

**ACOUSTIC DATA FOR AMERICAN ENGLISH /r/ AND /ʒ/
IN TYPICALLY SPEAKING ADOLESCENTS**

Phonology Project Technical Report No. 10

Peter Flipsen Jr.*

Lawrence D. Shriberg

Gary Weismer

Heather B. Karlsson

Jane L. McSweeney

February, 2000

Phonology Project, Waisman Center on Mental Retardation and Human Development,
University of Wisconsin-Madison

Preparation of this report was supported by research grant DC00496 from the National
Institute on Deafness and Other Communication Disorders, National Institutes of Health
(Lawrence D. Shriberg, P.I.)

*affiliated with Minnesota State University, Mankato

INTRODUCTION

The attached tables provide raw and derived acoustic data for each of 26 typically speaking adolescents as summarized in Flipsen, Shriberg, Weismer, Karlsson, and McSweeny (2000). The following text is included in the Flipsen et al. article and is repeated here (with some minor modifications for continuity) for the interested reader.

METHOD

Participants

Typically speaking children in the present study were recruited to provide comparison data for participants in a follow-up study of adolescent children with histories of several types of speech-sound disorders. Two typically speaking children of each sex for each grade level from grades 4 to 9 were recruited. To allow comparison of the present data to the Lee, Potamianos, and Narayanan (1999) data, speaker age, rather than class grade, was ultimately used in the analyses. Classroom teachers in the Madison Metropolitan School District randomly selected four typically developing children from each class in which children with speech disorders had been obtained for the follow-up study. In addition to grade and sex criteria, typically speaking participants met the following criteria: (a) no history of speech problems as confirmed by the school speech-language pathologist; (b) no history of special education services as confirmed by school records; (c) standard scores above 90 on the Peabody Picture Vocabulary Test-Revised, Form M (Dunn & Dunn, 1981), as later determined by the examiner who administered the speech protocol; (d) no dialectal differences from General American speech as later confirmed by the examiner; and (e) no dental braces or other orthodontic appliances as later confirmed by the examiner. Parents were invited by mail to participate in the study. The children of those parents who responded and who met study criteria were scheduled for assessment. The recruitment procedure yielded 24 typically speaking children eventually tested in a 3-month period. To fill a gap in the age distribution for males, data for two typically speaking boys identified through acquaintances and siblings of children enrolled in other studies were added several months later. The ages of the typically speaking children ranged from 9;7 to 15;2 with a mean age of 12;4 ($SD = 1;9$). There was no significant age difference between female and male speakers, $t(22) = 0.01$, $p = .99$.

Speaker Validation

To evaluate the representativeness of the sample of speakers for this age range, speaking fundamental frequency (f_0) values were obtained using the average from as many as 10 tokens per speaker from productions of "Say assign

again" (taken from the speech task described below), including five measurements each from /ēī/ in *say* and /āī/ in *assign*. The interval from the 5th glottal pulse of the vowel to a point 50 ms later in time was isolated. The pitch period was identified using the two most similar contiguous glottal pulses, and the software program CSpeech (Milenkovic, 1996) provided f_0 values derived from the inverse of this period. Female values were relatively stable, ranging from 191 to 228 Hz ($M = 209$, $SD = 12$), whereas male values predictably dropped significantly across this developmental period (range = 118–279, $M = 200$, $SD = 48$). Individual speaker values were consistent with age and sex expectations (Wilson, 1987, pp. 119–124).

Administration of the Speech Task

A speech production task assessing the articulation of /r/, /ʒ/, and /s/ was administered to each of the 26 children as part of a 90-minute test assessment battery. All testing was conducted by one speech-language examiner in a comfortable test suite at the Waisman Center on Mental Retardation and Human Development on the University of Wisconsin campus. Parents had the option of observing the assessment through a one-way mirror. The speech task was the fourth task in the assessment protocol and required approximately 10 minutes to complete. A Shure Model SM10-A low-impedance, unidirectional headset microphone was placed on each subject's head, and the headband was adjusted for head size and comfort. The microphone was positioned approximately 1.5 inches from the lips and no more than 2 inches from the subject's nose, and the microphone head was tilted so that it pointed toward the nose. Prior experience indicated that this configuration provides optimal signal capture while minimizing negative effects from plosive bursts. Productions were recorded on a Sony TCM-5000EV analog cassette recorder. Recording volume was manually adjusted while the child produced pretest words. The examiner later transcribed all the samples following a system of narrow-phonetic transcription and conventions developed for research in child phonology (Shriberg, 1986; Shriberg & Kent, 1995).

