /i/ after counting 1-3	.000*	.000*	.153	.441		
20^{th} percentile of range	.033*	.021*	.318	.409	.695	

* indicates significance

Figure 1. *Boxplot of fundamental frequency distributions across tasks.*



Reliability

In order to establish within-subject consistency, 20% (i.e., 4) of the participants were randomly selected to be immediately retested. The difference between the mean values for the first and second trials recorded for within-subject consistency was 4.37, with a strong correlation of 0.939. To establish interjudge reliability, a second person, not directly involved with the study, reanalyzed the data of 20% of the participants. To establish intrajudge reliability, the primary investigator also reanalyzed the data of 20% of the participants. Correlation coefficients were calculated from the SF_0 values derived from retesting. The difference between the mean values for interjudge reliability was 0.99, with a strong correlation of 0.997. The difference between the mean values for intrajudge reliability was 4.25 with a strong correlation of 0.989.

Discussion

The current study examined whether the speaking fundamental frequency (SF_0) of women varies significantly among six different tasks. These tasks included 1) the first paragraph of the phonetically-balanced “Rainbow Passage,” 2) the middle 30 seconds of a 60-second spontaneous speech sample, 3) counting from 1-10, 4) an 8-second sustained vowel /a/, 5) a 5-second sustained vowel /i/ after counting from 1-3, and 6) the 20th percentile of the F_0 range. Some studies have reported differences between a reading passage and a spontaneous speech sample, where other studies have not found a difference (Hudson & Holbrook, 1982; Mysak, 1959; Ramig & Ringel, 1983). Studies have also reported differences in SF_0 between sustained phonation and reading or spontaneous speech (Britto & Doyle, 1990; Murry et al., 1995; Zraick et al., 2000). Zraick et al. (2000) examined the effect of task on SF_0 in men, women, and children, and found a significant effect of task on SF_0 in women, but not in men or children. The tasks included: (1) counting from 1 to 10, (2) reading 10 seconds of the "Grandfather Passage,” (3) producing spontaneous speech for 10 seconds, (4) sustaining the vowel /a/ for 8 seconds, (5) producing the utterance "um-hum” with a closed mouth, as if he or she were agreeing with someone, (6) sustaining the vowel /i/ for 1 second after counting from 1 to 3, and (7) producing "uh-huh" with an open mouth. For the women, the SF_0 from the sustained /i/ after counting from 1 to 3 was significantly higher than the SF_0 from counting from 1 to 10, reading the “Grandfather Passage,” spontaneous speech, and producing “uh-huh.” The SF_0 from “um-hum” was significantly higher than from counting 1-10 and spontaneous speech. Also, the SF_0 from the sustained /a/ was significantly higher than from spontaneous speech. The current study was designed to determine if the effect of task on SF_0 found by Zraick et al. (2000) in women could be replicated.

The results of the current study indicated that SF_0 was in fact significantly different among tasks. Pairwise comparisons for tasks indicated that the mean SF_0 values from the reading passage and spontaneous speech tasks were both significantly lower than the mean SF_0 values from the counting from 1-10 task, sustained /a/, sustained /i/ after counting 1-3, and the 20^{th} percentile of the F_0 range. In the study by Zraick et al. (2000), the SF_0 from the sustained /a/, as well as from the sustained /i/ after counting from 1-3, were also significantly higher than from the reading passage and spontaneous speech tasks, as in the current study. However, Zraick et al. also found that the SF_0 from the sustained /i/ after counting from 1-3 was significantly higher than the counting 1-10 task, a finding that was not replicated in this study. Table 6 displays a comparison of results for the tasks evaluated by both the current study and Zraick et al. (2000). As can be seen in Table 6, all tasks evaluated in both studies had similar mean SF_0s for each task, with the exception of counting 1-10.

