LAUGHTER IN CONGENITALLY DEAF VERSUS NORMALLY HEARING COLLEGE STUDENTS: AN ACOUSTIC ANALYSIS

A Thesis
Presented to the Faculty of the Graduate School
of Cornell University
In Partial Fulfillment of the Requirements for the Degree of
Master of Arts

by
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January 2006

ABSTRACT

The developmental and phylogenetic origins of human laughter are not well understood, with available evidence inconsistently suggesting both innate stereotypy and high variability in laughter acoustics. We examined this issue by investigating laughter in 19 congenitally deaf college students, with little or no auditory experience, and in 23 normally hearing college students. Acoustic analyses focused on temporal and spectral features, as well as vocal production modes. Repeated-measures ANOVA testing indicated marked similarity in laughter produced by the two groups. Acoustic differences that did occur in amplitudes ($p < 0.01$) and durations ($p < 0.01$) of the laughs likely reflect socially prescribed suppression of loud vocalizations by the profoundly deaf, but may also result from higher phonation thresholds or weakened vocal-fold responsivity. Finding overall similarity in laugh acoustics indicates an innate foundation for the neural circuitry involved, and that specific auditory experience is not a prerequisite for the development of these species-typical sounds. Nonetheless, laugh acoustics within both groups were also quite variable, suggesting diversity, rather than stereotypy in underlying motor behavior.

BIOGRAPHICAL SKETCH

Maja's broad research interests surround the study of social and vocal behaviors of mammals, including humans. Prior to her arrival at Cornell University, Maja prepared herself for graduate work by participating in a selection of academic and practical work experiences. As an undergraduate, she attended the University of Virginia, Charlottesville, VA (Bachelor of Arts in Biology, May, 2001), and spent one year in the Biology and Ecology Department at the University of Wroclaw, Wroclaw, Poland. Her work experience is quite diverse and includes investigating segmentation genes as a laboratory assistant in Dr. E. Seaver's lab at the Pacific Biomedical Research Center, University of Hawaii, Honolulu, HI, analyzing coyote vocalizations as a research associate working with Dr. Brian Mitchell on the Dye Creek Preserve Preditor Research Project, U.C. Berkeley, Los Molinos, CA, caring for bottlenose dolphins and assisting with research on dolphin cognition as an intern at the Kewalo Basin Marine Mammal Laboratory, University of Hawaii, Honolulu, HI, designing nesting compartments for captive penguins as an intern in the Ethology Department at Zoo de Vincennes, Paris, France, caring for the wellbeing of barn animals as an animal attendant a the Busch Gardens Williamsburg Menagerie, Williamsburg, VA, helping collect data on the human visual perception of movement as a research assistant at Dr. Michael Kubovy's Cognitive Psychology Laboratory, University of Virginia, Charlottesville, VA, and helping with everyday research and cleaning tasks as a student researchers at the Elephant /Rhino/Taper House at the Virginia Zoological Park, Norfolk, VA.

In her free time Maja enjoys dancing, singing, especially with Cornell's Chordials, running, sailing, hiking, skipping, unicycling and teaching. In the past she has participated as a camp counselor and co-coordinator at music camps for special needs youth hosted in Poland. She has co-coordinated and taught summer day camps for children from financially collapsed neighborhoods. Most recently she has enjoyed working with the Cornell University Graduate Student School Outreach Program, Cornell University, Ithaca, NY. Though this program she has created and implemented an interactive 8-lesson program on Cetacean Ecology and Research at Lou Gosset Correctional Facility, Lansing, NY (Spring 2004), and an interactive course entitled The Brain, Perception, Sensation, and Illusion which was presented to the AP Biology class in Ithaca High School, Ithaca, NY (Spring 2005).

To Krystyna Karminska-Makagon, Andrzej Makagon, Mateusz Makagon, Jessica Wimmer and Shawn Stuart for their support, motivation and belief in me.

ACKNOWLEDGMENTS

I would foremost like to acknowledge and publicly thank all the individuals who have contributed to this project with their time and effort: Dr. Michael J. Owren for his guidance, support, and expertise at every step of the way, without it this study would not have been started nor completed, Dr. E. Sumie Funayama and Raylene Lotz for sharing with me deaf culture, and for their help with data collection at Gallaudet University, Amy Chu and Maria Borejsza-Wysocka for the countless hours spent processing and analyzing acoustic data, and Danielle Inwald and Douglas Markant for help during the early stages of the project. I would also like to acknowledge John Anderson, Eric Patel, the undergraduate assistants of the Psychology of Voice and Sound Research Lab for their help and input. Finally, many thanks to the many people who have had an indirect impact on this project by having a direct impact on my Cornell University experiences. This project was in part supported by a grant from Cornell University Field of Psychology Graduate Student Research Awards Fund.

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LIST OF ABBREVIATIONS

CU: Cornell University, Ithaca, NY

GU: Gallaudet University, Washington, DC

CHAPTER 1

INTRODUCTION

Laughter is a non-verbal mode of communication that functions in parallel with language, and is common to all humans (Provine & Fischer, 1989; Provine & Yong, 1991). Laughter has been described as innate and universal (Hirson, 1995; Provine, 2000), occurring independently of culture (India: Savithri, 2000; Norway: Svebak, 1975; Tanganyika: Provine, 1996; United States: Bachorowski, Smoski, & Owren, 2001), age, and gender (infants and children: Hall & Allin, 1897; Sroufe & Wunsch, 1972; Grammer & Eibl-Eibesfeldt, 1990; Nwokah, Davies, Islam, Hsu, & Fogel, 1993; Mowrer, 1994; adults: Hall & Allin, 1897; LaPointe, Mowrer, & Case, 1990; Bachorowski et al., 2001).

Laughter is first produced by 4-6 month old infants (Grammer & Eibl-Eibesfeldt, 1990), and remains relatively unchanged during the first year (Sroufe & Wunsch, 1972). Emergence of laughter in normal form in deaf-blind babies (Black, 1984), who due to their condition are unable to learn the behavior through mimicry, supports the idea of laughter innateness, and suggests a possible early evolutionary origin (Darwin, 1872; Grammer & Eibl-Eibesfeldt, 1990; Nwokah et al., 1993). This latter interpretation of early phylogeny is supported by anecdotal evidence of laugh-like sounds occurring in several great ape species (chimpanzees: Darwin, 1872; van Hooff, 1972; Marler & Tenaza, 1977; Goodall, 1986; gorillas: de Waal, 1988; bonobos: Barmejo & Omedes, 1999), and perhaps other mammalian species (rats: Panksepp & Burgdorff, 2000).

To better understand the origins of laughter at the intra- or inter-species level it is important to first understand the development of the behavior, and particularly to differentiate between aspects of the behavior that are inborn and those that are learned. This differentiation can be accomplished by investigating the degree to which the emergence of laughter depends on exposure to laughter of others. To that end, the current work looks at the long-term development of laughter in the absence of auditory experience, by examining laughter produced by congenitally, bilaterally, and profoundly deaf adults, and comparing it to that produced by normally hearing adults.

Laughter innateness, and the role of experience.

Innateness is a biological concept, the use of which has often caused confusion (Alberts & Decsy, 1990). Two central issues contributing to this confusion are what it means for a behavior to be innate, and what about the behavior is presumed to be innate (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1996). The concept of innateness (that a characteristic is predetermined) is often confused with being congenital (that a characteristic is present at birth) (Alberts & Decsy, 1990). Unlike congenital features, which are only constrained in time, innate features are governed by chronotypy, referring to their occurrence at a particular age, heritability, the influence of genetic variance, and coupling in sender-receiver systems (Alberts & Decsy, 1990; Elman et al., 1996). It is also important to note that the development of any behavior is an interactive process that merges innate characteristics governed by population-based parameters with the effects of variable experiences at the level of the individual (Alberts & Decsy, 1990). Therefore, a behavior may have features that fit the criteria outlined above and be presumed to be innate, while also having features that are shaped by individual experience.

Past research indicates that laughter may have components of an innate behavior. Laughter seems to be constrained by chronotypy, as it consistently emerges between the 4th and 6th month of life. Although no studies have addressed the heritability of laughter directly, Black's (1984) account of normal laughter production and onset in a deaf-blind infant suggests that the behavior requires neither visual or auditory experience, may therefore be genetically preprogrammed, and is not primed or learned (Hirson, 1995). This interpretation gains some support from laughter's ubiquitous (Citardi, Yanagisawa, & Estill, 1996) and involuntary (Nwokah, Hsu, Davies, & Fogel, 1999) nature, and from the observation that laughter episodes seem to proceed in an automated, reflex-like fashion once triggered (Hirson, 1995; Provine, 2000). Anecdotal evidence for signaler-receiver coupling comes from descriptions of laughter as an easily recognizable behavior (Provine & Yong 1991; Nwokah et al., 1993).

While available information suggests laughter is innate, components of the behavior may nonetheless be undergoing socially and environmentally guided modification (Alberts & Decsy, 1990; Nwokah et al., 1993; Mowrer, 1994; Hirson, 1995). Le Pointe et al. (1990) noted significant changes in several acoustic measures of laughter produced by 20- versus 70-year old adults, these included differences in number of laughs produced, pitch-related measures and the rate of laughter production. Although differences in physiology and sense of humor may have played a role in their results, the possibility of alternate environmental factors, such as social learning, cannot be excluded.

Laughter lacks a definition

Laughter consists of two components, a visual display and a vocalization. The visual display has been thoroughly discussed in scientific literature (e.g., Darwin, 1872; van Hooff, 1972), while the acoustics of human laughter have only more recently begun to receive significant scientific attention (Bachorowski et al., 2001; Kipper & Todt, 2001). Because deaf individuals have access to the visual, but not the auditory component of laughter, the current study focuses on the latter. Therefore, the term “laughter” will be used to refer solely to vocal aspects of the behavior.

Despite laughter’s status as an apparently ubiquitous human behavior (Citardi et al., 1996), it has yet to be empirically defined (Ruch & Ekman, 2001; Mowrer, 1994). Commonly cited descriptions characterize laughter as stereotyped “ha-ha” vocalizations associated with social playfulness and positive affect (Nwokah et al., 1993; Provine & Yong, 1991; Pelsmaekers, 2004). These intuitive descriptions are, however, challenged by multiple qualitative and quantitative analyses indicating that laughter encompasses an array of sounds (Darwin, 1872; Hall et al., 1897; Nwokah et al., 1993; Edmonson, 1987; Mowrer, LaPointe, & Case, 1987; Bachorowski et al., 2001), and that it can be triggered by a variety of positive and negative stimuli, including glee, humor, tickling, surprise, nervous tension, embarrassment, and threat, just to name a few (Hirson, 1995; Kipper & Todt, 2001; Ruch & Ekman, 2001; Pelsmaekers, 2004).

The large number of contexts that are believed to trigger laughter have made it difficult to interpret the function of this behavior. High rates of occurrence in social interactions suggest that laughter plays an important role in communication (Mowrer et al., 1987; Provine & Yong, 1991; Nwokah et al., 1993; Nwokah et al., 1999). Reports that laughter occurs in over 56% of infant social episodes associated with pleasure (Papousek, Papousek, & Koester, 1986) indicate that laughter may play a role in mother-infant bonding (Nwokah et al., 1993). In addition, its common occurrence in conversational speech suggests that laughter might also function to clarify and punctuate speech content (Nwokah et al., 1999; Provine, 1993). Grammer (1994) postulated that in combination with body position, laughter can be used to carry information about the laugher’s attitude towards the listener. In contrast, the affect-induction theory (Owren & Rendall, 1997) suggests that rather than communicate specific information about the laugher, laughter functions to instill a positive emotional state in the listener (Owren & Bachorowski, 2003).

Laughter acoustics

A review of laughter acoustics studies reveals two different views. The first, outlined by Provine et al. (1991), describes laughter as having a simple and stereotyped structure. The other emphasizes structural variability and was anecdotally described in the works of Darwin (1872) and Hall and Allin (1897). More recently, quantitative evidence of variability has been provided by Mowrer et al. (1987), Nwokah et al. (1993), Bachorowski et al. (2001), and Vettin and Todt (2004). The discrepancy between the two views may in part reflect differences in the operational definition of laughter used or in laughter context (Hirson, 1995). Findings from several influential studies are outlined below.

In their work, Provine and Yong (1991) elicited laughter by asking 51 participants, 28 females and 23 males, to “simulate hearty laughter” (p. 116). The resulting data were almost entirely composed of what the authors qualitatively called “ha-ha” laughter, which they concluded to be the most common variant. They reported that laughter was composed of nearly identical laugh-notes that resembled the syllables “ha,” “he,” or “ho,” and that it was temporally symmetrical, so that laughter sounded the same whether each note was played forwards or backwards. Although Provine and Yong described the syllables as vowel-like, they emphasized that the vocal tract resonances (or formant frequencies) involved were not the same as those used in speech (see Table 1.1 for definitions of these and other terms from acoustics and vocal production). Each laugh was found to be composed of a minimum of 4 and maximum of 16 notes, with each note lasting approximately 75 ms. Note durations were found not to vary across participants, although durations of the first 4 notes did vary by position for female participants in particular. For both sexes, internote intervals significantly increased, and note amplitudes decreased over the course of a laugh. Provine and Yong concluded that laughter has a “sonic signature” characterized

Table 1.1
Definitions [and unit labels] of terms and measures from acoustics and vocal production.

Measure	Definition
Bout	
Duration	Time between bout onset and offset. [s]
Percent-voicing	Average amount of voicing per bout; Σ(call percent-voicing)/no. calls per bout. [%]
Call	
Duration	Time between call onset and offset. [s]
Fundamental frequency (F0)	Lowest frequency component of a sound. [Hz] Component of a sound that is perceived as pitch.
Formant frequency	Central frequency of a formant, where a formant refers to the resonance of the vocal tract[1]. [Hz]
Percent-voicing	Average amount of voicing per call, where voicing refers to the production of sound through the vibration of the vocal fold. [%]
Raw amplitude	Strength of a sound without regard to its frequency content[2]. [dB] Component of a sound that is perceived as loudness.
Relative amplitude	Normalized call amplitude; mean call amplitude divided by the amplitude of a 700-Hz calibration tone.

[1] From Kent (1997)
[2] From White (1987)

by stereotyped features, including note structure, duration, and amplitude. Provine (2000) further stated that taken together with the idea of laughter innateness, these results suggest that laughter is a fixed behavior, one that does not change over time.

Nwokah et al. (1993) recorded four 3-year-old children during spontaneous free-play with their mothers. These researchers used a different terminology than Provine and Yong (1991) and described laughter in terms of "syllables" rather then notes. The syllables were reported to last 200-220 ms, or longer for laughter produced during heightened states of arousal. The fundamental frequency (F0), or pitch (see Table 1.1), was highly variable and ranged from 300-3000 Hz. Mean F0 fell between 400-500 Hz and was reported as higher than the mean F0 of infant speech (300 Hz). Based on differences in F0, harmonic structures, and the number of amplitude peaks per laugh event, Nwokah et al. distinguished among 4 acoustic laughter-types, which they suggested were also perceptually different. Individual differences in laughter acoustics were also reported.

Mowrer et al. (1987) elicited laughter from 11 male college students by showing them a funny video-clip. The researchers analyzed the first 5 laugh events produced by each participant, and compared the acoustics of these sounds to the acoustics of speech produced by the same individual. The result was a list of acoustic characteristics deemed to be typical of laughter. A high maximum F0 (see Table 1) was considered the strongest feature of laughter, and was reported to reach values twice as high as the mean F0 of speech. Large F0 range (106.5-450.6 Hz) was also considered a distinguishing feature, with the first syllable being similar to speech, but varying thereafter. Laugh duration, which ranged from 0.19-3770 ms, was positively correlated with the number of syllables within one laughter episode (between 1 and 25). Laugh rate was measured as an average of 5.55 syllables/s, distinctly slower than the rate of speech, which was 3.84-3.94 syllables/s. Finally, laughter was characterized by great variability in all measures within and between individuals. Mowrer and his colleagues suggested that these differences might reflect the amount of humor perceived by each participant.