Stimuli for the speech task consisted of five randomized lists of 24 words (120 total tokens) produced in the carrier phrase "Say ____ again." Words were presented live by the examiner, who read from a typed list; the child could not see the list or the examiner's face during this task. Speakers were asked to repeat the target in the carrier phrase while maintaining loudness within a preset range as indicated by the VU meter on the tape recorder. The examiner monitored the participants' alertness and performance and asked children to repeat a phrase if the target appeared not to be understood, was produced incorrectly, or contained obvious interword pauses or dysfluencies. All 120 tokens were recorded within a single session. Speakers were permitted a brief break after 60 tokens or if the examiner sensed any fatigue on the part of the speaker. At completion of the entire assessment protocol each participant received \$25.00.

The present study involved acoustic analysis of the 60 items containing rhotic sounds, which consisted of five repetitions each of the following 12 words: *bird*, *burg*, *burr*, *ride*, *rude*, *rebel* (noun), *rebel* (verb), *pried*, *cried*, *tried*, *crude*, and *prude*. These 12 words sampled both consonantal /r/ and /ɝ/ in four canonical forms, four word positions, and in several consonant and vowel contexts.

Acoustic Analysis

Acoustic analyses were accomplished by two trained research assistants, each of whom was randomly assigned to half of the subjects. The assistants, who had completed a course in speech acoustics, followed a well-developed protocol for the analyses (Flipsen, Tjaden, Weismer, & Karlsson, 1996). Using a second Sony 5000EV tape recorder as the input source, tokens were digitized using a Sound Blaster AWE32 PNP A/D sound card connected to a Pentium-based PC. The signal was sampled at 22 kHz with 15 bits of quantization, a pass-band attenuation of -72 dB, and low-pass filtered at 9.8 kHz using the record utility of the software program CSpeech (Milenkovic, 1996). During digitization, tokens were eliminated if they included incorrect productions, dysfluencies, or obvious interword pauses. Pauses, defined as any period of silence 250 ms or longer (Miller, Grosjean, & Lomanto, 1984), were measured from the wide-band spectrograms generated with a bandwidth of 500 Hz. In addition, to ensure that there was sufficient acoustic energy present in both F2 and F3 of /r/ and /ɝ/, tokens were evaluated during both digitization and subsequent measurements so that both formants could be reliably tracked throughout their entire duration from the preceding segment to the following segment.

Of 1,560 possible tokens, 281 (18%) were rejected due to the production of an incorrect target or the presence of interword pauses, dysfluencies, or inadequate formant energy. The target word in the interval from the start of /eɪ/ in "say" to the closure for /g/ in "again" was isolated and stored. Speakers were excluded from the analysis for a word if there were not at least three acceptable tokens for that word because the data from each speaker were to be represented by mean values for eligible repetitions of each target. The yield after all exclusions was 1,216 (78%) useable tokens. Token loss was most frequently due to insufficient energy present in F3, a problem reported by other investigators (e.g., Hoffman, Stager, & Daniloff, 1983; Huer, 1989). With one exception, the exclusions did not result in large per-speaker or per-target losses. The exception was for the word *rebel* (noun) in which only six male and eight female speakers produced at least three useable tokens. Because only 56 useable tokens (43% of the intended tokens) were available for *rebel* (noun), findings for this target word (Table 6 & Figure 6) should be viewed with some caution.

For all 12 words, the formant frequencies of F2 and F3 were calculated within the constriction interval for /r/ and /ɜ:/ defined as the point at which F2 and F3 are closest together. Within the constriction interval, the flat portion was identified and both formant values were measured at the same point in time. When there was no flat portion (e.g., in /r/ cluster contexts in which the formants might rise immediately after the burst release of the stop), the lowest point of F3 was used to make the measurement for all three formants. The frequencies were identified by isolating the center 20 ms of the flat portion (or a 20 ms window centered at the low point of F3 in the case of cluster contexts) and then having CSpeech compute an LPC (Linear Predictive Coding) spectrum using 24 coefficients.