Table 6. *Comparison of results from current study and Zraick et al. (2000) for selected tasks.*

Current Study *N* = 21		Zraick et al. (2000) *N* = 12	
Task	SF_0	Task	SF_0
Reading passage (~30 s)	191.24	Reading passage (10 s)	192.26
Spontaneous speech sample (30 s)	186.96	Spontaneous speech sample (10 s)	187.64
Counting 1-10	203.77	Counting 1-10	186.78
Sustained /a/ (8 s)	204.08	Sustained /a/ (8 s)	201.30
Sustained /i/ after counting 1-3 (5 s)	209.39	Sustained /i/ after counting 1-3 (1 s)	205.47

Note: All SF_0 values are in Hertz. *N* represents number of participants.

Several other studies have also indicated that the SF_0 values obtained from a sustained vowel or sustained vowel after counting from 1 to 3 were significantly higher than from reading or spontaneous speech samples in populations of children, young women, older women and young men (Murry et al., 1995; Sorensen, 1989; Zraick et al., 2000). However, two studies of young adults did not find a significant difference between a sustained vowel and connected speech tasks (Britto & Doyle, 1990; Fitch, 1990). In the current study, the values from the sustained /a/ and the sustained /i/ after counting 1-3 were significantly higher than the reading and spontaneous speech tasks.

Some studies have also found that SF_0 is significantly higher in reading tasks than in spontaneous speech samples in populations of children, young adults, older men, and male and female adult trained singers (Hudson & Holbrook, 1982; Mysak, 1959; Ramig & Ringel, 1983; Schultz-Coulon, 1975; Sorensen, 1989). Other studies have not found a significant difference between reading and spontaneous speech tasks (Britto & Doyle, 1990; Fitch, 1990; Murry et al., 1995; Zraick et al., 2000). In the current study, the mean SF_0s from the reading passage and spontaneous speech task were 191.24 and 186.96 Hz, respectively. Although the SF_0 from the reading passage was slightly higher than the SF_0 obtained during spontaneous speech, the difference was not significant.

Research, including the present study, has repeatedly found that reading passages and spontaneous speech samples result in lower SF_0 values than tasks such as sustained vowels. The lower SF_0 values could be attributed to the presence of glottal fry, which appeared more excessively in the reading passage and spontaneous speech tasks than in the other tasks. Auditory-perceptual judgments of the investigator and voice experts, as well as visual inspection of the acoustic speech samples, were used to confirm the presence of glottal fry. Aperiodicity from glottal fry can interfere with the F_0 measurement of acoustic analysis software, lowering the measured SF_0 (Bielamowicz, Kreiman, Gerratt, Dauer, & Berke, 1996; Hixon, Weismer, & Hoit, 2008). Because of this interference, the SF_0 values measured from the reading passage or spontaneous speech sample were lower than expected for some participants and not representative of what a listener would perceive to be the participant's habitual pitch. For example, the SF_0 from the spontaneous speech sample of one participant with a perceptually normal habitual pitch, but excessive glottal fry, was 124.59 Hz, approximately 75 Hz lower than the typical SF_0 value for young women.

The prevalence of glottal fry in young female college students was noted by Gottliebson, Lee, Weinrich, and Sanders (2007). These investigators screened 104 first-year students in a Master's degree speech-language pathology program for voice problems, which were 94% female and 6% male. Glottal fry was identified in 31 of the female students. Of these, 15 presented with other perceptual voice quality abnormalities, including low conversational pitch, hoarseness, breathiness, strain, juvenile resonance characteristics, abnormally low pitch on a sustained vowel, and abnormal voice breaks while obtaining a frequency range. However, glottal fry was the most common aberrant voice quality observed in the students investigated. The authors of this study noted that glottal fry is common in the speech of teens and young adults. Voice-related symptoms were reported by 12 of the students exhibiting glottal fry, including hoarseness, breathiness, strain, vocal fatigue, shortness of breath, throat clearing, voice breaks, medical conditions such as heartburn and asthma which may affect voice, and difficulty with activities requiring loud talking or singing. Upon videostroboscopic examination, one student was diagnosed with vocal nodules. Since glottal fry is commonly considered to result in phonotrauma, the prevalence of glottal fry in this population may indicate a need to screen for voice-related symptoms among young women.