Bachorowski et al. (2001) expanded on the Mowrer et al. (1987) study, producing the most comprehensive acoustic analysis of laughter to date. The researchers analyzed a total of 1024 laughter episodes from 97 participants, 52 females and 45 males, and included all sounds that would be perceived as laughter by ordinary listeners in their analysis. They found that laughter could be either voiced and vowel-like (produced though vibration of the vocal folds), or unvoiced and noisy (produced with turbulent air flow and not vocal-fold vibration). Although this distinction had been described a decade earlier by Grammer and Eibl-Eibesfeldt (1990), most investigators only considered the voiced type in their research. In doing so they included only a fraction of laughter sounds in their analyses, which may have biased those results. Bachorowski and colleagues reported that unvoiced laughs were the most common type, making up 48% of the total number of laughter events analyzed. Fully voiced laughs, which Provine and Yong (1991) had reported to be the most common variant, and which most research has focused on, made up only 30% of this sample. The remaining 22% was a mix of types. Laughs were also categorized according to production mode. The researchers reported laughs being produced using open- and closed-mouth positions, and on inhalation as well as exhalation. Laughs lasted just under 1 s, and contained an average of 3.39 syllables, which in this study were referred to as “calls.” Mean call duration was 170 ms, and laughs were produced at a rate of 4.37 calls/s, lower that that reported by Mowrer et al. (1987), but higher than in speech. Mean F0s of voiced laughter were 405 Hz and 272 Hz for female and male participants, respectively, both significantly higher than reported mean F0s of speech. Formant frequency analysis indicated that whether voiced or unvoiced, laughter was largely unarticulated, meaning that it did not have distinctive vowel qualities (such as “ha,” “ho,” or “he”). Overall, Bachorowski and colleagues provided strong support for the position that laughter is highly variable.

Vettin and Todt (2004) investigated laughter occurring spontaneously during the course of conversation. For this study, laughter was not purposefully elicited, but instead recorded opportunistically from 10 individuals (6 females, 4 males) in a natural, as well as an experimental setting. The researchers found that conversational laughter was characterized by a mean of 3 syllables, ranging between 1 and 21 syllables. Mean F0 was reported to be 315 Hz for females and 171 Hz for males, with maximum F0s of 357 Hz and 199 Hz, respectively. Similar to laughter elicited by humorous videos, conversational laughs were characterized by quite variable temporal and F0 characteristics. Overall, however, both the number of syllables per laugh and mean F0 in these syllables were lower than in humor-induced laughs. The researchers concluded that laughs produced under various contexts may be acoustically differentiated, and suggested that results from any one particular analysis may not be generalizable to laughter as a whole. This conclusion supported earlier findings (Milford, 1980) of acoustic specificity in laughter produced in different contexts.

Overall, studies of laughter have often produced inconsistent results. Different operational definitions of laughter, particularly the inclusion of unvoiced as well as voiced types of laughs in the analyses, have likely contributed to these variable results. As Mowrer et al. (1987) and Nwokah et al. (1993) suggested, differences may also reflect variation in the individual reaction to particular humorous stimuli or other stimulation involved. Similarly, some of the differences found between Provine and Yong’s (1991) findings and the other research may be due to differences in context, as suggested by Vettin and Todt (2004). The laughter produced by Provine and Yong’s participants may also not have been completely spontaneous, as they were explicitly asked to simulate laugh sounds. Overall, discrepancies between the reviewed studies underscore the variability that has been reported by Darwin (1872), Hall and Allin (1892), Mowrer et al. (1987), Nwokah et al. (1993), Bachorowski et al. (2001), and Vettin and Todt (2004).

The current work

The current study extends previous laughter acoustics research, and investigates current theories of laughter development and innateness by comparing acoustic features of laughter as it emerges in the absence versus presence of auditory experience. Laughter produced by congenitally, bilaterally, and profoundly deaf college students was acoustically analyzed and compared to laughter from normally hearing students elicited in the same context. If socially proscribed long-term development affects the behavior, laughter produced by the deaf participants (who have had minimal experience with sound) should be significantly different than laughter produced by hearing participants (who have had a lifetime of experience with laughter sounds). These differences should be greater then those traceable to factors such as individual intensity in response (Mowrer et al., 1987), or individual differences in vocal physiology (Nwokah et al., 1993). The results of this study provide information on the emergence of laughter in the absence of exposure to laughter sounds, which has implications for the innate and phylogenic origins of this behavior.

CHAPTER 2

METHODS

Participants

Eight female and 5 male students enrolled at Gallaudet University (GU) and 6 female and 6 male students enrolled at Cornell University (CU) were recruited for this study. GU students were recruited with fliers posted throughout campus, while CU participants were recruited through an experiment participation recruitment website (susan.psych.cornell.edu). The recruits were instructed to come to the laboratory with a same-sex friend, bringing total participation to 26 GU and 24 CU students.

All participants reported fluency in written English, good or corrected-to-good vision, and the absence of any respiratory ailments. GU students were screened for age at diagnosis of deafness, severity and type of deafness, and history of hearing-aid use. Those meeting the strict criteria of congenital, bilateral, and profound deafness were included in the deaf study group. Refer to Table 2.1 for a summary of GU participant demographics and to Table 2.2 for the definitions of deafness severity used to screen GU participants. CU participants were screened for the lack of hearing problems, and constituted the hearing group for this study.

Recordings from 5 GU students (3 females, 2 males) were excluded from analysis due to recent hearing-aid use (less then 6 years since last use). Additionally, 1 GU male did not meet the hearing loss severity criteria, and 1 GU female produced no laughter. Data from 1 CU female were discarded due to poor sound quality. In the end, 19 GU (12 profoundly deaf females, 6 profoundly deaf males, and 1 severely deaf male) and 23 CU participants constituted the deaf and hearing samples, respectively. Data from the severely deaf participant were included in the analysis, as that participant had never used hearing aids, and his experience with sound was deemed comparable to that of profoundly deaf individuals with a history of hearing-aid use.

Table 2.1
Gallaudet University Participant Demographics.

Participant	Age	English fluency	First language	Deafness severity	Hearing aid use	Time since last use	Helpful?	Vision: good/ corrected	Respiratory ailments
M1	19	Y	ASL	Profound	N			Y	N
*M2	18	Y	ASL	Mild	Y	>10 yrs	N	Y	N
F3	29	Y	Hebrew	Profound	Y	>10 yrs	N	Y	N
F4	20	Y	ASL	Profound	N			Y	N
F5	19	Y	ASL	Profound	Y	>10 yrs	N	N/Y	N
*F6	19	Y	ASL	Profound	Y	1 month	N	Y	Y
M7	21	Y	ASL	Profound	Y	>10 yrs	N	Y	N
M8	23	Y	English/ ASL	Profound	Y	>10 yrs	N	N/Y	N
F9	22	Y	ASL	Profound	Y			Y	Y
F10	22	Y	ASL	Profound	Y	>10 yrs	N	Y	N
M11	29	Y	ASL	Severe	Y	>20 yrs	N	Y	N
M12	21	Y	ASL	Profound	N			Y	N
F13	20	Y	English/ ASL	Profound	Y	6 yrs	N	Y	N
*F14	35	Y	ASL	Severe	Y	days	Y	Y	Y
F15	45	Y	n/a	Profound	Y	>10 yrs	N	Y	N
F16	52	Y	ASL	Profound	Y	> 40 yrs	Y	N/Y	N
F17	19	Y	ASL	Profound	Y	6 yrs	N	N/Y	N
F18	20	Y	ASL	Profound	N			Y	N
F19	22	Y	ASL	Profound	Y	6 yrs	N	Y	N
*F20	22	Y	English/ ASL	Severe	Y	2 yrs	Y	N/Y	Y
*F21	34	Y	ASL	Profound	Y	>10 yrs	N	N/Y	N
F22	35	Y	ASL	Profound	Y	>20 yrs	N	Y	N
M23	22	Y	ASL	Profound	Y	>10 yrs	N	N/Y	N
*M24	24	Y	ASL	Profound	Y	7 yrs	Y	Y	Y
*M25	22	Y	English	Severe	Y	1 day	Y	Y	N
M26	26	Y	ASL	Profound	N			Y	N

* Data removed from analysis

Table 2.2
Deafness Category Definitions

Category	Definition
Congenital	Present at birth.
Bilateral	Affects both ears.
Mild	A 26-40 dB loss. Difficulty in understanding normal speech.
Moderate	A 41-55 dB loss. Difficulty in understanding loud speech.
Moderate to severe	A 56-70 dB loss. Difficulty in understanding speech without amplification (hearing aids) unless speech is very loud.
Severe	A 71-90 dB loss. Inability to understand speech without amplification (hearing aids). With amplification speech can be understood through a combination of speech-reading and auditory support.
Profound	A >90 dB loss. Inability to understand speech even with amplification. Awareness of vibrations but not sound.

Stimuli

Eight short movie clips compiled on a DVD were used as stimuli. Half of the clips were funny, chosen for their laugh-inducing potential, while the others were deemed to be neutral and were included to validate the cover story. In order to appeal to both deaf and hearing students, the clips emphasized physically based action with minimal reliance on dialogue. All clips included English subtitles. Deaf students viewed the movie clips without sound, while hearing students viewed the clips at a preset low volume level. Presenting the clips at this quiet volume was explained as an attempt to minimize the amount of background noise on the audio recordings, while the presence of subtitles was said to be a clarification of the dialogue in the event that the volume was too low. Table 2.3 provides an overview of movie titles, clip descriptions, and clip durations.

Apparatus

Participant testing at both GU and CU occurred in small rooms equipped with two captain's chairs, two head-worn microphones, and a 20" Scott Technology model HT200 television (Dallas, TX). The DVD containing the movie clips was created on a Power Mac G5 processor equipped with Mac OSX iMovie and iDVD software (Apple Computer, Cupertino, CA), and was played from an Apex AD-660 DVD player (Apex Digital, Walnut, CA) located in an adjacent control room. The control room also housed all audio-recording equipment. A two-way mirror allowed visual access from the control room into the testing room.

Each participant's vocalizations were recorded through a head-worn microphone, the tip of which was positioned 1 inch from the left corner of the participant's mouth, and perpendicular to the axis of the face. The signal from the microphone was routed through a Whirlwind SP1x3 Mic Splitter (Whirlwind, Rochester, NY), and the two resulting signals were fed into the left and right channels

Table 2.3
Stimulus Movie Clip Summary

Movie Title	Clip Description	Duration [s]
Robin Hood Men in Tights[a] (Brooks,1993)	Robin Hood returns to Locksley only to find his castle is being repossessed.	195
Harry Potter and the Sorcerer’s Stone (Columbus, 2001)	Harry and Ron battle a troll that has cornered Hermoine in the girl’s bathroom.	207
Grumpy Old Men[a] (Petire, 1993)	Max and John engage in a war of pranks.	150
The Trouble with Mr. Bean[a] (Atkinson et al., 1989-95)	Mr. Bean goes to the dentist.	207
Ocean’s Eleven (Sodenberg, 2001)	The Ocean's 11 team attempts to blow up a casino vault door.	255
The Naked Gun[a] (Zucker, 1988)	Detective Nordberg has a series of mishaps as he attempts to stop a cocaine deal.	135
Reign of Fire (Bowman, 2002)	Young Quinn watches as his mother accidentally wakes a dragon.	144
Cast Away (Zemeckis, 2000)	Chuck is spotted by a ship while floating in the ocean on a home-built raft.	287

Note. Movie clips appear on DVD in the order listed.
[a] Laughter-inducing movie clip

of a Marantz CDR300 professional CD recorder (D&M Holdings, Itasca, IL). To ensure high-quality recordings of laughs produced at any amplitude, these channels were set at different recording levels. Levels were calibrated prior to each session to a constant-amplitude 700-Hz tone produced by a Shure A15TG tone generator (Shure, Niles, IL) connected to an Audio-Technica AT8202 adjustable in-line attenuator (Audio-Technica U.S., Stow, OH), set at –10 dB.

Recordings were made digitally at a 44.1 kHz sampling rate and stored in AIFF format on the resulting CDs. Acoustic data were processed with Praat (Boersma and Weenink, 1996; available at www.praat.com) running on the Power Mac G5, and analyzed with ESPS/waves+ 5.3 (Entropic Research Lab, Washington, D.C.) software running on a Silicon Graphics O2 unix-based processor with the Irix 6.3 operating system (SGI, Mountain View, CA). A Dell Dimension 2400 (Dell Computer, Round Rock, TX) equipped with Microsoft Windows XP Professional, and running NCSS Statistical Analysis System (NCSS, Kaysville, UT) was used for statistical analysis.

Procedure

Participants came to the laboratory in same-sex friend pairs under the impression that they would be participating in a study investigating a possible link between emotion and breathing sounds. This belief was reflected information outlined in the recruitment materials, and was reinforced once the participants arrived at the lab. This cover story was meant to explain why recordings were being done, and to help ensure that any laughter produced during the session was spontaneous and natural. Prior to testing, each participant completed short demographic and screening questionnaires, and read and signed a general procedure consent form explicitly permitting both audio recording of the session and subsequent use of audio-recorded data.

Instructions given to hearing students were read aloud from a form. Deaf students received the same instructions translated into American Sign Language by a native ASL signer. Participants were given multiple opportunities to ask questions, and were informed that they would be compensated for their participation whether or not they completed the study. In the instructions the two participants were asked to make themselves comfortable in the captain's chairs, to relax, and to imagine themselves at a friend's house watching television. They were prompted to put on the head-worn microphones, which the experimenter adjusted to the standard recording position. Participant attention was then directed toward the television screen, which was located 6 feet in front of the chairs. Before leaving the testing room, the experimenter reminded participants that their only task was to sit back, relax, and watch the movie clips. At the end of the session, participants were thoroughly debriefed, learned the true nature of the study, and read and signed a fully informative consent form.

Laugh selection, classification, and acoustic analysis

Data processing and analysis was conducted in the Psychology Department at Cornell University. Acoustic data were uploaded onto a Power Mac G5 processor. Two independent listeners, an undergraduate research assistant and the author, extracted laughter clips from the recordings. Praat software was used for simultaneous sound extraction from the left and right recording channels. Only sounds from the better-quality channel, and that both listeners identified as laughter, were used in analysis. Segments containing speech directly preceding, directly following, or overlapping the laughter episode were later excluded from analysis, as speech has been shown to alter laughter acoustics (Nwokah et al., 1999). The remaining uninterrupted laughter files were uploaded onto the SGI workstation.

Each laughter file was labeled at the bout and call level. Following Bachorowski et al. (2001), a bout was defined as one entire laughter episode, while a call was a discrete event or syllable within that episode. Onset and offset times for bouts and calls were marked with cursor-based labels by one of three trained undergraduate research assistants. Each call was further labeled as being produced on an inhalation or exhalation, and through either an open, closed, or mixed mouth position. The mixed mouth position described calls in which the laugher alternated between open and closed mouth positions. All onset, offset, and descriptive labeling was later checked for accuracy and consistency by the author.

Prior to automated and semi-automated measurement extraction, all laughter files were down-sampled to 11.025 kHz. Bout duration, as well as call duration, raw amplitude, F0, percentage-voicing, and intercall interval duration data were automatically extracted using unix-scripts. Relative amplitudes were calculated by dividing raw call amplitudes by the amplitude of the baseline 700-Hz tone recorded on the appropriate channel at the beginning of the session. Formant frequencies were extracted from all calls produced by deaf laughers with enough voicing to allow for this analysis, and from a representative sample of calls produced by hearing laughers. Formant measurement procedures followed those outlined in Bachorowski et al. (2001), and involved automatic registration of formant-peak locations apparent in LPC spectra (10 coefficients; 40-ms Hamming analysis window; autocorrelation method) overlaid on FFT spectra (40-ms, Hanning analysis window) computed over the same waveform segment (see Bachorowski et al., 2001). Definitions of each measure are given in Table 1.1.

Percent-voicing outcomes from the automatic F0 extraction were used to sort each call and bout into one of three voicing categories: unvoiced, mixed, and voiced. An unvoiced sound was one containing 25% or less voicing, mixed sounds contained between 25 and 75% voicing, and voiced sounds were those having 75% or more voicing. Percent-voicing values of calls within each bout were used to compute a mean percentage-voicing at the bout level.

Descriptive statistics and repeated-measures ANOVAs (between factors: hearing status, gender; subject variable: participant number) were used to describe and compare features of laughter produced by the deaf and hearing groups. At the bout level, these features included voicing classification, percent-voicing, and duration. At the call level, measurements included voicing classification, percent-voicing, duration, relative amplitude, mouth position, inhalation/exhalation, and intercall interval.