Normalization procedures

For each of the 26 speakers in the current study, individual mean values were computed across each of the 12 words for F2 and F3. Individual speaker means for each formant were used to avoid confounding across-speaker variance with across-token variance. Each speaker's mean for each formant was then converted to a z score using the means and standard deviations reported by Lee et al. for typical production of /ɜ:/ in the word *bird*.

In addition to raw formants, values for F3-F2 and F3/F2 were also calculated. Lee et al. (1999) did not report data on these derived variables. To accomplish the normalization of the derived variables, individual token data for *bird* from each of the speakers in Lee et al. were obtained from S. Lee and F3-F2 and F3/F2 values were calculated for each token. Means and standard deviations for each age and sex from 5 to 18 years and for adults are provided in the Appendix in Flipsen et al. (2000). F3-F2 and F3/F2 values for each token produced by the 26 speakers in the current study were computed and averaged by speaker for each of the 12 word targets. Speaker averages were again used to avoid confounding across-token variance with across-speaker variance. Using the Lee et al. age by sex data for each word (as summarized in the Appendix in Flipsen et al., 2000), speaker averages on these derived variables were then also converted to z scores.

RESULTS

Tables 1–12 provide the individual speaker data for F2, F3, F3-F2, and F3/F2, and the corresponding z scores for each of these variables for each of the 12 targets. Each table includes data for a single target. Speaker age and sex are included for reference purposes. Cell entries represent speaker means and are expressed in Hz for F2, F3, and F3-F2. Data for F3/F2 are dimensionless. Note that data are not reported unless at least three (3) useable tokens were available. Thus, the reported means were based on 3–5 tokens per target per speaker.

Two dimensional plots of F2 by F3 z scores for each of the 12 targets are shown in Figures 1–12. The data in each figure are formatted with z scores of 0 for F2 and F3 at the center of each axis, allowing for visual examination of pattern of departures from 0 on either or both formants by the 26 speakers. The data are divided by sex of speaker.

REFERENCES

- Dunn, L. M., & Dunn, L. M. (1981). *Peabody Picture Vocabulary Test - Revised*. Circle Pines, MN: American Guidance Service.
- Flipsen, P., Jr., Shriberg, L. D., Weismer, G., Karlsson, H. B., & McSweeney, J. L. (2000). Acoustic characteristics of American English /r/ and /ɜ/. Manuscript submitted for publication.
- Flipsen, P., Jr., Tjaden, K., Weismer, G., & Karlsson, H. (1996). *Acoustic analysis protocol* (Tech. Rep. No. 4). Phonology Project, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison.
- Hoffman, P. R., Stager, S., & Daniloff, R. G. (1983). Perception and production of misarticulated /r/. *Journal of Speech and Hearing Disorders*, 48, 210–215.
- Huer, M. B. (1989). Acoustic tracking of articulation errors: /r/. *Journal of Speech and Hearing Disorders*, 54, 530–534.
- Lee, S., Potamianos, A., & Narayanan, S. (1999). Acoustics of children's speech: Developmental changes in temporal and spectral parameters. *Journal of the Acoustical Society of America*, 105, 1455–1468.
- Milenkovic, P. (1996). CSpeech (Version 4) [Computer program]. Madison, WI: University of Wisconsin-Madison, Department of Electrical Engineering.
- Miller, J. L., Grosjean, F., & Lomanto, C. (1984). Articulation rate and its variability in spontaneous speech: A reanalysis and some implications. *Phonetica*, 41, 215–225.
- Shriberg, L. D. (1986). *PEPPER: Programs to Examine Phonetic and Phonologic Evaluation Records*. Hillsdale, NJ: Lawrence Erlbaum.
- Shriberg, L. D., & Kent, R. D. (1995). *Clinical phonetics* (2nd ed.). Boston, MA: Allyn & Bacon.
- Wilson, D. K. (1987). *Voice problems of children* (3rd ed.). Baltimore, MD: Williams & Wilkins.