Clinical Implications

Regardless of the explanation for the difference between task types, the difference found certainly justifies attention, since these tasks are all used to establish SF_0 in clinical and research settings. For example, many of the tasks evaluated in this study have been used to publish SF_0 norms for various populations, including women, men, children, professional singers, and speakers of various races (Andrianopoulos et al., 2001; Benjamin, 1986; Brown et al., 1991; Chae et al., 2001; Harnsberger et al., 2008; Higgins & Saxman, 1991; Hollien & Jackson, 1973; Hollien & Malcik, 1962; Hollien & Shipp, 1972; Hudson & Holbrook, 1982; McGlone & Hollien, 1963; Meurer et al., 2009; Moran, et al., 1995; Morris, 1997; Morris et al., 1995; Mysak, 1959; Russell et al., 1995; Sapienza, 1997; Stoicheff, 1981; Wheat & Hudson, 1988; Xue & Mueller, 1996). However, since SF_0 can vary significantly among tasks, as the results of this study suggest, it is inappropriate to compare values measured with some of the different tasks. For example, if a young woman exhibits an SF_0 of 195 Hz during a spontaneous speech sample, it would be inappropriate to compare this value with the mean SF_0 of 235 Hz found by Higgins & Saxman (1991), who measured SF_0 from young adult women who sustained vowels. Because SF_0 was measured from spontaneous speech and not from a sustained vowel, the young woman's SF_0 value of 195 Hz could be inappropriately interpreted as low. Such a comparison is invalid and may lead to an inappropriate diagnosis or conclusions. Due to this discrepancy, it may be necessary for clinicians and researchers to distinguish SF_0 from other measures of fundamental frequency (F_0). This is advisable, since SF_0 is a measure of connected speech by definition, and the data gathered in this study suggest that measures of connected speech result in significantly lower F_0 values than other tasks, such as sustaining vowels.

Many experts have called for standardization of acoustic measurement of voice (Bielamowicz, 1996; Hicks, 1991; Hirano, 1989; Titze, 1994). Hirano (1989) noted, "Unfortunately there are no internationally standardized methods for voice evaluation. Comparisons of vocal function cannot be made across different voice clinics and across different periods without common standard tests" (pp. 89-92). Titze (1994) discussed the advantages of standardization for acoustic measurement of voice. He points out that standards help to educate beginning clinicians, simplify procedures, conserve time, money, and effort, and help authorities to certify products or procedures. However, since premature standardization can be a hindrance to progress, standards should be designed carefully, through expert consensus. Standards are often designed and recommended by an appropriate professional society. Since most standards are voluntary, all factors must be considered, and "all minority opinions must be heard exhaustively until there is no reasonable argument against the standard" (Titze, 1994, p. 2). A well-designed standard will facilitate convenience, simplicity, and unity. Hicks (1991) also emphasized the benefit of standardization of acoustic measurement of voice. He noted that standardization should allow for interpretable and generalizeable results, representative and useable norms, reliable and valid results, and differentiation between true performance variability and variability due to measurement protocols. Hicks also called for research testing various protocols of acoustic measurement, in order to provide data necessary for standardization. The results of this study provide support for standardization of SF_0 measurement, in order to facilitate comparison of SF_0 values in clinical and research settings.

In order to identify an appropriate protocol for measurement of SF_0, it is necessary to determine a task with both validity and reliability. To ensure validity, it is important to choose a task that will result in an SF_0 value that represents most closely a listener's perception of the individual's habitual pitch during natural spontaneous speech. To ensure reliability, it is important to choose a task with a small standard deviation, or relatively little variation in performance across individuals. A small standard deviation indicates consistency and repeatability of measurement. These factors must be considered in order to choose a task which will yield meaningful results.