CHAPTER 3

RESULTS

Bout-level outcomes

Table 3.1 provides an overview of descriptive statistics associated with bout-level analysis, separated by hearing status and gender. Table 3.2 gives overviews of means and standard deviations of individual participant outcomes. A total of 278 bouts of laughter produced by deaf participants and 734 bouts of laughter produced by hearing participants were analyzed. Of deaf laughter bouts, 78.4% were classified as unvoiced, 16.9% as mixed, and 4.7% as voiced. Similarly, 71.3% of hearing laughter bouts were unvoiced, 25.7% were mixed, and 3% were voiced. The number of bouts of each type did not vary by hearing status, $F(1, 1011) = 0.95$, $p = 0.33$, or gender, $F(1, 1011) = 0.07$, $p = 0.79$. Furthermore, no significant difference was found in the average amount of voicing per bout with respect to hearing status, $F(1, 1011) = 0.12$, $p = 0.73$, or gender, $F(1, 1011) = 0.18$, $p = 0.67$. Table 3.3 presents results of repeated-measures ANOVA comparisons of percent voicing with respect to hearing status, gender, and bout voicing types. Relevant means are shown in Figure 3.1. The box plots in Figure 3.2a show variation in percent-voicing data by hearing status, while box plots in Figure 3.2b and 3.2c show variation in percent-voicing data by participant. These plots suggest that the percent-voicing distributions are similar for both study groups.

Not all participants produced laughter bouts in all 3 voicing categories. Unvoiced bouts were produced by 17 of 19 deaf participants and 22 of 23 hearing participants. Eleven deaf and 21 hearing individuals produced mixed bouts, and 3 deaf and 6 hearing participants produced fully voiced bouts.

Duration analysis revealed that deaf laughter bouts (M = 2.03, SD = 2.51) were significantly longer than hearing laughter bouts (M = 1.50, SD = 1.50), $F(1, 1011) =$

Table 3.1
Descriptive statistics associated with bout-level analysis, separated according to laugher hearing status and gender. Standard deviation values are given in parentheses.

Deaf Females (n=12)		Bout-level	
Total (n)	187		
M Calls per bout	4.12 (4.21)		
M Duration[a]	1.92 (0.18)		
M % Voicing	14.21 (21.98)		
Bout type	Unvoiced	Mixed	Voiced
% Total deaf female laughs	77.54	20.32	2.14
% Total deaf laughs	52.15	13.67	1.44
M Duration[a]	1.94 (2.55)	2.10 (0.34)	1.47 (1.23)
Deaf Males (n=7)			
Total (n)	91		
M Calls per bout	5.84 (6.95)		
M Duration[a]	2.23 (2.67)		
M % Voicing	15.14 (29.11)		
Bout type	Unvoiced	Mixed	Voiced
% Total deaf male laughs	80.22	9.89	9.89
% Total deaf laughs	26.26	3.24	3.24
M Duration[a]	2.32 (0.34)	2.15 (1.20)	1.53 (0.62)
Hearing Females (n=11)			
Total (n)	362		
M Calls per bout	4.72 (4.40)		
M Duration[a]	1.42 (1.32)		
M % Voicing	14.64 (20.35)		
Bout type	Unvoiced	Mixed	Voiced
% Total hearing female laughs	72.65	25.69	1.66
% Total hearing laughs	35.83	12.67	0.82
M Duration[a]	1.27 (1.27)	1.89 (1.35)	0.65 (0.82)
Hearing Males (n=12)			
Total (n)	372		
M Calls per bout	4.51 (4.29)		
M Duration[a]	1.57 (1.64)		
M % Voicing	19.05 (25.48)		
Bout type	Unvoiced	Mixed	Voiced
% Total hearing male laughs	69.89	25.81	4.3
% Total hearing laughs	35.42	13.08	2.18
M Duration[a]	1.46 (1.50)	2.02 (2.00)	0.66 (0.36)

[a] measured in seconds [s]

Table 3.2.

Means (and standard deviations) of (a) hearing; and (b) deaf individual participant bout-level outcomes.

a)

Participant Number	Duration [s]	Number of Calls per Bout	Proportion Unvoiced	Proportion Voiced	Proportion Mixed	Percent-Voicing	Number of Calls per Second
Female							
CF11	1.53 (1.03)	6.67 (4.56)	0.50 (0.33)	0.20 (0.24)	0.30 (0.22)	2.09 (3.19)	4.57 (1.05)
CF14	2.02 (1.32)	5.11 (2.95)	0.76 (0.26)	0.07 (0.15)	0.16 (0.21)	15.31 (18.07)	3.09 (1.65)
CF16	1.02 (1.09)	3.24 (2.73)	0.70 (0.41)	0.07 (0.15)	0.22 (0.35)	20.69 (20.24)	4.04 (1.62)
CF24	1.51 (1.30)	3.73 (3.46)	0.82 (0.24)	0.04 (0.10)	0.13 (0.20)	12.03 (15.41)	2.86 (1.35)
CF13	0.82 (1.07)	2.59 (2.59)	0.90 (0.21)	0.06 (0.18)	0.04 (0.11)	8.03 (18.22)	4.18 (1.45)
CF15	2.08 (1.59)	9.14 (6.37)	0.93 (0.15)	0.02 (0.07)	0.05 (0.10)	4.48 (10.51)	4.80 (1.29)
CF7	1.58 (1.22)	5.13 (3.36)	0.92 (0.18)	0.05 (0.14)	0.03 (0.08)	6.10 (14.36)	3.72 (1.63)
CF8	0.97 (1.01)	4.00 (2.65)	0.12 (0.11)	0.69 (0.30)	0.19 (0.20)	69.43 (17.96)	7.32 (4.91)
CF12	0.74 (0.55)	2.32 (1.58)	0.65 (0.40)	0.05 (0.17)	0.30 (0.38)	19.60 (22.07)	3.47 (1.48)
CF17	0.92 (1.37)	2.63 (2.92)	0.67 (0.39)	0.14 (0.27)	0.19 (0.30)	26.78 (24.17)	6.03 (5.49)
CF18	1.76 (1.48)	4.82 (2.89)	0.53 (0.36)	0.15 (0.26)	0.32 (0.30)	30.95 (25.75)	3.79 (1.72)
Male							
CM1	1.86 (1.25)	5.45 (3.56)	0.45 (0.33)	0.33 (0.27)	0.22 (0.28)	40.03 (27.73)	3.06 (1.37)
CM3	2.90 (2.52)	7.02 (7.14)	0.96 (0.12)	0.00 (0.00)	0.04 (0.11)	2.17 (5.62)	2.54 (0.86)
CM9	1.16 (1.19)	3.38 (2.61)	0.80 (0.30)	0.05 (0.13)	0.15 (0.22)	11.20 (18.72)	4.01 (1.96)
CM4	1.47 (1.74)	3.90 (4.42)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	15.55 (20.06)	3.45 (1.85)
CM2	1.47 (1.04)	5.00 (3.21)	0.43 (0.39)	0.16 (0.21)	0.40 (0.29)	40.25 (24.35)	3.81 (2.11)
CM22	1.53 (1.05)	3.73 (2.15)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.84 (0.99)
CM5	1.21 (1.62)	3.30 (4.17)	0.93 (0.18)	0.02 (0.07)	0.05 (0.13)	4.86 (11.82)	4.44 (4.74)

Table 3.2 (Continued)

CM6	1.71 (2.07)	4.44 (4.59)	0.38 (0.33)	0.13 (0.16)	0.49 (0.35)	35.78 (20.43)	3.33 (1.44)
CM10	0.73 (0.68)	2.73 (1.77)	0.91 (0.23)	0.02 (0.07)	0.07 (0.19)	5.87 (14.14)	4.73 (1.65)
CM21	1.81 (1.36)	3.57 (2.24)	0.76 (0.32)	0.15 (0.21)	0.09 (0.14)	19.42 (23.25)	2.33 (1.11)
CM19	1.18 (1.58)	3.45 (3.01)	0.21 (0.34)	0.37 (0.39)	0.42 (0.37)	55.04 (26.73)	4.10 (2.42)
CM20	2.14 (1.30)	7.02 (4.33)	0.77 (0.23)	0.01 (0.04)	0.22 (0.22)	13.17 (11.31)	3.46 (0.79)

b)

Participant Number	Duration [s]	Number of Calls per Bout	Proportion Unvoiced	Proportion Voiced	Proportion Mixed	Percent-Voicing	Number of Calls per Second
Female							
GF3	1.09 (1.03)	2.20 (1.67)	0.78 (0.37)	0.07 (0.23)	0.15 (0.28)	13.70 (22.28)	2.75 (1.85)
GF9	1.75 (1.31)	2.60 (1.26)	0.86 (0.19)	0.00 (0.00)	0.14 (0.19)	9.11 (11.09)	2.25 (1.46)
GF13	2.57 (0.97)	5.38 (2.88)	0.15 (0.14)	0.50 (0.25)	0.34 (0.22)	66.24 (13.82)	2.36 (1.27)
GF15	3.53 (4.37)	6.56 (4.50)	0.79 (0.37)	0.12 (0.24)	0.09 (0.18)	15.90 (29.08)	2.79 (1.48)
GF17	0.40 (0.24)	2.00 (1.26)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.08 (1.80)
GF19	1.65 (0.85)	4.27 (3.26)	0.72 (0.28)	0.04 (0.07)	0.24 (0.27)	17.93 (13.42)	2.50 (0.87)
GF4	1.86 (2.57)	4.91 (8.43)	0.93 (0.16)	0.00 (0.00)	0.07 (0.16)	51.64 (9.32)	3.07 (1.27)
GF5	1.30 (0.77)	3.50 (1.51)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.99 (0.79)
GF10	1.66 (1.91)	3.10 (2.19)	0.98 (0.11)	0.00 (0.00)	0.02 (0.11)	2.24 (3.92)	2.43 (1.20)
GF16	2.09 (1.37)	5.29 (3.31)	0.91 (0.15)	0.03 (0.07)	0.05 (0.10)	5.22 (8.88)	2.75 (1.02)
GF18	1.13 (0.45)	2.80 (1.20)	0.88 (0.20)	0.01 (0.06)	0.11 (0.18)	8.26 (10.68)	2.61 (0.95)
GF22	2.43 (1.82)	4.25 (3.33)	0.96 (0.10)	0.00 (0.00)	0.04 (0.10)	0.85 (2.93)	2.38 (1.46)

Table 3.2 (Continued)

Male							
GM1	0.64 (0.31)	2.00 (1.60)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.06 (5.00)	4.33 (4.70)
GM7	2.61 (1.87)	9.76 (9.30)	0.99 (0.04)	0.00 (0.01)	0.01 (0.04)	0.61 (2.12)	3.77 (2.04)
GM11	4.36 (6.56)	7.50 (11.70)	0.89 (0.31)	0.00 (0.00)	0.11 (0.31)	9.20 (21.39)	3.19 (3.31)
GM23	1.64 (1.05)	4.06 (2.75)	0.30 (0.41)	0.57 (0.38)	0.13 (0.17)	61.00 (37.33)	2.50 (0.75)
GM8	2.38 (1.77)	5.05 (3.05)	0.91 (0.17)	0.03 (0.07)	0.06 (0.13)	6.89 (10.35)	2.79 (1.31)
GM12	1.03 (0.75)	2.50 (0.93)	0.85 (0.27)	0.04 (0.12)	0.10 (0.20)	9.73 (19.49)	3.22 (1.47)
GM26	1.76 (0.76_	2.75 (1.26)	0.94 (0.13)	0.00 (0.00)	0.06 (0.13)	1.99 (3.98)	1.77 (1.27)

Table 3.3
Repeated-measures ANOVA outcomes for percent bouts in each voicing category, separated by statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Unvoiced Bouts	*F*(1, 1011) = 0.53 *p* = 0.47	*F*(1, 1011) = 0.00 *p* = 0.99	*F*(1, 1011) = 0.07 *p* = 0.80
Mixed Bouts	*F*(1, 1011) = 1.55 *p* = 0.22	*F*(1, 1011) = 0.36 *p* = 0.55	*F*(1, 1011) = 38 *p* = 0.54
Voiced Bouts	*F*(1, 1011) = 0.72 *p* = 0.40	*F*(1, 1011) = 2.10 *p* = 0.16	*F*(1, 1011) = 0.51 *p* = 0.48

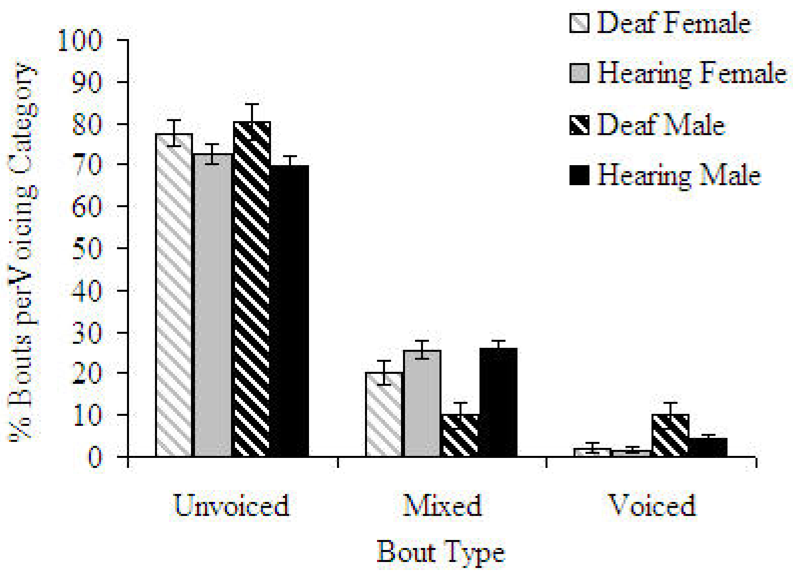
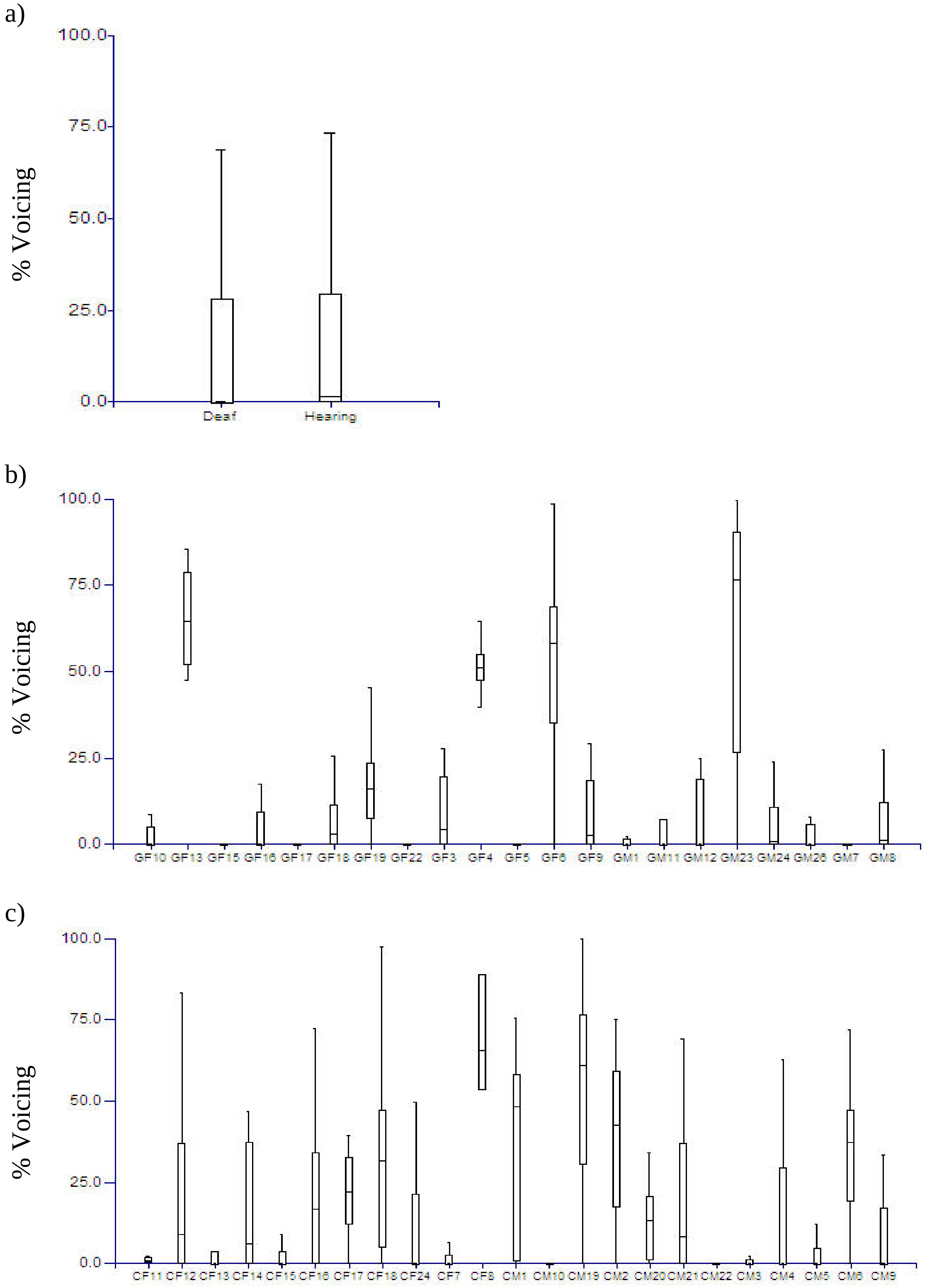


Figure 3.1. Mean percent of bouts in each category (+SE) for deaf females, hearing females, deaf males, and hearing males, separated by bout type.