Table 1
Acoustic data for *bird* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1512	-1.50	2080	-1.20	567	0.22	1.38	0.82
2	F	9	2024	1.64	2548	1.37	524	-0.14	1.26	-0.63
3	F	10	1538	-1.44	2067	-0.76	529	-0.01	1.35	0.27
4	F	11	1482	-1.40	2083	-0.56	601	0.73	1.41	1.27
5	F	11	2011	3.16	2711	3.68	700	1.66	1.35	0.42
6	F	11	1607	-0.33	2135	-0.21	528	0.05	1.33	0.13
7	F	12	1646	-0.10	2204	-0.10	558	-0.07	1.34	-0.09
8	F	13	1848	1.28	2398	1.27	550	0.49	1.30	-0.03
9	F	13	1585	-0.59	2127	-0.18	542	0.43	1.35	0.65
10	F	14	1517	-1.35	1994	-0.67	477	0.01	1.32	0.32
11	F	14	1687	0.52	2218	0.57	632	0.39	1.32	0.32
12	F	15	1552	-0.30	2036	0.79	484	1.19	1.31	1.20
13	M	9	-	-	-	-	-	-	-	-
14	M	9	2005	3.01	2442	1.65	437	-0.62	1.22	-1.19
15	M	10	1719	0.50	2187	0.08	468	-0.35	1.28	-0.39
16	M	10	1908	1.77	2522	1.67	614	0.52	1.32	0.03
17	M	11	1563	0.20	2245	1.25	682	1.22	1.43	1.06
18	M	11	-	-	-	-	-	-	-	-
19	M	12	1482	-0.39	1982	-0.15	500	0.14	1.34	0.16
20	M	12	-	-	-	-	-	-	-	-
21	M	13	1426	0.28	1809	-0.69	383	-1.30	1.27	-1.34
22	M	13	1332	-0.49	1745	-1.08	412	-1.04	1.31	-0.88
23	M	13	1488	0.78	1918	-0.04	430	-0.89	1.29	-1.12
24	M	13	1391	-0.01	1783	-0.85	392	-1.21	1.28	-1.20
25	M	14	1392	-0.79	1912	0.29	520	1.00	1.37	1.04
26	M	14	1255	-1.94	1830	-0.33	576	1.43	1.46	1.89

Table 2
Acoustic data for *burg* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1595	-1.00	2191	-0.59	596	0.46	1.37	0.81
2	F	9	1945	1.15	2526	1.24	580	0.33	1.30	-0.15
3	F	10	1396	-2.49	1981	-1.10	585	0.24	1.42	0.84
4	F	11	1491	-1.33	2063	-0.71	572	0.45	1.38	0.92
5	F	11	1882	2.04	2711	3.68	829	2.86	1.45	1.86
6	F	11	1584	-0.52	2105	-0.42	521	-0.02	1.33	0.12
7	F	12	1616	-0.28	2221	-0.06	606	0.06	1.38	0.07
8	F	13	1800	0.94	2406	1.31	606	0.99	1.34	0.53
9	F	13	1615	-0.37	2101	-0.32	486	-0.07	1.30	0.01
10	F	14	1525	-1.25	1972	-0.79	447	-0.20	1.29	0.06
11	F	14	1615	-0.26	2157	0.23	542	0.46	1.34	0.58
12	F	15	1555	-0.28	1998	0.45	443	0.79	1.29	0.77
13	M	9	-	-	-	-	-	-	-	-
14	M	9	1934	2.51	2445	1.66	511	-0.10	1.26	-0.76
15	M	10	1730	0.57	2202	0.15	473	-0.32	1.27	-0.42
16	M	10	1856	1.43	2457	1.36	601	0.44	1.32	0.03
17	M	11	1568	0.24	2174	0.87	606	0.77	1.39	0.63
18	M	11	1551	0.10	1972	-0.22	421	-0.31	1.27	-0.31
19	M	12	1379	-1.22	1925	-0.48	546	0.43	1.40	0.63
20	M	12	-	-	-	-	-	-	-	-
21	M	13	1392	0.00	1740	-1.11	348	-1.59	1.25	-1.55
22	M	13	1319	-0.60	1757	-1.00	438	-0.82	1.33	-0.63
23	M	13	1452	0.50	1908	-0.10	456	-0.67	1.32	-0.83
24	M	13	1389	-0.02	1776	-0.89	387	-1.26	1.28	-1.24
25	M	14	1401	-0.71	1938	0.48	537	1.13	1.38	1.14
26	M	14	1207	-2.34	1727	-1.10	520	1.00	1.43	1.61