Although a spontaneous speech sample is the most natural task for acoustic measurement, the SF_0 value analyzed from connected speech may not be representative of the individual's habitual pitch due to the prevalence of aperiodicity in connected speech samples. In the current study, it was noted that substantial glottal fry was present in the connected speech samples and interfered with SF_0 measurement of speakers with normal voices. In addition to glottal fry, the voices of individuals with vocal pathology have aperiodicity due to characteristics such as hoarseness, breathiness, and roughness which may also interfere with analysis of SF_0 (Bielamowicz et al., 1996). Since acoustic measurement is typically used to analyze the voices of individuals with vocal pathology, any task designed for standardized acoustic measurement must be valid for pathological voices also. However, to obtain a valid SF_0 measurement from a sample of connected speech, it would be necessary to remove the areas of F_0 calculation error by manually editing the sample. This strategy for obtaining an SF_0 measurement from a connected speech sample would be valid, but overly time-consuming for clinical settings. Therefore, connected speech samples do not provide a practical candidate for valid measurement of SF_0.

The variability or standard deviation of each task must be considered also. Of the 6 tasks, the reading passage and the sustained /i/ after counting 1-3 had the smallest standard deviations. Their standard deviations were 14.2 and 16.1 Hz, respectively. The 20th percentile of the F_0 range and the sustained /a/ task had the largest standard deviations, at 37.5 and 24.1 Hz. Although the reading passage had the smallest standard deviation, there were 2 participants whose SF_0 values from the reading passage were below 160 Hz, outliers when compared with the mean of 191.2 Hz and standard deviation of 14.2 Hz. The low SF_0 values of these outliers were a result of excessive glottal fry, which was present in all the connected speech tasks of many participants. The sustained /i/ after counting 1-3 also had a small standard deviation, with no outliers. Surprisingly, although this task is similar to the sustained /a/, the sustained /a/ had a relatively large standard deviation of 24.1 Hz. This may be due to the tendency of many participants to sustain the vowel /a/ at an unnatural pitch not characteristic of their habitual pitch during connected speech. Counting 1-3 before sustaining /i/ may have provided a segue from natural connected speech into a sustained vowel at a pitch more characteristic of their habitual pitch. Since only the sustained vowel portion of the task was analyzed, and not the counting portion, glottal fry interfered minimally with SF_0 measurement. Because of these factors, a task such as sustaining /i/ after counting 1-3 may be more representative of an individual's habitual pitch while also being a repeatable measure, creating a comparitively valid and reliable option for SF_0 measurement. More research is needed to confirm this hypothesis, and to test it among other populations. However, regardless of the conclusion reached, steps towards standardization should be taken, and considerations such as those presented will facilitate valid and reliable acoustic measurement of voice.

Limitations and Future Research

Several limitations to the present study should be acknowledged. One limitation was that this study included a relatively small number of participants, as only 21 young female adults were evaluated. Since the present study evaluated the effect of task type on SF_0 in women with normal voices, it should be noted that these results cannot be generalized to men, children, or speakers with vocal pathology. In addition, the participants in this study were young women ranging from the ages of 20 to 34 years, precluding generalization to normal female speakers of other ages. Further studies are necessary to determine whether these results can be replicated in men and children, as well as in individuals with vocal pathology. Future research examining the effect of task on SF_0 must be performed before standards can be designed that will be appropriate for diverse populations with and without vocal pathology.

Another finding of this study was a prevalence of glottal fry among the young female participants. Future studies could investigate further the prevalence of voice problems or symptoms in young women and the potential need for voice rehabilitation. Many of the participants in this study were graduate students in speech-language pathology, and entering a profession with high vocal demands. Further research may identify a need to screen students who are at risk for voice problems.

Summary

Twenty-one healthy young women with normal voices between the ages of 20 and 34 years were recorded performing 6 tasks commonly used to assess SF_0. SF_0 was found to differ significantly among tasks at the .011 level of confidence. Specifically, the reading passage and spontaneous speech tasks were found to be significantly different than the counting from 1-10 task, sustained /a/, sustained /i/ after counting 1-3 task, and the 20th percentile of the F_0 range. Many of the participants exhibited glottal fry during connected speech, which may be partially responsible for the low SF_0 values measured from the reading and spontaneous speech tasks. Since all the tasks evaluated are commonly used in clinical and research settings, these results support development of standards for acoustic measurement of voice.