Figure 3.2. Box plots of bout-level percent-voicing outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR


a)
% Voicing
100.0
75.0
50.0
25.0
0.0
Deaf
Hearing
b)
% Voicing
100.0
75.0
50.0
25.0
0.0
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF6
GF9
GM1
GM11
GM12
GM23
GM24
GM26
GM7
GM8
c)
% Voicing
100.0
75.0
50.0
25.0
0.0
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

5.06 *p* = 0.03. This difference was also evident in individual analyses of unvoiced, but not mixed or voiced bouts (see Table 3.4 and Figure 3.3). Figure 3.4 shows box plots of bout duration data by hearing status (a), and participant (b and c), and indicates that the distributions of this data were similar for both groups, and were not influenced by data from any one participant. No significant differences were found in bout duration by gender, $F(1, 1011) = 0.77$ $p = 0.39$.

The number of calls constituting a bout was found to be variable in both deaf and hearing participants, ranging from 1 to 42 for deaf laughter bouts and 1 to 40 for hearing laughter bouts, with means of 4.68 and 4.61, respectively, $F(1, 1011) = 0.23$, $p = 0.64$. No significant differences were found by gender, $F(1, 1011) = 1.00$, $p = 0.32$. There were no differences in the number of calls constituting any one bout type (see Table 3.5 and Figure 3.5). Figure 3.6 shows box plots number of calls per bout outcomes by hearing status (a), and participant (b and c), and indicates that the distributions of this data were similar for both groups, and were not influenced by data from any one participant. Both deaf and hearing laughter bouts, included calls of all three voicing types, produced through an open, closed, and mixed mouth position, and on inhalations and exhalations. Of deaf laugher calls 41.2% of were produced through an open-mouth, 56.2% through a closed-mouth, and only 0.002% through a mixed-mouth position. The remaining 2.6% of deaf laugh calls could not be identified from acoustic data alone. Hearing laughers produced 64.4% closed-mouth calls, 33.0% open-mouth calls, 2.5% mixed-mouth calls, and 8% calls that were unidentified. The majority of calls, 67.3% from deaf laughter and 72.7% from hearing laughter, were produced on exhalation. However, contradictory to previous reports (Provine & Yong, 1991), a substantial amount, 22.1% of deaf laughter calls and 17.0% of hearing laughter calls were produced on inhalation. Direction of breath could not be determined for 10.6% of deaf laughter and 10.3% of hearing laughter.

Table 3.4
Repeated-measures ANOVA outcomes for bout duration, separated by voicing type and statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Unvoiced Bout Duration	*F*(1, 740) = 6.39 *p* = 0.016*	*F*(1, 740) = 0.94 *p* = 0.34	*F*(1, 740) = 0.09 *p* = 0.76
Mixed Bout Duration	*F*(1, 235) = 0.03 *p* = 0.86	*F*(1, 235) = 0.09 *p* = 0.76	*F*(1, 235) = 0.00 *p* = 0.95
Voiced Bout Duration	*F*(1, 34) = 5.30 *p* = 0.61	*F*(1, 34) = 0.01 *p* = 0.93	*F*(1, 34) = 0.00 *p* = 0.95

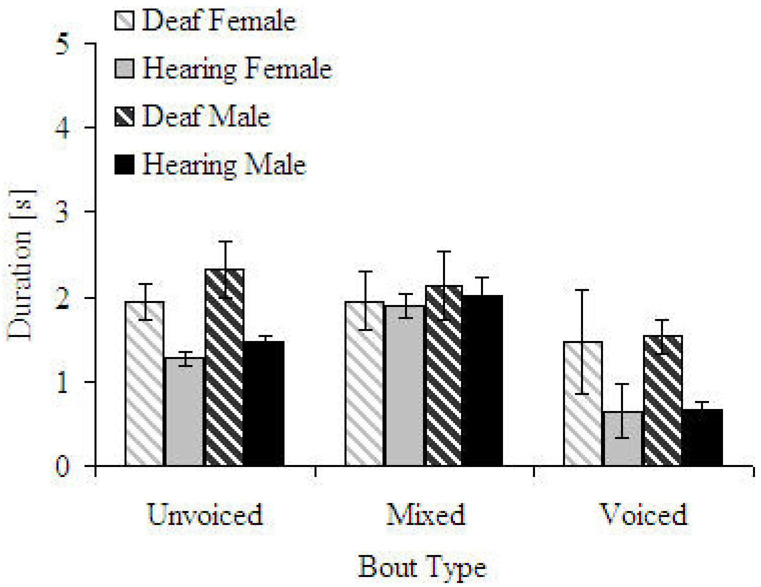
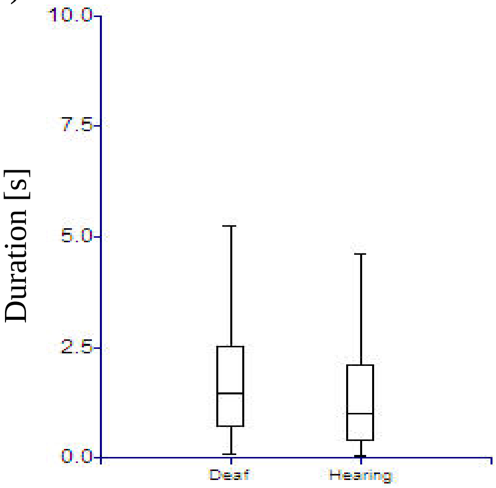


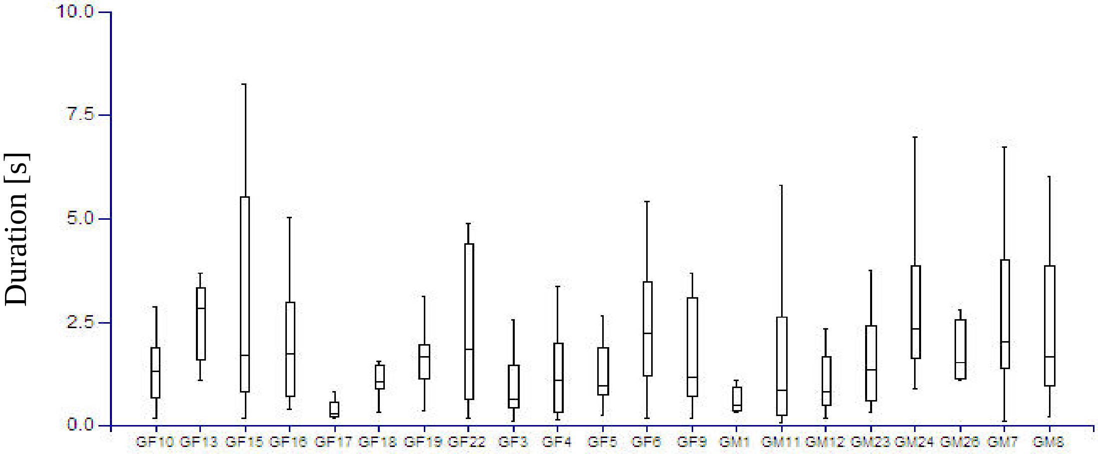
Figure 3.3. Mean duration (±SE) for deaf females, hearing females, deaf males, and hearing males, separated by bout type.

Figure 3.4. Box plots of bout duration outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR

a)


10.0
7.5
5.0
2.5
0.0
Duration [s]
Deaf
Hearing

b)


10.0
7.5
5.0
2.5
0.0
Duration [s]
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF6
GF9
GM1
GM11
GM12
GM23
GM24
GM26
GM7
GM8

c)

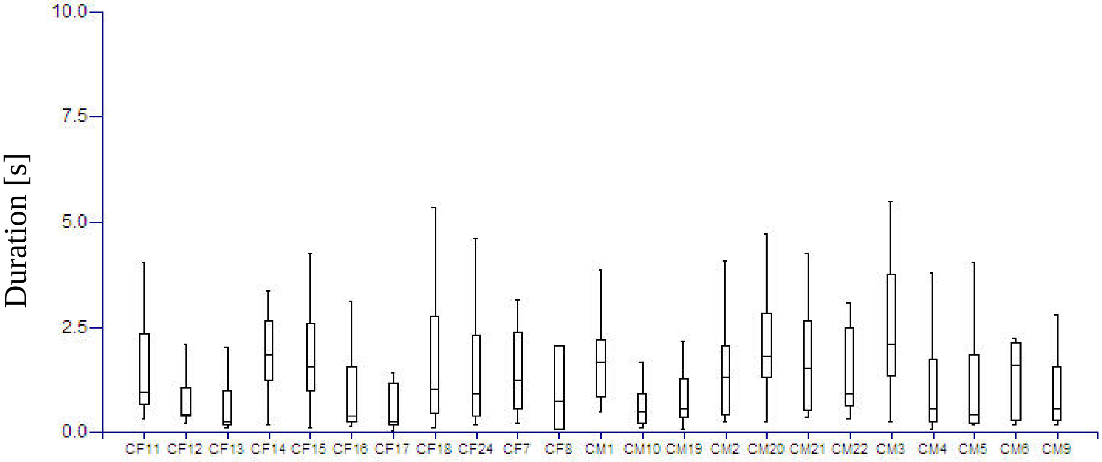

10.0
7.5
5.0
2.5
0.0
Duration [s]
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

Table 3.5
Repeated-measures ANOVA outcomes for number (No.) of calls per bout, separated by voicing type and statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
No. calls per Unvoiced Bout	*F*(1, 740) = 0.68 *p* = 0.42	*F*(1, 740) = 0.93 *p* = 0.34	*F*(1, 740)= 1.91 *p* = 0.17
No. calls per Mixed Bout	*F*(1, 235) = 0.20 *p* = 0.66	*F*(1, 235) = 0.10 *p* = 0.75	*F*(1, 235) = 0.01 *p* = 0.94
No. calls per Voiced Bout	*F*(1, 34) = 2.12 *p* = 0. 19	*F*(1, 39) = 1.47 *p* = 0.27	*F*(1, 39) = 0.81 *p* = 0.40

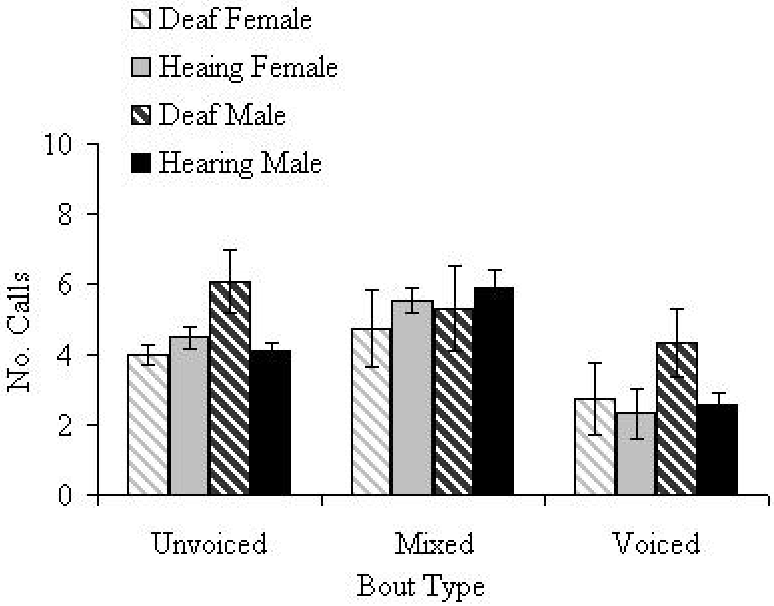
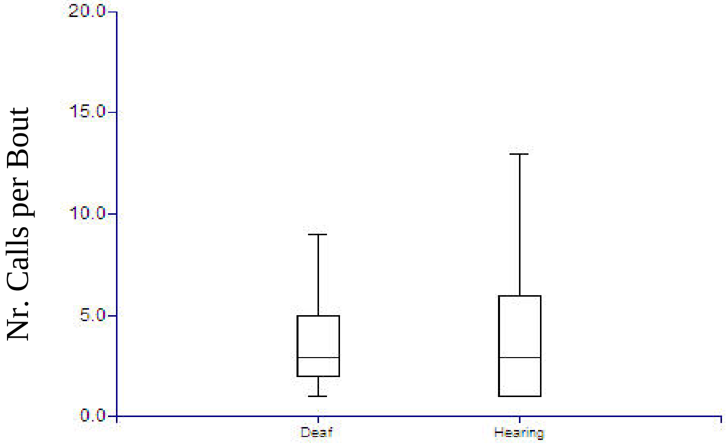


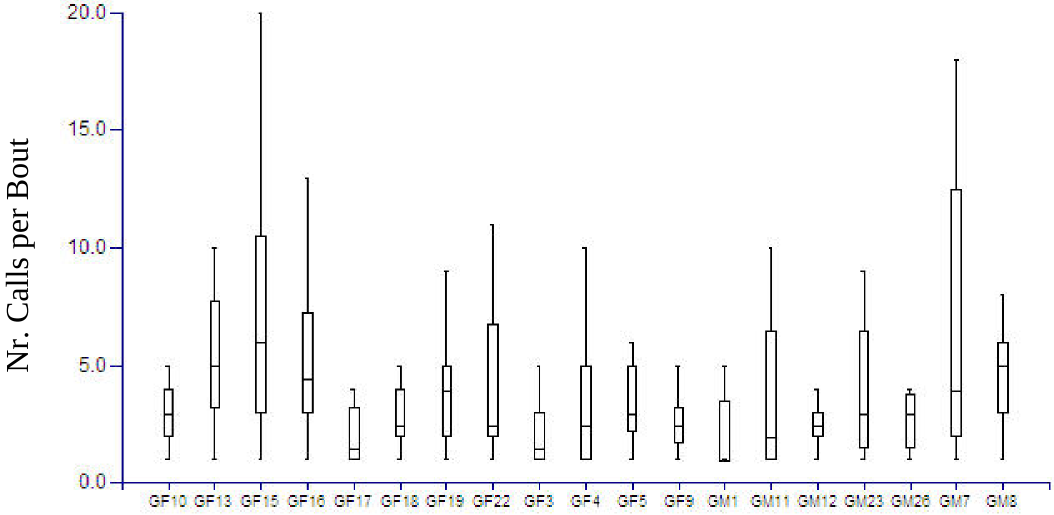
Figure 3.5. Mean number of calls per bout (±SE) for deaf females, hearing females, deaf males, and hearing males, separated by bout type.

Figure 3.6. Box plots of number of calls per bout outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.