Table 3
Acoustic data for *burr* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1697	-0.37	2154	-0.79	457	-0.71	1.27	-0.47
2	F	9	1912	0.95	2527	1.26	614	0.62	1.32	0.16
3	F	10	1431	-2.24	1938	-1.26	507	-0.11	1.36	0.35
4	F	11	1452	-1.66	2037	-0.88	585	0.58	1.40	1.18
5	F	11	2002	3.08	2703	3.62	700	1.66	1.35	0.48
6	F	11	1586	-0.51	2062	-0.71	477	-0.43	1.30	-0.27
7	F	12	1650	-0.07	2148	-0.25	498	-0.24	1.30	-0.26
8	F	13	1822	1.09	2312	0.81	490	-0.04	1.27	-0.45
9	F	13	1581	-0.62	2067	-0.50	486	-0.17	1.31	0.12
10	F	14	1469	-1.86	1985	-0.72	516	0.28	1.35	0.79
11	F	14	1676	0.40	2165	0.28	490	0.10	1.29	0.03
12	F	15	1534	-0.47	1990	0.37	456	0.92	1.30	0.97
13	M	9	-	-	-	-	-	-	-	-
14	M	9	1981	2.85	2393	1.41	412	-0.79	1.21	-1.27
15	M	10	1616	-0.19	2105	-0.31	490	-0.22	1.30	-0.15
16	M	10	1865	1.48	2406	1.12	541	0.09	1.29	-0.26
17	M	11	1530	-0.08	2118	0.57	589	0.67	1.39	0.64
18	M	11	-	-	-	-	-	-	-	-
19	M	12	1371	-1.28	1886	-0.71	516	0.24	1.38	0.47
20	M	12	1346	-1.48	1798	-1.23	451	-0.16	1.34	0.13
21	M	13	1418	0.21	1783	-0.85	365	-1.44	1.26	-1.47
22	M	13	1147	-2.01	1590	-2.01	443	-0.78	1.38	-0.06
23	M	13	1418	0.21	1831	-0.57	413	-1.04	1.29	-1.09
24	M	13	1365	-0.23	1724	-1.20	360	-1.50	1.26	-1.40
25	M	14	1379	-0.89	1740	-1.00	361	-0.22	1.26	-0.08
26	M	14	1173	-2.63	1680	-1.46	507	0.90	1.43	1.63

Table 4
Acoustic data for ride produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1585	-1.05	2355	0.31	769	1.92	1.49	2.20
2	F	9	–	–	–	–	–	–	–	–
3	F	10	1315	-3.10	2006	-1.00	691	0.73	1.54	1.78
4	F	11	1236	-3.53	2079	-0.60	843	2.99	1.71	5.51
5	F	11	–	–	–	–	–	–	–	–
6	F	11	1469	-1.51	2093	-0.50	623	0.94	1.42	1.49
7	F	12	1500	-0.97	2238	-0.02	739	0.42	1.50	0.65
8	F	13	1432	-1.67	2306	0.77	873	3.57	1.62	4.55
9	F	13	1594	-0.52	2136	-0.14	542	0.42	1.34	0.59
10	F	14	1153	-5.34	2156	0.22	1003	3.68	1.87	7.29
11	F	14	1640	0.01	2349	1.29	709	1.63	1.43	1.78
12	F	15	–	–	–	–	–	–	–	–
13	M	9	–	–	–	–	–	–	–	–
14	M	9	2002	2.99	2608	2.46	606	0.54	1.31	-0.34
15	M	10	–	–	–	–	–	–	–	–
16	M	10	1848	1.37	2492	1.53	645	0.70	1.35	0.28
17	M	11	–	–	–	–	–	–	–	–
18	M	11	–	–	–	–	–	–	–	–
19	M	12	1196	-2.69	1898	-0.64	702	1.40	1.59	2.23
20	M	12	–	–	–	–	–	–	–	–
21	M	13	1199	-1.58	1684	-1.44	485	-0.41	1.41	0.22
22	M	13	1026	-3.00	1929	0.02	903	3.19	1.88	5.47
23	M	13	1375	-0.14	1923	-0.01	548	0.13	1.41	0.17
24	M	13	1251	-1.16	1775	-0.90	524	-0.08	1.42	0.36
25	M	14	1169	-2.67	1809	-0.49	640	1.92	1.56	2.85
26	M	14	1044	-3.73	1727	-1.10	683	2.25	1.66	3.86