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Appendix A

Voice Research Study

Be part of an important research study

- **Are you a female between 19 and 40 years of age?**
- **Are you a nonsmoker?**
- **Do you not have any formal voice training?**

If you answered ***YES*** to these questions, you may be eligible to participate in a voice research study.

Different tasks such as reading, conversational speech, and counting are used to measure the habitual pitch of the voice. The purpose of this research study is to determine the effect of using different tasks to measure habitual pitch.

Your participation should take less than 1 hour.

This study is being conducted by Dr. Laura Plexico and Amy Schiwitz in the Department of Communication Disorders at Auburn University.

For more information, please contact:
Dr. Laura Plexico
lwp0002@auburn.edu
(334) 884-9620
or Amy Schiwitz
acs0025@auburn.edu

Appendix B

Recruitment Script (in person)

My name is (*Amy Schiwitz, Dr. Laura Plexico*), and I am a (*graduate student, assistant professor*) in the Department of Communication Disorders at Auburn University. I would like to invite you to participate in a research study being conducted by (*myself under the direction of Dr. Laura Plexico, myself and Amy Schiwitz, a graduate student)* as part of a Master's Thesis in Speech-Language Pathology. This research study will examine the effect of using different tasks to measure the habitual pitch of the voice. Habitual pitch is a common measurement taken by voice clinicians in order to evaluate vocal pathology and to monitor progress in treatment.

In order to participate in this study, you must be a female between 19 and 40 years old, not smoke, not have formal vocal training, not be pregnant, not taking any medication other than vitamins or oral contraceptives, and not have any history of reflux or laryngeal pathology, in addition to other criteria for participating in this study.

If you decide to participate, you will be asked to complete a questionnaire with some personal questions and be audio-recorded completing different tasks used to measure habitual pitch, such as reading aloud and counting. Participation should take no more than 1 hour.

If you would like to participate in this research study, we can schedule a time for us to meet now, or you can contact us later in person, by phone or by email. You can contact me at acs0025@auburn.edu or Dr. Plexico at 334-844-9600 or lwp0002@auburn.edu.

Appendix C

Participation Screener

Confidentiality Note: All information provided by you is for the sole use of this research study, and will not be shared with anyone but those directly involved with the research. Furthermore, answers provided will in no way affect your standing with the University or any other organization.

Please read the following criteria and indicate if any of the following criteria apply to you. You do not need to indicate which one of the criteria below applies to you.

Are you under the age of 19 years, or over the age of 40 years?
Do you or have you ever smoked?
Are you pregnant?
Have you experienced menopause?
Have you ever had vocal training?
Are you taking any medications other than vitamins or oral contraceptives?
Have you been diagnosed with asthma (other than childhood asthma)?
Have you been diagnosed with gastroesophageal reflux disease (GERD) or do you experience any symptoms of GERD?
Have you ever had any laryngeal pathology or voice disorder?
Have you ever had a chronic respiratory infection or serious respiratory illness (excluding typical childhood infection and illness)?

If you answered *no* to *all* of them, you may be eligible to participate in this study.

If you answered *yes* to *any* of them, we would like to thank you for your time. However, due to the nature of this study, you will not be able to participate.

Appendix D

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
For a Research Study Entitled
The Effect of Task Type on
Speaking Fundamental Frequency in Adult Females

You are invited to participate in a research study to investigate the effect of a variety of task types on speaking fundamental frequency. Speaking fundamental frequency (SF_0) is the mean or modal fundamental frequency, or habitual pitch, of the voice. This study is being conducted by Amy Schiwitz, under the direction of Dr. Laura Plexico, Assistant Professor in the Auburn University Department of Communication Disorders. You were selected as a possible participant because you are: a) between 19 and 40 years of age, b) a nonsmoker, c) not pregnant, d) have had no vocal training, e) are taking no medications (with the exception of oral contraceptives), f) have no history of asthma, g) do not have reflux, h) have no history of laryngeal pathology, and i) have not had any serious respiratory infection or illness.