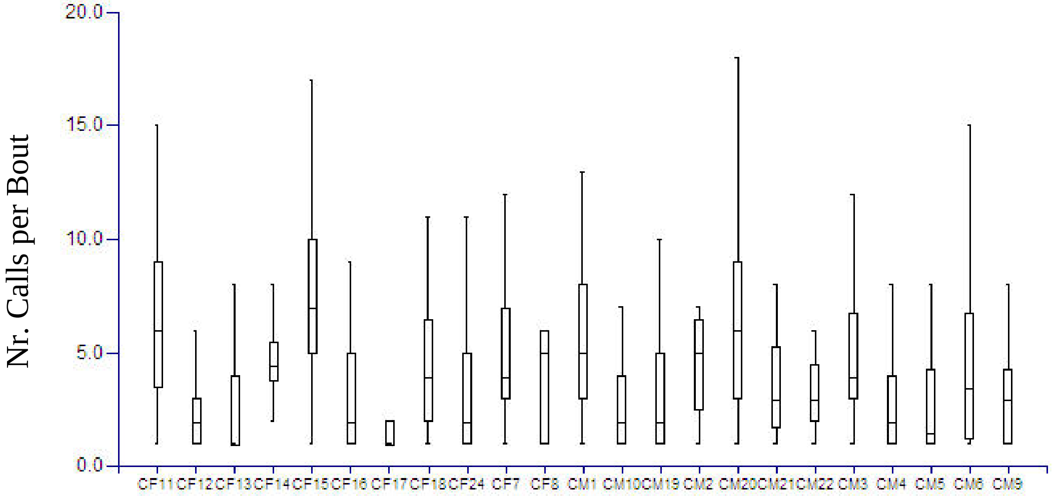
a)


Nr. Calls per Bout
20.0
15.0
10.0
5.0
0.0
Deaf
Hearing

b)


Nr. Calls per Bout
20.0
15.0
10.0
5.0
0.0
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF9
GM1
GM11
GM12
GM23
GM26
GM7
GM8

c)


Nr. Calls per Bout
20.0
15.0
10.0
5.0
0.0
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

Call-level outcomes

Call-level descriptive statistics of the total 1296 deaf laughter and 3461 hearing laughter calls are shown in Table 3.6. Table 3.7 summarizes means and standard deviations of individual participant call-level outcomes. A clear majority of laughter calls were unvoiced (86.7% and 68.3% for deaf and hearing laughter, respectively), a smaller proportion were mixed (7.1% and 20.8%), and only a few were voiced (6.3% and 11.0%). Deaf participants produced significantly more unvoiced and less mixed calls then hearing individuals. Gender had no effect (see Table 3.8 and Figure 3.7). All participants produced unvoiced calls, 16 of 18 deaf and 22 of 23 hearing participants produced mixed calls, and 9 deaf and 22 hearing participants produced voiced calls. Individuals who did not produce mixed calls also did not produce voiced calls. Overall, duration of deaf laughter calls (M = 0.37, SD = 0.74) did not vary significantly from hearing laughter call duration (M = 0.25, SD = 0.49), F (1, 4756) = 2.76, p = 0.11, nor was there a gender effect, F (1, 4756) = 0.47, p = 0.50. However, these outcomes were influenced by the large proportion of unvoiced calls recorded. Finer analysis indicated that although unvoiced call durations did not differ between groups, deaf laughers elongated mixed and voiced calls (see Table 3.9 and Figure 3.8). Figure 3.9 shows box plots of call duration outcomes by hearing status (a) and participant (b and c), and indicate that the distributions of call duration are similar among the groups.

Intercall intervals, defined as the duration between two successive calls, were longer in deaf laughter (M = 0.24, SD = 0.51) than hearing laughter (M = 0.16, SD = 0.25), F (1, 3731) = 10.85, p = 0.002. However, this outcome held only for intervals that followed unvoiced calls (see Table 3.10 and Figure 3.10). Figure 3.11 shows box plots of intercall interval outcomes by hearing status (a) and participants (b and c).

Table 3.6
Descriptive statistics associated with call-level analysis, separated according to laugher hearing status and sex. Standard deviation values are given in parentheses.

Deaf Females (n=12)		Call-level	
Total (n)	765		
M Call duration[a]	0.27 (0.24)		
M % Voicing	8.57 (21.81)		
Call type	Unvoiced	Mixed	Voiced
% Female laughs	87.58	8.5	3.92
% Total laughs	51.7	5.02	2.31
M Duration[a]	0.27 (0.20)	0.29 (0.20)	0.39 (0.69)
M %Voicing	1.22 (4.28)	45.88 (15.72)	91.55 (7.81)
Deaf Males (n=7)			
Total (n)	531		
M Call duration[a]	0.21 (0.23)		
M %Voicing	11.94 (29.35)		
Call type	Unvoiced	Mixed	Voiced
% Male laughs	85.31	5.09	9.6
% Total laughs	34.95	2.08	3.94
M Duration[a]	0.19 (0.22)	0.28 (0.19)	0.31 (0.28)
M %Voicing	0.49 (2.76)	46.45 (13.36)	95.40 (5.80)
Hearing Females (n=11)			
Total (n)	1731		
M Call duration[a]	0.18 (0.20)		
M %Voicing	19.79 (31.05)		
Call type	Unvoiced	Mixed	Voiced
% Female laughs	70.02	20.34	9.64
% Total laughs	35.02	10.17	4.82
M Duration[a]	0.20 (0.16)	0.16 (0.11)	0.14 (0.43)
M %Voicing	1.47(4.92)	49.39 (15.10)	90.40 (8.21)
Hearing Males (n=12)			
Total (n)	1730		
M Call duration[a]	0.22 (0.17)		
M %Voicing	22.83 (32.61)		
Call type	Unvoiced	Mixed	Voiced
% Male laughs	66.47	21.27	12.26
% Total laughs	33.23	10.63	6.13
M Duration[a]	0.23 (0.18)	0.21 (0.14)	0.16 (0.16)
M %Voicing	2.36 (6.10)	47.22 (15.93)	90.97 (8.17)

[a] measured in seconds [s]

Table 3.7
Means (and standard deviations) of (a) hearing; and (b) deaf individual participant bout-level outcomes.

a)

Participant Number	Duration [s]	Intercall Interval [s]	Relative Amplitude	Percent Voicing	Mean F0 [Hz]
Female					
CF11	0.14 (0.10)	0.10 (0.14)	0.64 (0.20)	42.65 (36.14)	378.81 (119.33)
CF14	0.26 (0.20)	0.17 (0.25)	0.75 (0.22)	21.59 (32.47)	368.12 (102.54)
CF16	0.21 (0.13)	0.16 (0.25)	0.83 (0.26)	32.43 (33.31)	339.65 (89.54)
CF24	0.25 (0.19)	0.21 (0.26)	0.78 (0.20)	20.33 (30.08)	397.41 (93.58)
CF13	0.21 (0.18)	0.17 (0.22)	0.57 (0.14)	15.49 (32.43)	304.55 (20.12)
CF15	0.11 (0.08)	0.13 (0.16)	0.68 (0.13)	6.95 (21.08)	464.84 (118.74)
CF7	0.22 (0.20)	0.12 (0.27)	0.81 (0.18)	9.63 (24.14)	336.51 (82.17)
CF8	0.13 (0.07)	0.14 (0.22)	0.75 (0.16)	62.63 (38.02)	296.34 (70.02)
CF12	0.26 (0.13)	0.10 (0.23)	0.77 (0.16)	23.25 (27.20)	312.05 (77.45)
CF17	0.15 (0.13)	0.33 (0.37)	0.51 (0.10)	30.47 (36.85)	161.58 (87.65)
CF18	0.19 (0.11)	0.22 (0.42)	0.77 (0.18)	33.67 (32.93)	352.08 (80.19)
Male					
CM1	0.21 (0.20)	0.17 (0.39)	0.90 (0.22)	51.74 (42.98)	207.81 (88.80)
CM3	0.21 (0.16)	0.24 (0.29)	0.74 (0.21)	6.04 (15.68)	234.39 (47.01)
CM9	0.20 (0.13)	0.21 (0.38)	0.69 (0.15)	17.31 (30.63)	159.86 (106.32)
CM4	0.24 (0.17)	0.19 (0.19)	0.61 (0.15)	21.56 (27.58)	167.41 (51.45)
CM2	0.20 (0.15)	0.11 (0.16)	0.72 (0.14)	49.10 (33.22)	177.25 (66.43)
CM22	0.34 (0.33)	0.08 (0.11)	0.82 (0.18)	0.00 (0.00)	N/A
CM5	0.22 (0.18)	0.20 (0.27)	0.70 (0.22)	10.92 (24.51)	326.57 (95.21)
CM6	0.24 (0.19)	0.19 (0.35)	0.77 (0.11)	44.94 (33.67)	203.13 (52.19)
CM10	0.20 (0.15)	0.10 (0.23)	0.66 (0.12)	9.05 (21.74)	132.08 (16.42)
CM21	0.32 (0.21)	0.27 (0.24)	0.62 (0.11)	25.33 (38.87)	95.48 (62.82)
CM19	0.21 (0.16)	0.19 (0.27)	1.05 (0.20)	54.62 (33.09)	187.68 (52.53)
CM20	0.21 (0.15)	0.10 (0.11)	0.74 (0.21)	14.45 (20.27)	248.41 (85.94)

Table 3.7 (Continued)

b)

Participant Number	Duration [s]	Intercall Interval [s]	Relative Amplitude	Percent Voicing	Mean F0 [Hz]
Female					
GF3	0.37 (0.20)	0.31 (0.47)	0.69 (0.18)	11.79 (22.49)	228.99 (18.50)
GF9	0.33 (0.21)	0.55 (0.74)	0.51 (0.17)	9.86 (21.24)	351.85 (100.01)
GF13	0.43 (0.57)	0.13 (0.44)	0.73 (0.16)	64.57 (32.77)	200.96 (58.13)
GF15	0.21 (0.20)	0.41 (1.04)	0.58 (0.15)	0.57 (3.92)	283.63 (79.51)
GF17	0.19 (0.10)	0.00 (0.01)	0.44 (0.09)	0.00 (0.00)	N/A
GF19	0.30 (0.20)	0.12 (0.15)	0.65 (0.15)	22.09 (26.74)	274.53 (31.77)
GF4	0.22 (0.15)	0.20 (0.26)	0.63 (0.12)	2.97 (10.10)	287.83 (42.89)
GF5	0.27 (0.11)	0.13 (0.23)	0.61 (0.10)	0.00 (0.00)	N/A
GF10	0.33 (0.25)	0.31 (0.39)	0.76 (0.18)	1.74 (5.74)	284.56 (8.07)
GF16	0.19 (0.15)	0.25 (0.26)	0.64 (0.12)	7.52 (21.84)	327.83 (83.57)
GF18	0.29 (0.17)	0.17 (0.19)	0.79 (0.25)	8.01 (17.00)	249.24 (31.83)
GF22	0.35 (0.27)	0.28 (0.25)	0.63 (0.15)	0.60 (4.26)	169.97 (0.00)
Male					
GM1	0.29 (0.18)	0.05 (0.06)	0.55 (0.11)	1.59 (4.38)	218.65 (54.62)
GM7	0.11 (0.15)	0.18 (0.20)	0.48 (0.07)	0.70 (7.26)	166.75 (12.77)
GM11	0.30 (0.25)	0.37 (0.60)	0.43 (0.08)	1.87 (8.93)	344.82 (72.62)
GM23	0.35 (0.24)	0.07 (0.11)	0.67 (0.13)	70.21 (38.28)	157.19 (31.10)
GM8	0.23 (0.25)	0.30 (0.43)	0.59 (0.14)	9.57 (22.77)	164.27 (76.55)
GM12	0.29 (0.11)	0.20 (0.29)	0.56 (0.09)	10.42 (25.02)	385.64 (162.74)
GM26	0.43 (0.32)	0.32 (0.37)	0.62 (0.09)	2.89 (9.59)	142.24 (0.00)

Table 3.8
Repeated-measures ANOVA outcomes for percentage of calls per voicing category, separated by statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Unvoiced Calls	*F*(1, 4757) = 5.34 *p* = 0.03*	*F*(1, 4757) = 0.14 *p* = 0.71	*F*(1, 4757) = 0.93 *p* = 0.94
Mixed Calls	*F*(1, 4757) = 11.14 *p* = 0. 002*	*F*(1, 4757) = 0.09 *p* = 0.77	*F*(1, 4757) = 0.27 *p* = 0.61
Voiced Calls	*F*(1, 4757) = 0.73 *p* = 0.40	*F*(1, 4757) = 0.72 *p* = 0.40	*F*(1, 4757) = 0.10 *p* = 0.75

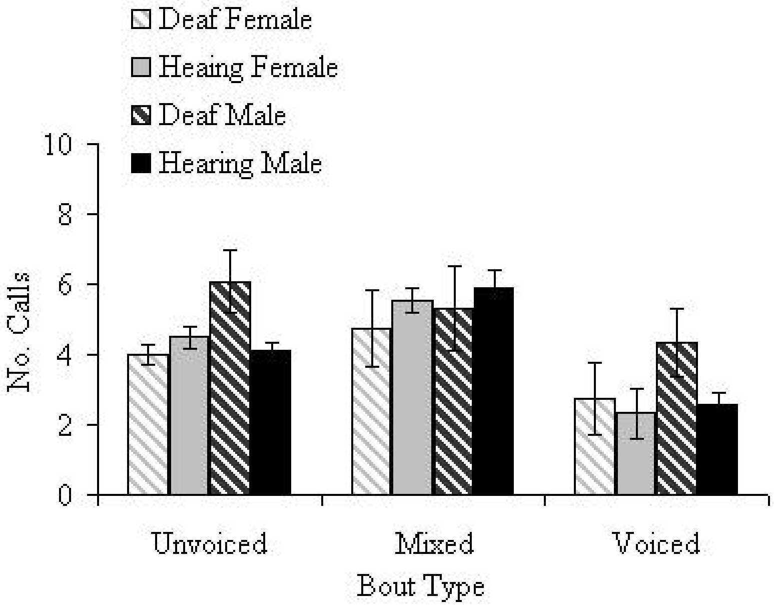


Figure 3.7 Mean number of calls per voicing category (±SE) for deaf females, hearing females, deaf males, and hearing males.

Table 3.9
Repeated-measures ANOVA outcomes for call duration, separated by voicing type and statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Unvoiced Call Duration	*F*(1, 3484) = 0.43 *p* = 0.57	*F*(1, 3484) = 0.66 *p* = 0.42	*F*(1, 3484) = 5.44 *p* = 0.025*
Mixed Call Duration	*F*(1, 811) = 10.10 *p* = 0.003*	*F*(1, 811) = 0.26 *p* = 0.61	*F*(1, 811) = 0.94 *p* = 0.34
Voiced Call Duration	*F*(1, 459) = 6.40 *p* = 0. 018*	*F*(1, 459) = 0.11 *p* = 0.74	*F*(1, 459) = 0.34 *p* = 0.56

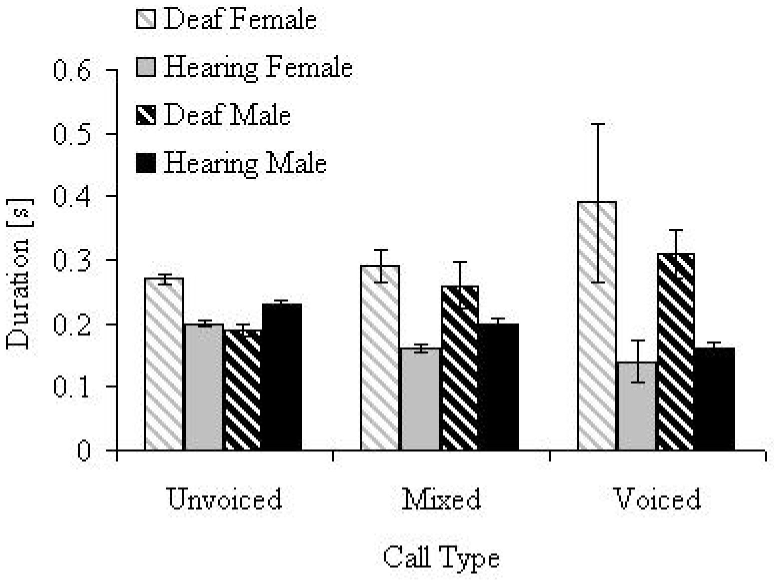
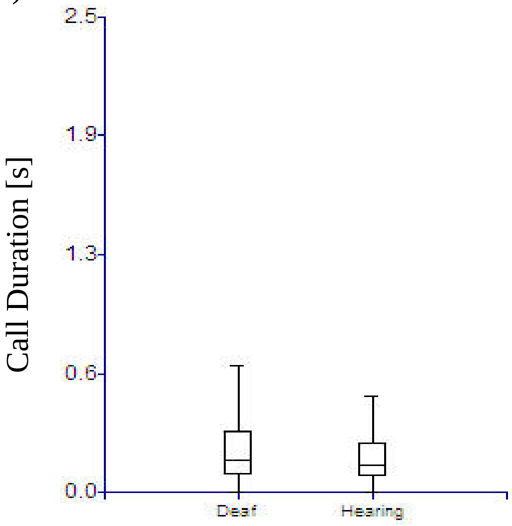


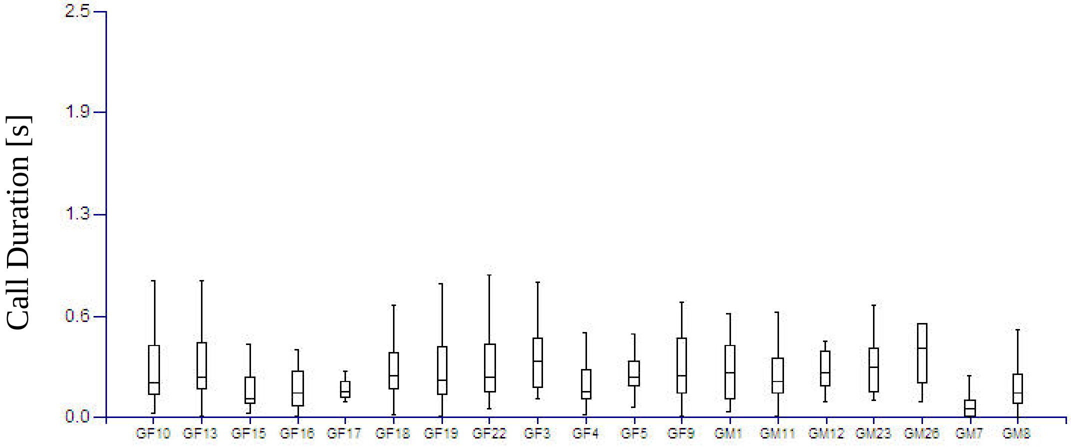
Figure 3.8. Mean call duration (±SE) for deaf females, hearing females, deaf males, and hearing males, separated by call type.