Table 5
Acoustic data for *rude* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1676	-0.50	2213	-0.47	537	-0.04	1.33	0.31
2	F	9	-	-	-	-	-	-	-	-
3	F	10	1397	-2.49	2063	-0.78	666	0.61	1.49	1.41
4	F	11	1212	-3.74	2101	-0.44	890	3.43	1.74	5.95
5	F	11	1604	-0.35	2908	5.00	1304	7.30	1.83	7.22
6	F	11	1392	-2.18	2200	0.22	808	2.66	1.58	3.74
7	F	12	1300	-2.17	2132	-0.29	832	0.68	1.64	1.27
8	F	13	-	-	-	-	-	-	-	-
9	F	13	1512	-1.10	2196	0.19	683	1.67	1.45	2.21
10	F	14	-	-	-	-	-	-	-	-
11	F	14	1397	-2.66	2471	1.97	1074	4.18	1.77	6.06
12	F	15	-	-	-	-	-	-	-	-
13	M	9	1504	-0.52	2007	-0.48	503	-0.17	1.34	-0.05
14	M	9	1810	1.64	2675	2.79	865	2.33	1.54	1.99
15	M	10	1446	-1.33	2048	-0.58	602	0.44	1.42	0.88
16	M	10	1751	0.72	2734	2.67	983	2.70	1.58	2.32
17	M	11	-	-	-	-	-	-	-	-
18	M	11	-	-	-	-	-	-	-	-
19	M	12	-	-	-	-	-	-	-	-
20	M	12	1024	-4.08	1798	-1.23	774	1.85	1.76	3.64
21	M	13	972	-3.44	1676	-1.49	704	1.47	1.76	4.10
22	M	13	-	-	-	-	-	-	-	-
23	M	13	1279	-0.93	1789	-0.82	510	-0.20	1.40	0.08
24	M	13	1117	-2.25	1826	-0.59	709	1.52	1.64	2.73
25	M	14	-	-	-	-	-	-	-	-
26	M	14	1079	-3.44	1727	-1.10	649	1.99	1.60	3.32

Table 6
Acoustic data for *rebel* (noun) produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1676	-0.50	2292	-0.03	616	0.63	1.37	0.71
2	F	9	-	-	-	-	-	-	-	-
3	F	10	1401	-2.46	2075	-0.73	675	0.65	1.48	1.33
4	F	11	1182	-3.99	2011	-1.05	829	2.86	1.73	5.80
5	F	11	-	-	-	-	-	-	-	-
6	F	11	1375	-2.33	2209	0.28	834	2.90	1.61	1.41
7	F	12	1328	-2.00	2127	-0.30	799	0.59	1.62	1.19
8	F	13	1457	-1.50	2385	1.20	928	3.84	1.67	5.22
9	F	13	1346	-2.28	2213	0.28	866	3.29	1.65	5.06
10	F	14	-	-	-	-	-	-	-	-
11	F	14	1604	-0.38	2413	1.65	809	2.33	1.50	2.68
12	F	15	-	-	-	-	-	-	-	-
13	M	9	-	-	-	-	-	-	-	-
14	M	9	1977	2.81	2611	2.47	634	0.74	1.32	-0.17
15	M	10	-	-	-	-	-	-	-	-
16	M	10	1495	-1.00	2561	1.85	1066	3.19	1.72	3.61
17	M	11	1375	-1.36	2027	0.07	652	1.05	1.48	1.40
18	M	11	-	-	-	-	-	-	-	-
19	M	12	-	-	-	-	-	-	-	-
20	M	12	-	-	-	-	-	-	-	-
21	M	13	1075	-2.60	1773	-0.91	698	1.42	1.65	2.90
22	M	13	-	-	-	-	-	-	-	-
23	M	13	1454	0.51	2005	0.48	552	0.16	1.38	-0.08
24	M	13	-	-	-	-	-	-	-	-
25	M	14	-	-	-	-	-	-	-	-
26	M	14	974	-4.32	1740	-1.01	766	2.89	1.79	5.17