What will be involved if you participate? If you decide to participate in this research study, you will be asked to complete a questionnaire that asks some personal questions and to pass a hearing screening in order to confirm your eligibility for participation. If it is confirmed that you are eligible to participate in this study, you will be asked to complete the tasks necessary to complete the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) and the tasks necessary to measure SF_0. Your total time commitment will be approximately 1 hour.

Are there any risks or discomforts? We do not anticipate any risks associated with participating in this study.

Are there any benefits to yourself or others? There are no direct benefits to participants in this study. However, this study is expected to contribute to the information necessary for standardization of acoustic measurement and for comparing data taken using different methods in research and clinical practice.

Will you receive compensation for participating? There is no compensation available for participants in this study.

If you change your mind about participating, you can withdraw at any time during the study. Your participation in this study is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Communication Disorders, Dr. Laura Plexico, or Amy Schiwitz.

Your privacy will be protected. Any information obtained in connection with this study will remain anonymous. Your identity and participation in this study will be known only to the primary investigator and co-investigators of this study. After the assessments are completed the primary investigator will remove all identifying information and code all data that is collected into a spreadsheet. The primary investigators will be the only individuals with access to the data that is identified by the participant's name. All information and data will be stored in a secure place under lock and key. Information obtained through your participation may be used by Dr. Laura Plexico and the co-investigators for other research purposes, for presentation at a professional meeting, or for developing a paper for publication in a professional journal.

If you have any questions about this study, *please ask them now or* contact Dr. Laura Plexico at (334) 844-9620 or lwp0002@auburn.edu. A copy of this document will be given to you to keep.

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334) 844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

_______________________________ _______________________________
Participant's Signature Date Investigator obtaining consent Date

_______________________________ _______________________________
Printed Name Printed Name

____
Co-Investigator Date

____
Printed Name

Appendix E

Recording Form
(All information will be kept anonymous.)

Participant number: ______________________

Age: ______________________

Use of oral contraceptives: ______________________

First day of last menstrual cycle: ______________________

Room temperature: ______________________ ºF

Room humidity: ______________________

Appendix F

Hearing Screening

Instructions to participant: *I am going to put these headphones on your head. When you hear a beep, please raise your hand on the side you heard the beep. For example, if you hear the beep in your right ear, please raise your right hand. Do you have any questions?*

Participant ID: ______________________

Audiometer ID: ______________________

Right Ear		**Left Ear**	
500 Hz:	______________________	500 Hz:	______________________
1000 Hz:	______________________	1000 Hz:	______________________
2000 Hz:	______________________	2000 Hz:	______________________
4000 Hz:	______________________	4000 Hz:	______________________

All tones presented at 20 dB.

Appendix G

Screening for Vocal Pathology – Instructions to Participant

1) "I want you to hold the vowel /a/ at a comfortable pitch and loudness for about 3 seconds. Let me know when you're ready." (Repeat with vowel /i/.)

2) "I'm going to show you some cards one at a time. Each card has a sentence on it. I would like you to read each sentence as if you are in a conversation with someone."

Sentences on cards:

a. The blue spot is on the key again.

b. How hard did he hit him?

c. We were away a year ago.

d. We eat eggs every Easter.

e. My mama makes lemon jam.

f. Peter will keep at the peak.

Appendix H

SF_0 Tasks – Instructions to Participant

1) "I want you to **read this passage** at a comfortable pitch and loudness. Let me know when you're ready."

2) "Using a comfortable pitch and loudness, I want you to tell me about what you like to do most in the summertime. I will tell you when to stop. Let me know when you're ready."

3) "Using a comfortable pitch and loudness, **count slowly from 1 to 10**. Let me know when you're ready."

4) "I want you to hold the **vowel /a/** at a comfortable pitch and loudness for about 8 seconds. I will tell you when to stop. Let me know when you're ready."

5) "Using a comfortable pitch and loudness, **count from 1 to 3, and hold the vowel /i/** at the end of the word "three" for about 5 seconds. I will tell you when to stop. Let me know when you're ready."