Figure 3.9. Box plots of call duration outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.

a)


Call Duration [s]
2.5
1.9
1.3
0.6
0.0
Deaf
Hearing

b)


Call Duration [s]
2.5
1.9
1.3
0.6
0.0
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF9
GM1
GM11
GM12
GM23
GM26
GM7
GM8

c)

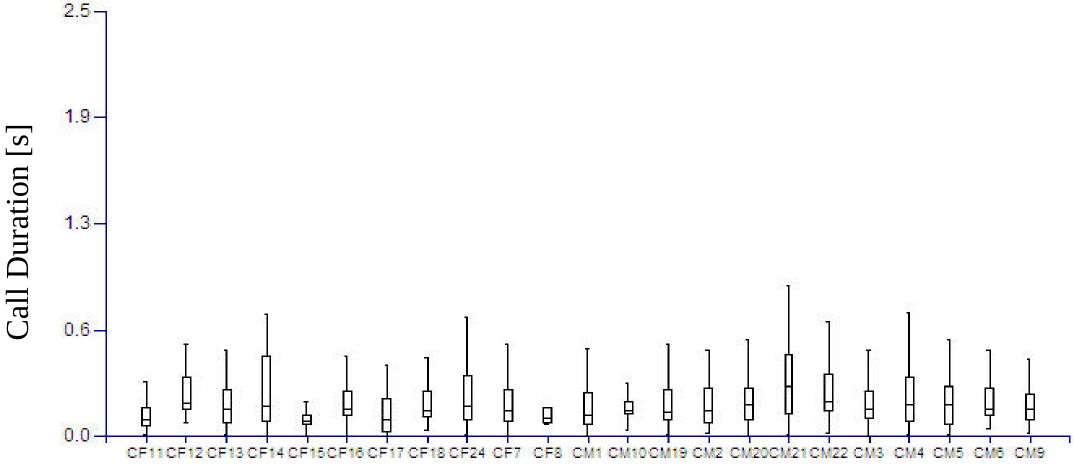

Call Duration [s]
2.5
1.9
1.3
0.6
0.0
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

Table 3.10

Repeated-measures ANOVA outcomes for intercall interval, separated by voicing type preceding the interval and statistical effect.

Measure[a]	Statistical Effect Hearing Status	 Gender	 Interaction
Intercall Interval (Unvoiced)	$F(1, 2610) = 14.05$ $p = 0.001$*	$F(1, 2610) = 0.18$ $p = 0.68$	$F(1, 2610) = 2.25$ $p = 0.14$
Intercall Interval (Mixed)	$F(1, 717) = 0.57$ $p = 0.43$	$F(1, 717) = 1.37$ $p = 0.21$	$F(1, 717) = 1.29$ $p = 0.26$
Intercall Interval (Voiced)	$F(1, 402) = 1.70$ $p = 0.20$	$F(1, 402) = 0.02$ $p = 0.88$	$F(1, 402) = 0.47$ $p = 0.50$

[a] Measured in seconds [s]

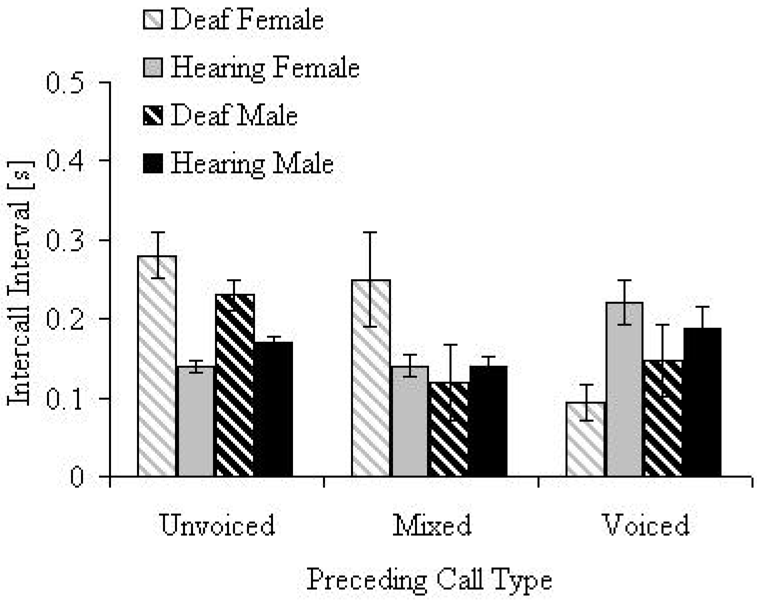
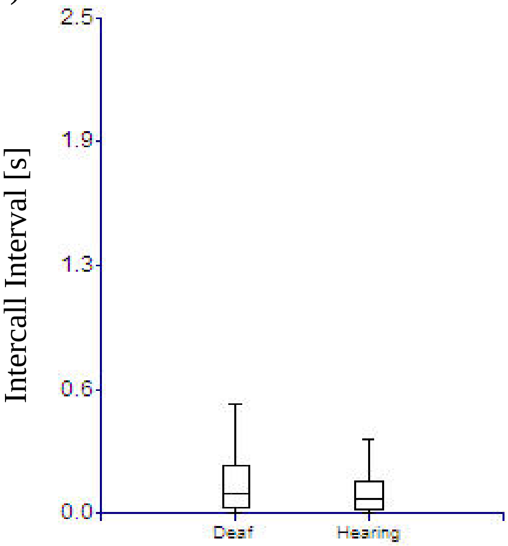


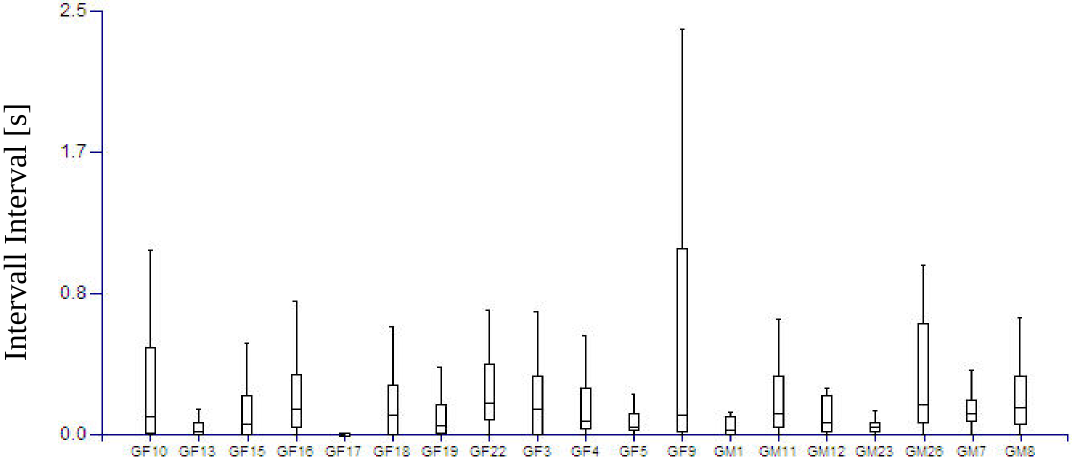
Figure 3.10. Mean intercall inteval (±SE) for deaf females, hearing females, deaf males, and hearing males, separated by call type preceding the intercall interval.

Figure 3.11. Box plots of intercall interval outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.

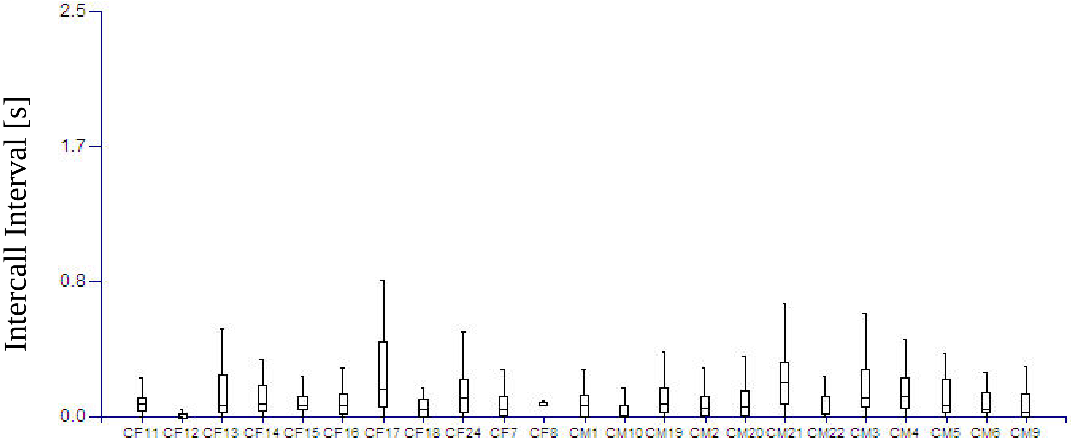
a)


Intercall Interval [s]
2.5
1.9
1.3
0.6
0.0
Deaf
Hearing

b)


Intervall Interval [s]
2.5
1.7
0.8
0.0
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF9
GM1
GM11
GM12
GM23
GM26
GM7
GM8

c)


Intercall Interval [s]
2.5
1.7
0.8
0.0
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

The rate of laughter production did vary by hearing status, *F*(1, 1062) = 14.27, $p < 0.001$, with mean rates of 2.7 calls/s and 3.8 calls/s produced by deaf and hearing laughers, respectively. Production rate did not vary by gender, *F*(1, 1062) = 0.12, $p = 0.73$.

The mean relative amplitude of calls produced by deaf individuals (M = 0.60, SD = 0.16) was significantly lower than that of hearing laughers (M = 0.74, SD = 0.21), *F* (1,4755) = 20.37, $p < 0.001$. No gender differences were found, *F*(1, 4755) = 1.44, $p = 0.28$. Significantly lower mean relative amplitudes of sounds produced by deaf individuals were evident in separately analyzed unvoiced calls and voiced calls, but not mixed calls (see Table 3.11 and Figure 3.12). Figure 3.13 shows box plots of relative amplitude outputs by hearing status (a), and participant (b and c).

F0 and formant outcomes

F0 and formant-related measurements were extracted from voiced parts of calls containing over 1% voicing. Because the majority of calls recorded were unvoiced, inclusion of some calls with less then 25% voicing served to increase the sample size. In all, 175 and 108 deaf laughter calls produced by female and male participants respectively, and 647 female and 767 male hearing laughter calls were used in the F0 analysis. Figure 3.14 summarizes the mean, minimum, and maximum F0 outcomes in relation to the reported mean F0s of speech. Figure 3.15 and 3.16 show box plots of mean F0 outcomes by hearing status (a) and participant (b and c) for females and males, respectively.

Not surprisingly, calls produced by females (M = 340.6, SD = 112.6) had a significantly higher mean F0 than calls produced by male participants (M = 200.4, SD = 82.9), *F*(1, 1619) = 21.13, $p < 0.0001$. Mean F0 values was significantly lower in laughter produced by deaf (M = 228.2, SD = 82.2) versus hearing (M = 275.2, SD = 125.1) participants, *F*(1, 1619) = 6.51, $p = 0.015$. This result was mainly a reflection

Table 3.11
Repeated-measures ANOVA outcomes for call relative amplitude, separated by voicing type preceding the interval and statistical effect.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Unvoiced Call Relative Amplitude	*F*(1, 3485) = 22.62 *p* < 0.0001*	*F*(1, 3485) = 8.81 *p* = 0.005*	*F*(1, 3485) = 6.72 *p* = 0.013*
Mixed Call Relative Amplitude	*F*(1, 811) = 2.72 *p* = 0.11	*F*(1, 811) = 0.28 *p* = 0.60	*F*(1, 811) = 0.80 *p* = 0.38
Voiced Call Relative Amplitude	*F*(1, 457) = 4.77 *p* = 0. 038*	*F*(1, 457) = 0.84 *p* = 0.37	*F*(1, 457) = 1.43 *p* = 0.24

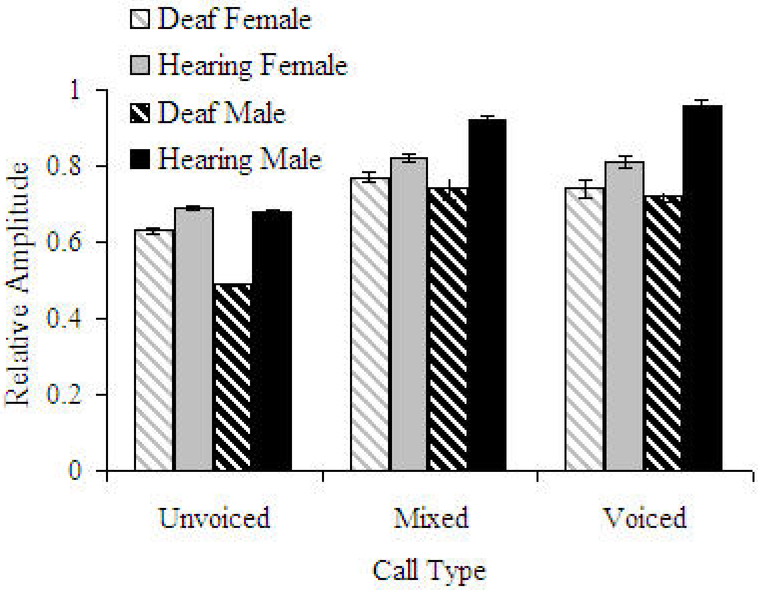
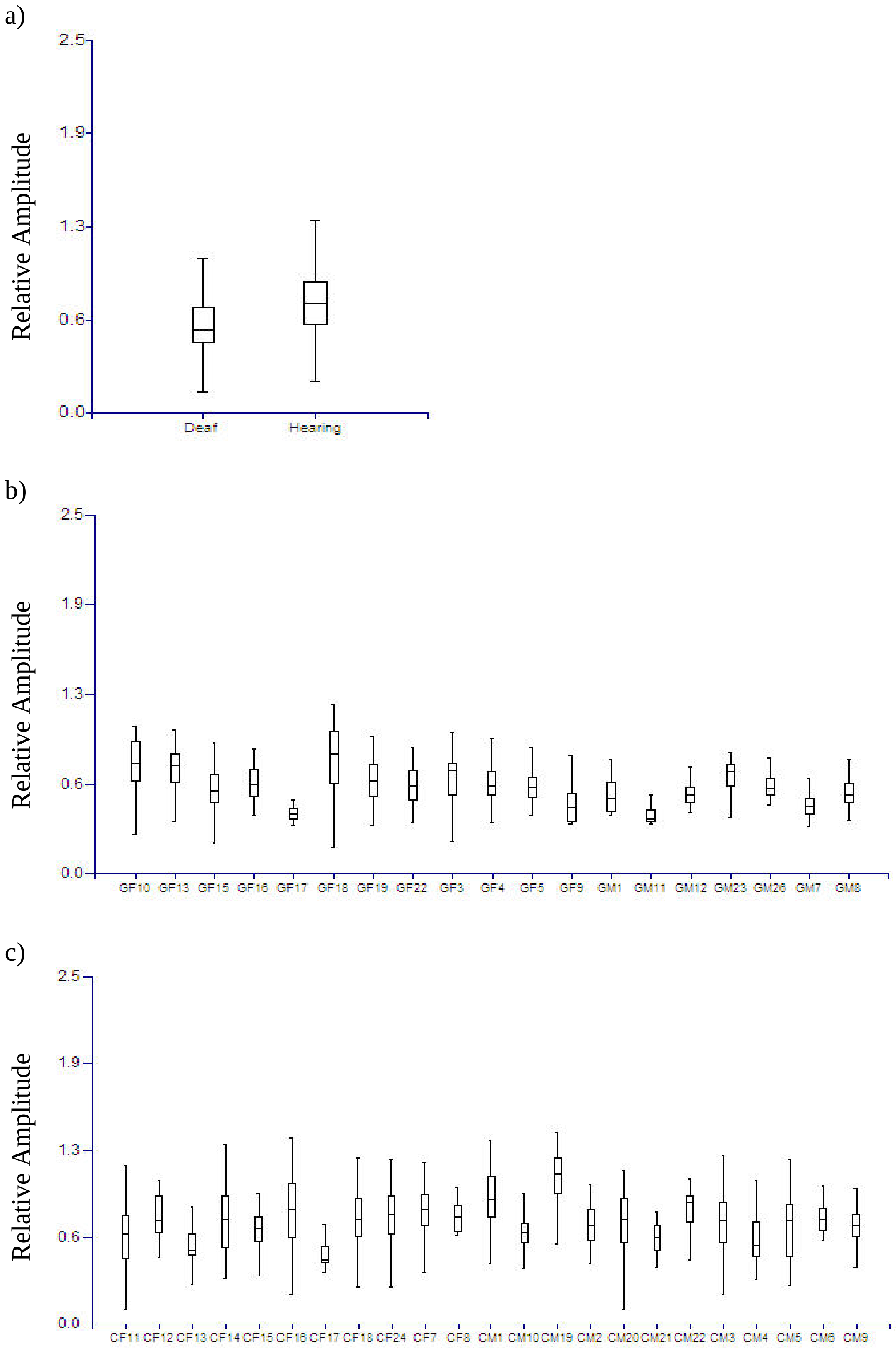


Figure 3.12. Mean call relative amplitude (±SE) for deaf females, hearing females, deaf males, and hearing males, separated by call type.

Figure 3.13. Box plots of call-level relative amplitude outcomes by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.


a)
Relative Amplitude
2.5
1.9
1.3
0.6
0.0
Deaf
Hearing
b)
Relative Amplitude
2.5
1.9
1.3
0.6
0.0
GF10
GF13
GF15
GF16
GF17
GF18
GF19
GF22
GF3
GF4
GF5
GF9
GM1
GM11
GM12
GM23
GM26
GM7
GM8
c)
Relative Amplitude
2.5
1.9
1.3
0.6
0.0
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8
CM1
CM10
CM19
CM2
CM20
CM21
CM22
CM3
CM4
CM5
CM6
CM9

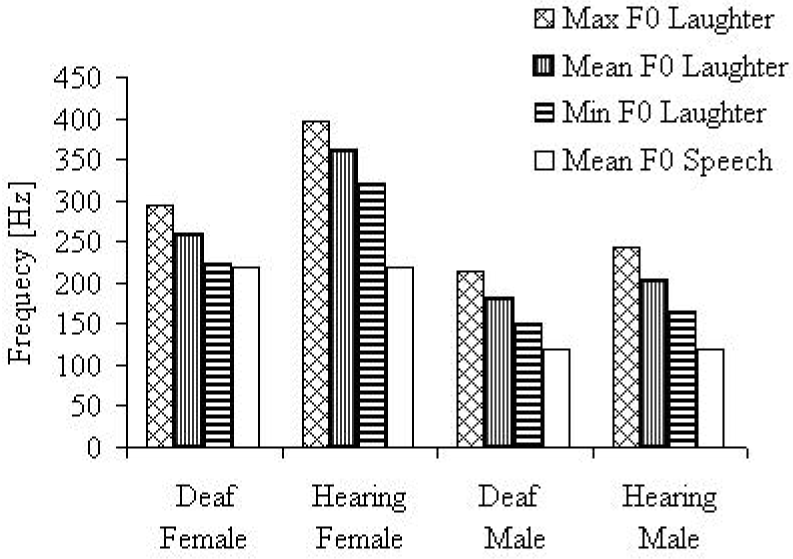
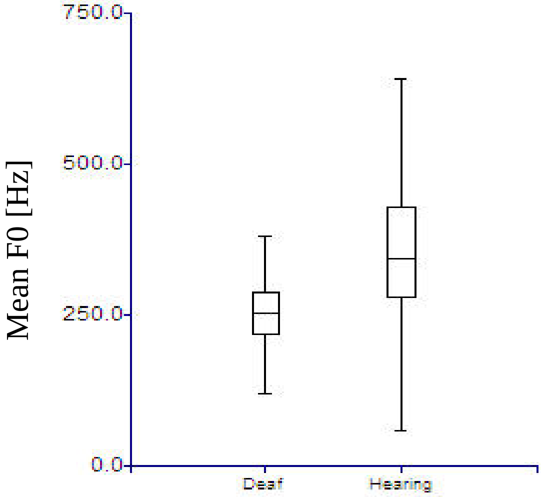


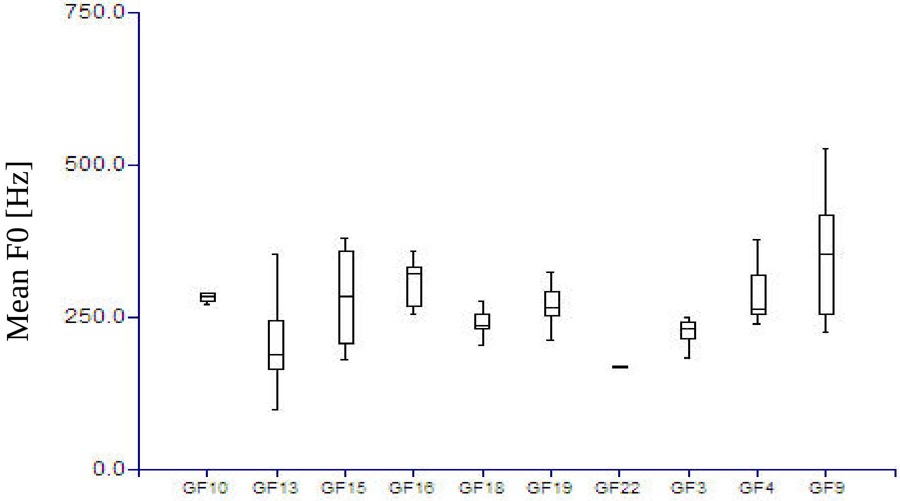
Figure 3.14. Comparison of F0 outcomes by hearing status and gender.

Figure 3.15. Box plots of call-level mean F0 outcomes for female participants by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25^{th} percentile, 50^{th} percentile (median) and 75^{th} percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.

a)


750.0
500.0
250.0
0.0
Mean F0 [Hz]
Deaf
Hearing

b)


750.0
500.0
250.0
0.0
Mean F0 [Hz]
GF10
GF13
GF15
GF16
GF18
GF19
GF22
GF3
GF4
GF9

c)

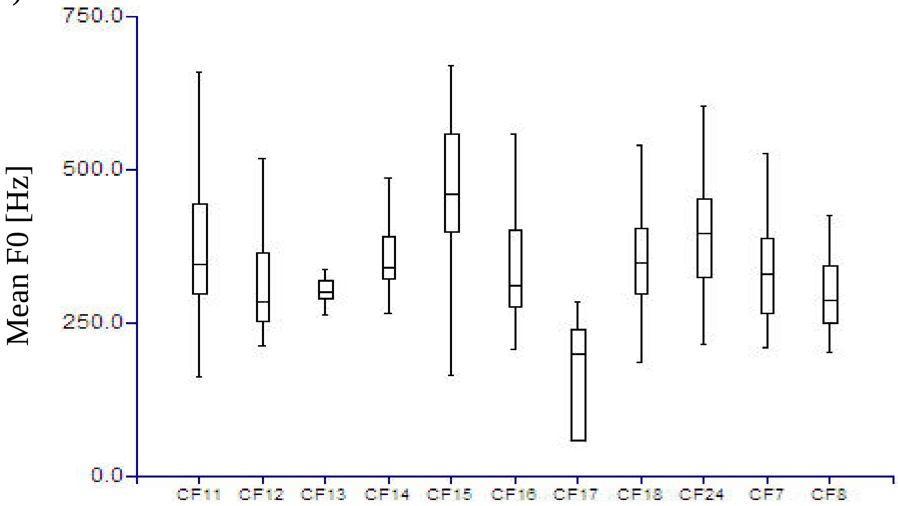
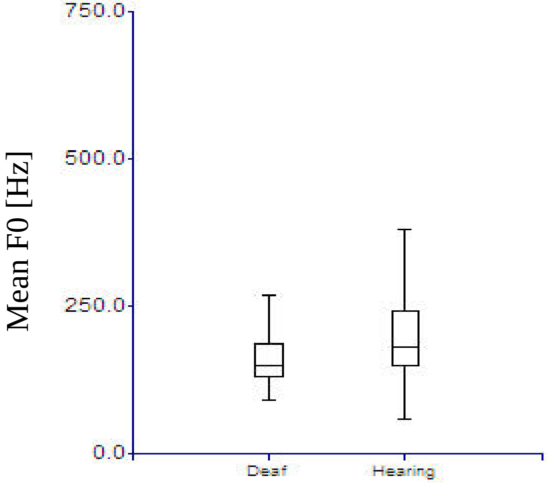
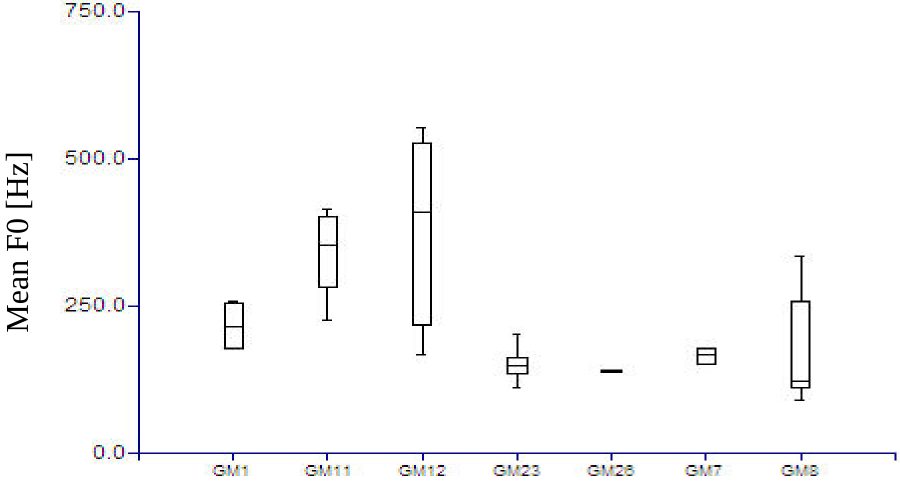

750.0
500.0
250.0
0.0
Mean F0 [Hz]
CF11
CF12
CF13
CF14
CF15
CF16
CF17
CF18
CF24
CF7
CF8

Figure 3.16. Box plots of call-level mean F0 outcomes for male participants by (a) hearing status; (b) deaf participant identification number; (c) hearing participant identification number. Each box represents the interquartile range (middle 50%) of the data. The bottom, middle, and top lines of each box represent the 25th percentile, 50th percentile (median) and 75th percentile, respectively. The T-shaped lines that extend from each end of the box represent adjacent values. The upper adjacent value is the largest observation that is less than or equal to the 75th percentile plus 1.5 times IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR.

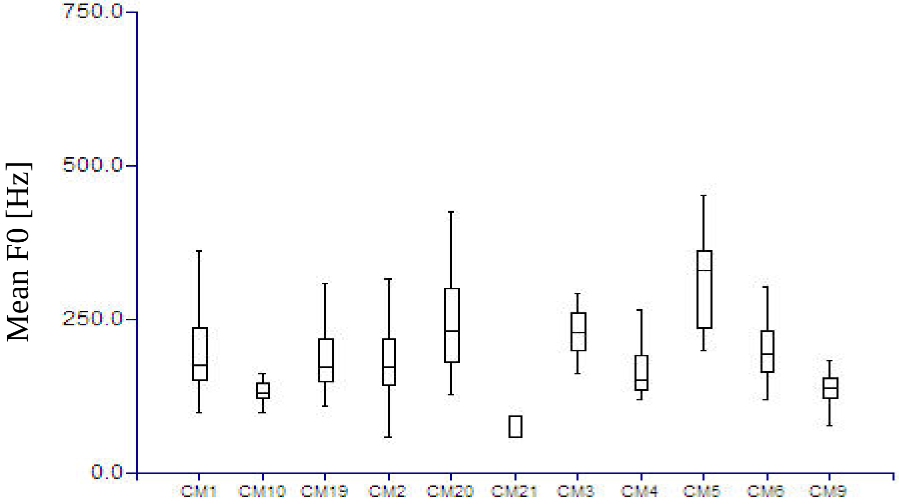
a)


Mean F0 [Hz]
750.0
500.0
250.0
0.0
Deaf
Hearing

b)


Mean F0 [Hz]
750.0
500.0
250.0
0.0
GM1
GM11
GM12
GM23
GM26
GM7
GM8

c)


Mean F0 [Hz]
750.0
500.0
250.0
0.0
CM1
CM10
CM19
CM2
CM20
CM21
CM3
CM4
CM5
CM6
CM9

of the relatively low mean F0 produced by deaf female participants (M = 258.5, SD = 66.6), which was significantly lower then for hearing females (M = 360.4, SD = 112.5), $F(1, 780) = 9.46$, $p < 0.006$. In contrast, there was no difference in the mean F0 between male deaf (M = 179.8, SD = 81.7) and male hearing laughter (M = 203.0, SD = 82.8, $F(1, 838) = 0.44$, $p = 0.52$. Results of analyses of maximum and minimum F0 values echoed the mean F0 findings. Maximum (Max F0) and minimum (Min F0) F0 values were significantly lower in deaf females (Max F0: M = 294.6, SD = 69.3; Min F0: M = 223.5, SD = 76.2) versus hearing females (Max F0: M = 395.4, SD = 122.29; Min F0: M = 319.9, SD = 108.2)(Max F0: $F(1, 780) = 9.30$, $p = 0.007$; Min F0: $F(1, 780) = 7.87$, $p < 0.011$). However, there were no differences between F0 values measured from male deaf laughter (Max F0: M = 213.7, SD =91.4; MinF0: M = 150.0, SD = 76.2) versus male hearing laughter (MaxF0; M = 244.2, SD = 107.3; MinF0: M = 164.8, SD = 69.2) (MaxF0: $F(1, 839) = 0.52$, $p = 0.48$; MinF0: $F(1, 780) = 0.29$; $p < 0.60$). Repeated-measures ANOVA outcomes of mean, maximum, and minimum F0 outcomes for deaf and hearing females and males are shown in Table 3.12.

Table 3.13 shows the means and standard deviations of the first (F1) and second (F2) formant frequencies, separated by gender, hearing status, and mouth position. Mean F1 and F2 values for open-mouth calls produced by deaf participants were 511 Hz and 1666 Hz, respectively. Hearing participants produced laughter with mean F1 of 549 Hz, and mean F2 of 1590. Mean F1 and mean F2 values for closed-mouth calls were 351 Hz and 1840 Hz for deaf laughter, and 346 Hz and 1740 Hz for hearing laughter. Figure 3.17 shows the outcomes for F1 and F2 values measured from a sample of calls produced by deaf and hearing participants, plotted in American-English vowel-space (Hillenbrand, Ghetti, Clark, & Wheeler, 1995). As formants are vocal tract resonances, which reflect oral and nasal cavity shape, vowel-space plots

Table 3.12
Repeated-measures ANOVA for F0 outcomes.

	Statistical Effect		
Measure	Hearing Status	Gender	Interaction
Mean F0	*F*(1, 1619) = 6.51 *p* = 0.015*	*F*(1, 1619) = 23.13 *p* <0.001*	*F*(1, 1619) = 2.56 *p* = 0.12
Max F0	*F*(1, 1619) = 5.72 *p* = 0.022*	*F*(1, 1619) = 24.16 *p* <0.001*	*F*(1, 1619) = 3.08 *p* <0.088
Min F0	*F*(1, 1619) = 6.06 *p* = 0.019*	*F*(1, 1619) = 18.90 *p* <0.001	*F*(1, 1619) = 1.73 *p* = 0.195

Table 3.13
F1 and F2 mean values (and standard deviations), separated by gender, hearing status, and call mouth position.