F_0 Range – Instructions to Participant

"When I tell you, begin at a comfortable pitch and step up to the highest pitch you can, like this [demonstrate]. Next I want you to start at a comfortable pitch and step down to the lowest pitch you can without sounding gravelly, like this [demonstrate]. It should not sound like this [demonstrate glottal fry].

Appendix I

Task #	Mean F_0	F_0 Standard Deviation	F_0 Range
_________	_____________ Hz	___________________ Hz	____________________ Hz
_________	_____________ Hz	___________________ Hz	____________________ Hz
_________	_____________ Hz	___________________ Hz	____________________ Hz
_________	_____________ Hz	___________________ Hz	____________________ Hz
_________	_____________ Hz	___________________ Hz	____________________ Hz

F_0 Range	_______________________________ Hz
Minimum F_0	_______________________________ Hz
Maximum F_0	_______________________________ Hz
Range in semitones	_______________________________
20th percentile	_______________________________

Appendix J

Rainbow Passage (Fairbanks, 1960, p. 127)

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Throughout the centuries men have explained the rainbow in various ways. Some have accepted it as a miracle without physical explanation. To the Hebrews it was a token that there would be no more universal floods. The Greeks used to imagine that it was a sign from the gods to foretell war or heavy rain. The Norsemen considered the rainbow as a bridge over which the gods passed from earth to their home in the sky. Other men have tried to explain the phenomenon physically. Aristotle thought that the rainbow was caused by reflection of the sun's rays by the rain. Since then physicists have found that it is not reflection, but refraction by the raindrops which causes the rainbow. Many complicated ideas about the rainbow have been formed. The difference in the rainbow depends considerably upon the size of the water drops, and the width of the colored band increases as the size of the drops increases. The actual primary rainbow observed is said to be the effect of superposition of a number of bows. If the red of the second bow falls upon the green of the first, the result is to give a bow with an abnormally wide yellow band, since red and green lights when mixed form yellow. This is a very common type of bow, one showing mainly red and yellow, with little or no green or blue.

Appendix K

Mean SF_0 values for each participant in all tasks

Participant	Rainbow Passage	Spontaneous Speech	Counting 1-10	Sustained /a/	Sustained /i/ after counting 1-3	F_0 Range		
						20th percentile	Minimum F_0	Maximum F_0
1	187.84	186.78	190.92	171.96	177.43	153.99	110.49	647.96
2	201.93	200.15	202.66	186.54	211.37	128.59	81.14	961.92
3	202.34	213.5	227.79	178.93	226.55	243.22	202.74	555.74
4	208.66	207.02	218.45	226.95	213.67	156.45	101.94	1029.19
5	197.44	188.52	209.25	249.86	213.32	236.50	182.90	725.73
6	185.84	174.89	186.59	192.06	187.00	135.85	87.58	929.97
7	202.77	205.93	199.37	223.21	207.12	211.31	172.41	525.55
8	195.14	187.15	185.31	219.70	199.99	211.72	170.90	560.48
9	212.79	223.62	247.32	167.29	246.17	252.20	192.97	819.38
10	183.35	176.55	190.19	190.30	223.50	237.98	188.03	657.61
11	200.67	203.58	219.61	214.00	218.06	222.69	172.22	682.96
12	190.13	163.44	202.79	208.55	210.49	242.83	183.82	627.49
13	190.93	165.27	218.06	217.76	219.52	248.78	192.40	801.82
14	156.68	160.83	222.50	167.44	209.50	226.51	178.91	622.18
15	193.95	202.82	211.74	187.72	226.85	233.03	190.13	559.07
16	180.12	172.81	200.71	214.91	204.45	229.14	177.21	713.65
17	200.49	202.36	219.97	220.09	187.99	222.19	164.63	839.67
18	157.03	124.59	157.27	174.32	207.68	239.41	197.44	569.00
19	184.04	174.81	178.37	225.92	191.06	190.10	139.35	754.18
20	195.69	206.25	193.62	234.68	221.90	228.13	174.55	748.25
21	188.20	185.32	196.57	213.46	193.62	203.63	166.14	490.42

Note: All SF_0 values are in Hertz