	F1 separated by mouth position		F2 separated by mouth position	
	Open	Closed	Open	Closed
Female				
Deaf	543 (278)	337 (64)	1692 (183)	1910 (258)
Hearing	538 (147)	353 (142)	1625 (216)	1802 (109)
Male				
Deaf	397 (73)	359 (59)	1569 (285)	1802 (124)
Hearing	553 (165)	342 (104)	1578 (153)	1727 (154)

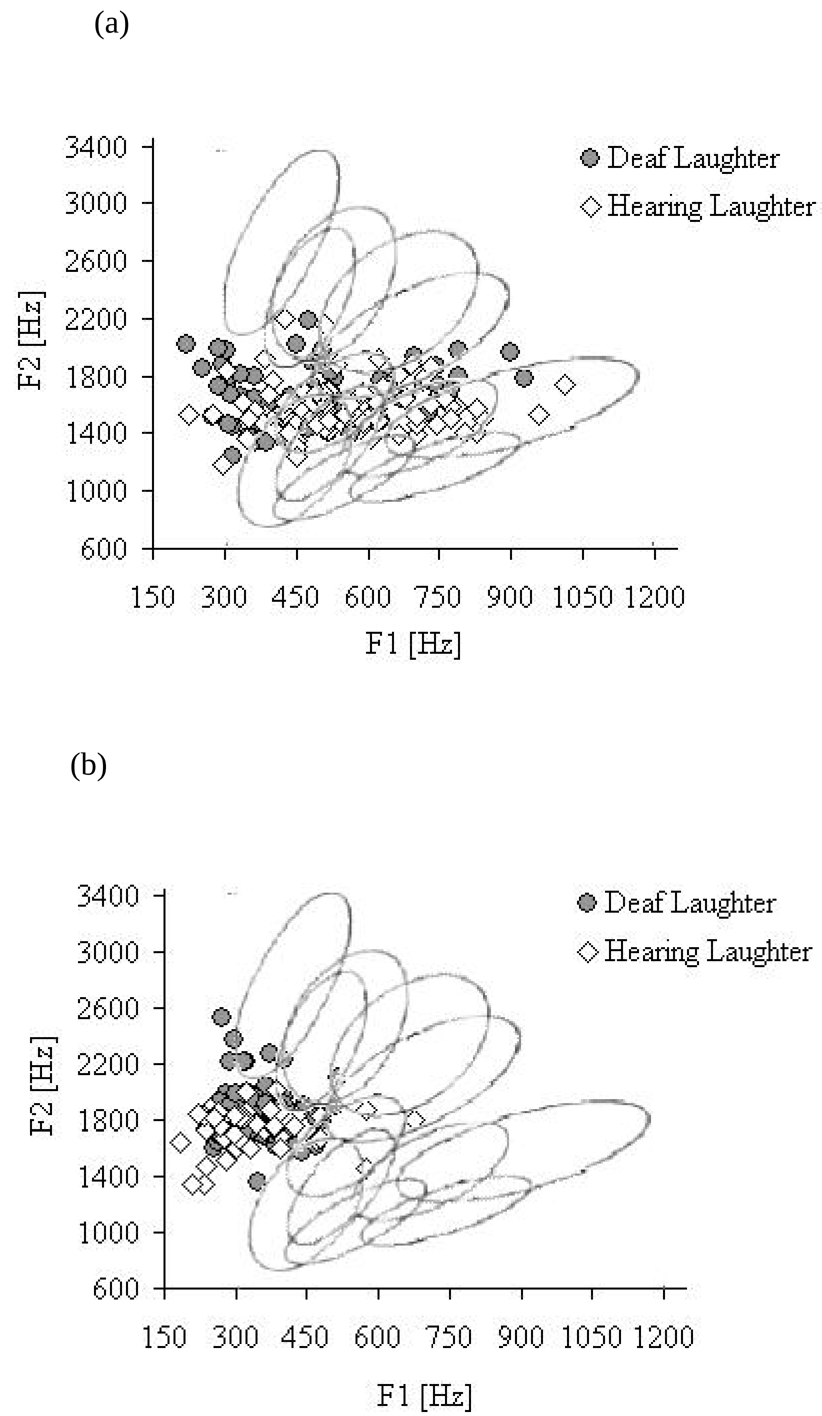


Figure 3.17. Values of F1 and F2 for deaf and hearing (a) open-mouthed calls, and (b) closed-mouthed calls with over 1% voicing plotted using Hillenbrand et al.'s (1995) vowel-space map. The ellipses represent typical vowel-sounds, the dark circles represent deaf laughter calls, and the light squares represent hearing laughter calls.

provide information about articulatory properties underlying each call, particularly vowel-qualities. The high degree of overlap between deaf and hearing laughs seen in Figure 3.17 indicates similarity in vowel-quality across deaf and hearing participants. The grouping of all open-mouthed calls around centralized areas of vowel space, and of all closed-mouth calls outside the articulated areas of vowel space suggest that laughter is relatively unarticulated, and lacks strong vowel-like qualities.

CHAPTER 4

DISCUSSION

This study provides the first acoustic characterization of laughter produced by congenitally, profoundly deaf individuals. High structural variability, elevated mean F0s and centralized formant structures were characteristic of laughter produced by deaf adults. Echoing previous studies (Mowrer et al., 1987; Bachorowski et al., 2001; Vettin & Todt, 2004), similar results were found for laughter produced by normally hearing adults. Differences between deaf and hearing laughter were associated with temporal, F0, amplitude, and percent-voicing measures. The following sections elaborate on these findings and discuss implications for laughter development, innateness, and stereotypy.

Similarities between deaf and hearing laughter

Laughter is structurally variable. High structural variability is a prominent acoustic component of laughter. Diversity in production modes (Bachorowski et al., 2001), and temporal and F0 measures (Mowrer et al., 1987; Bachorowski et al., 2001) contribute to this variability.

Laughter production is also associated with variability in mouth position (Bachorowski et al., 2001) and direction of air flow (Nwokah et al., 1999; Bachorowski et al., 2001). Both deaf and hearing data sets contained examples of laughter produced through open, closed, and mixed mouth positions, and on inhalation as well as exhalation. Laughter produced by deaf and hearing individuals also included calls containing varying amounts of voicing. The percent-voicing measure indicates the amount of time within each call that the vocal folds are vibrating in a synchronized manner. Presence of unvoiced, mixed, and voiced call types indicates variability in production mode with respect to vocal fold activity.

Deaf and hearing laughter was also characterized by temporal variability at all levels of analysis. At the bout level, deaf laughter lasted a minimum of 0.08 s and a maximum of 24.61 s. Hearing laughter bouts were as short as 0.04 s and as long as 12.40 s. Similarly, at the call level, laughs lasted between 0.004 s and 3.06 s for deaf laughers, and between 0.002 s and 4.02 s for hearing laughers. Considerable variation was also present in the number of calls constituting a bout, and the temporal spacing of these individual components within a bout (as measured by intercall intervals). In deaf and hearing laughs, variability in bout, call, and intercall interval durations, and number of calls per bout was found to be greater than had been previously reported (e.g., Mowrer et al., 1987; Bachorowski et al., 2001). These discrepancies likely reflect in part inter- and intra-individual differences in intensity of response to the particular stimuli used in the various studies (Mowrer, 1994).

Large F0 ranges, thought to be a defining characteristic of hearing laughter (Mowrer et al., 1987), were also present in deaf laughter. Female deaf laughers produced calls with a 456.7 Hz total range between the smallest and largest mean F0 value. Similarly, mean F0 values associated with laughs produced by deaf males spanned 460.9 Hz. The ranges in mean F0 values were even greater in calls from hearing laughers, 742.4 Hz for females, and 550.0 Hz for males.

Laughter is characterized by increased F0 values and fast production rates. Several previous studies (e.g., Provine & Yong, 1991; Bachorowski et al., 2001; Vettin & Todt, 2004) have found the mean F0 of hearing laughter to be much higher then the reported mean F0 of speech. Other studies have further suggested that due to the large range in F0 measures of laughter, the maximum F0 in laughter should be more then a doubling of the mean F0 of speech (Mowrer et al., 1987). In the current study, mean F0 values for both deaf and hearing laughter were in fact much larger than those of speech. Although the mean maximum F0 values of deaf and hearing laughter were lower than those reported by Mowrer et al. (1987), they were nearly twice the mean F0 values reported in speech. Because the mean F0 of deaf speech is thought to be similar to that of hearing speech (Lane, Wozniak, Matthies, Svirsky, Perkell, O’Connell, & Manzella, 1997), the values of 220 Hz and 120 Hz (Bachorowski et al., 2001) were used for the female and male comparisons, respectively (see Figure 3.8). However, since mean F0 measures for deaf speech vary significantly by individual (e.g., Lane et al., 1997), these results should be considered preliminary.

Mean laughter production rates for hearing participants (3.82 calls/s) were found to be somewhat lower then those reported by Bachorowski et al. (2001; 4.37 calls/s), but nonetheless higher than reported rates of speech (3.26 syllables/s; Venkatagiri, 1999). Mean rates were lower in deaf laughter (2.82 calls/s), perhaps reflecting on generally slower vocal production rates for that group. Leder and Spitzer (1993), Osberger and Levitt (1979), Osberger and McGarr (1983), and Okalidou and Harris (1999) have all reported that low production rates are characteristic of deaf speech. Possible reasons for these findings are discussed below.

Centralized formant structures are characteristic of laughter. A plot of F1 and F2 outcomes in American-English vowel space (Hillenbrand et al., 1995) showed a clustering of open-mouth voiced deaf and hearing laughter calls around central, and unarticulated regions. Location of calls in these regions gives support to previous findings that laughers do not produce a range of vowel qualities in these sounds (Bachorowski et al., 2001), which is different then in speech (Ruch, 1993). Due to the low amplitude levels of deaf open-mouth unvoiced laughter, formant analysis of these sounds was not possible. However, based on results by Bachorowski et al. (2001), the resulting vowel-space plots should be similar to those for open-mouthed voiced calls. The plot of closed-mouth voiced deaf and hearing laughter sounds indicates that these sounds lack articulation, which is not surprising, since during these calls all energy is passed through the nasal cavity.

Differences between deaf and hearing laughter

Despite overall similarity in acoustic characteristics of laughter produced by profoundly deaf and normally hearing participants, several differences were also found. These differences concern duration, F0, amplitude, and percent-voicing measures, and warrant some discussion.

Temporal structure. Deaf-speech researchers have suggested that deficiencies in laryngeal and oral muscle control (LaPointe et al., 1990; Okalidou & Harris, 1999) may account for some temporal differences between deaf and hearing speech. Since speech and laughter both utilize the same physical apparatus (Nwokah et al., 1999), it is likely that laughter production is governed by similar constraints. Indeed, a look at the temporal structures of deaf speech and deaf laughter reveals some parallels. Just as elongated vowels are characteristic of deaf speech (Bakkum, Plomp, & Pols, 1995; Okalidou & Harris, 1999) laughter is marked by long voiced-call durations. Similarly, between-syllable and between-phoneme temporal distortions found in deaf speech (Rothman, 1976) seem analogous to the elongated intercall intervals of deaf laughter. However, because intercall intervals were only longer following unvoiced calls, further research is needed to clarify this possible relationship.

Mean F0 range. Numerous studies have reported that the mean speaking F0 of deaf individuals does not to vary from the mean F0 of normal speech (e.g., Waldstein, 1990), while others have found mean F0 values to be higher for deaf speakers (e.g., Leder & Spitzer, 1993). Higher individual variability in F0 outcomes in deaf speech than hearing speech, resulting from variable speech experiences of deaf individuals, may be the key to these inconclusive F0 results (Lane et al., 1997). Interestingly, the range of mean F0 values was smaller in deaf laughter then in hearing laughter, by almost 200 Hz for females and almost 100 Hz for males. This discrepancy may be a result of less intensive reactions to humorous stimuli in the deaf laughers (Mowrer et al., 1987), especially when taken together with finding amplitude and an increased percentage of unvoiced calls in their sounds.

Amplitude and percent-voicing. The low relative amplitude and large percentage of unvoiced calls found in deaf laughter could be an indication of a socially conditioned vocal suppression. Amplitude levels of infant vocalizations are reported not to differ for deaf and hearing babies (Oller, Eilers, Bull, & Carney, 1985), suggesting that this amplitude-dampening emerges later in life. The influence of social pressures on deaf vocalizers is reflected in concerns over excessive loudness reported by deaf speakers (Leder & Spitzer, 1993). In the absence of the ability to auditorily monitor their speech, many deaf individuals also report being embarrassed to vocalize, and fearing that their vocalizations may sound “funny” (Higgins, 1980, p. 94). This fear may account for the lower percent-voicing values associated with deaf laughter. On the other hand, in the present study, only one deaf participant reported concern over the recording of his voice, and did so only after learning the true nature of the work. This overall lack of apparent concern may reflect that at time of recording, participants were under the impression that only breathing sounds were of interest, and that during the post-test debriefing participants were assured that only laughter sounds would be considered. As laughter is a mostly spontaneous behavior (Nwokah et al., 1999), any vocal suppression that may have occurred would likely have been unconscious.

Implications for development, stereotypy, and innateness

Overall, results of this study suggest that laughter is a preprogrammed behavior that is, nonetheless, shaped by individual experience. An underlying acoustic similarity in deaf versus hearing laughter was first suggested by the observation that two independent listeners easily recognized laughter produced by deaf and hearing individuals. Subsequent acoustic analysis showed that laughter produced by deaf and hearing participants was, indeed, characterized by several acoustic features previously described by Mowrer et al. (1987) and Bachorowski et al. (2001). Voiced laughter was characterized by relatively high F0 outcomes and unarticulated vowel-like sounds. All laughs were characterized by variability in temporal and F0 features, and production mode. As deaf participants were naïve to the sound of laughter, this overall similarity in laugher lends support to the view that laughter may be preprogrammed. It follows that the acoustic variability found in adult laughter is not acquired through social learning or mimicry, but is innate. This finding directly contradicts the view that laughter is a stereotyped behavior (Provine & Yong, 1991).

If laughter is a preprogrammed behavior, then differences in outcomes within this study likely represent differences in environmental experiences of individuals. Of particular interest to this study were the effects of auditory experience on laughter acoustics. Differences were apparent in temporal and F0 outcomes, as well as relative amplitudes and percentage of calls per voicing category. Such differences in temporal and F0 outcomes have also been reported in deaf versus hearing speech, so it is likely that these outcomes are a reflection on auditory experience with sound. Alternatively, differences in speech experience of deaf versus hearing individuals may impact physiological factors such as lung capacity and laryngeal muscle control (LaPointe et al., 1990; Okalidou et al., 1999). Based on the fact that all deaf participants reported ASL as their primary or native language, and that all currently live in a deaf community (Gallaudet University), it is not unreasonable to assume that their experience with speech is less than that of hearing participants, who all reported English as their native language. Unfortunately, data on the deaf students' speaking abilities are not available. Possible socially-prescribed vocal inhibition would also likely be a result of individual experience, although further research is necessary to strengthen this claim.

An alternate view, that a neural closed-loop feedback mechanism may govern the production of laughter, is unlikely. Research on speech production by post-lingually deafened adults suggest that such a mechanism is necessary for phonemic and temporal fine-tuning (Waldstein, 1990; Lane et al., 1991). However, the results of this and previous laughter acoustics studies suggest variability in laughter sounds, while a feedback mechanism would likely lead to uniformity in sounds.

CHAPTER 5

CONCLUSIONS

By comparing the acoustic characterizations of laughter produced by congenitally, bilaterally, profoundly deaf adults and adults with normal hearing, the current study investigated the long-term development of the behavior in the absence of auditory experience, and provided new insight on laughter innateness and development. The data presented here indicate strong similarity between laughter produced by deaf and hearing adults. High variability in production mode and acoustic structure characterized laughter in both groups. This variability has previously been reported in analyses of laughter produced by both, normally hearing children and adults (e.g., Darwin, 1892; Hall & Allin, 1897; Mowrer et al., 1987; Nwokah et al., 1993; Bachorowski et al., 2001; Vettin & Todt, 2004), and seems to be a prominent feature of the behavior. Furthermore, voiced laughter produced by deaf and hearing individuals was characterized by high mean F0 values and relatively unarticulated wowel qualities, as compared to speech sounds.

As the deaf participants had been affected by profound hearing loss since birth, the similarities found between deaf and hearing laughter cannot be due to social learning or mimicry effects. These results, considered together with the apparent universality of laughter among human cultures and its emergence as “normal” in deaf-blind babies, support the idea of laughter innateness.

The data also showed some significant differences between deaf and hearing laughter, which may be informative for laughter development processes at the level of the individual. Differences in production rate, mean F0 range, and call-durations could reflect physiological differences in vocal physiology, perhaps relating to differences in speech experience. Lower amplitude levels, mean F0 values, and a smaller proportion of voiced laughs in deaf laughter could simply indicate culturally based differences in reactions to the stimuli, meaning that the deaf participants may have found the movies less funny. In addition, socially factors, such as embarrassment associated with the production of vocalizations, may have caused deaf laughers to partially suppress their responses. Both explanations support the notion of laughter undergoing socially-based modifications. Because of the large amount of variability in laughter sounds it is unlikely that like speech, laughter relies on a closed-circuit auditory feedback mechanism for vocal fine-tuning. In all, the similarities found in laughter acoustics support the notion of laughter innateness, while the differences likely represent effects of socially- and environmentally-guided development at the individual level.

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