Table 7
Acoustic data for *rebel* (verb) produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1856	0.61	2389	0.50	533	-0.07	1.30	-0.15
2	F	9	-	-	-	-	-	-	-	-
3	F	10	1680	-0.39	2230	-0.13	550	0.09	1.33	0.15
4	F	11	1448	-1.70	1998	-1.14	550	0.25	1.38	0.91
5	F	11	2134	4.22	2915	5.05	780	2.40	1.37	0.69
6	F	11	1885	2.07	2696	3.58	811	2.69	1.45	1.84
7	F	12	1534	-0.77	2227	-0.05	692	0.29	1.45	0.43
8	F	13	1938	1.92	2613	2.41	674	1.60	1.35	0.70
9	F	13	1744	0.54	2213	0.28	468	-0.23	1.27	-0.43
10	F	14	1531	-1.19	2202	0.48	672	1.37	1.44	1.88
11	F	14	-	-	-	-	-	-	-	-
12	F	15	1539	-0.42	2148	1.83	609	2.44	1.40	2.42
13	M	9	1561	-0.11	2141	0.18	580	0.37	1.37	0.33
14	M	9	2290	5.02	2827	3.53	537	0.07	1.24	-1.01
15	M	10	1627	-0.11	2321	0.71	693	0.98	1.43	0.97
16	M	10	1968	2.17	2788	2.93	820	1.73	1.42	0.89
17	M	11	1751	1.75	2374	1.94	623	0.88	1.36	0.45
18	M	11	1617	0.64	2337	1.74	720	1.45	1.45	1.19
19	M	12	-	-	-	-	-	-	-	-
20	M	12	1444	-0.70	2054	0.28	610	0.83	1.43	0.95
21	M	13	1302	-0.74	1929	0.03	627	0.81	1.50	1.17
22	M	13	1386	-0.05	2106	1.08	720	1.61	1.53	1.60
23	M	13	1654	2.15	2075	0.90	421	-0.97	1.26	-1.50
24	M	13	1268	-1.02	2020	0.57	752	1.89	1.61	2.46
25	M	14	1392	-0.78	1955	0.61	563	1.33	1.41	1.38
26	M	14	1225	-2.20	2011	1.03	786	3.05	1.65	3.81

Table 8
Acoustic data for *pried* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	2050	1.80	2621	1.76	572	0.26	1.28	-0.39
2	F	9	1955	1.22	2607	1.70	652	0.93	1.33	0.29
3	F	10	1517	-1.60	2118	-0.57	602	0.32	1.40	0.66
4	F	11	1563	-0.71	2208	0.27	645	1.14	1.41	1.35
5	F	11	2071	3.67	2707	3.65	636	1.06	1.31	-0.18
6	F	11	1783	1.19	2359	1.30	575	0.49	1.32	0.06
7	F	12	1572	-0.54	2277	0.08	705	0.33	1.45	0.42
8	F	13	1907	1.70	2713	2.95	806	2.76	1.42	1.77
9	F	13	1697	0.21	2197	0.19	500	0.05	1.29	-0.08
10	F	14	1714	0.83	2294	0.99	580	0.73	1.34	0.60
11	F	14	1753	1.25	2385	1.49	632	1.09	1.36	0.88
12	F	15	1663	0.68	2131	1.67	468	1.04	1.28	0.75
13	M	9	1598	0.15	2114	0.05	516	-0.08	1.32	-0.16
14	M	9	1993	2.93	2589	2.36	596	0.48	1.30	-0.41
15	M	10	1681	0.25	2256	0.41	575	0.28	1.34	0.20
16	M	10	1875	1.55	2594	2.01	720	1.14	1.38	0.58
17	M	11	1676	1.13	2277	1.42	602	0.75	1.36	0.41
18	M	11	1548	0.06	2111	0.53	564	0.53	1.37	0.48
19	M	12	1332	-1.60	1913	-0.56	581	0.65	1.45	1.05
20	M	12	1411	-0.96	1977	-0.18	566	0.55	1.40	0.69
21	M	13	1427	0.28	1891	-0.21	464	-0.59	1.33	-0.72
22	M	13	1332	-0.49	1869	-0.33	537	0.03	1.40	0.14
23	M	13	1495	0.85	1985	0.36	490	-0.37	1.33	-0.69
24	M	13	1319	-0.60	1809	-0.69	490	-0.37	1.37	-0.20
25	M	14	1405	-0.67	2028	1.16	623	1.79	1.44	1.73
26	M	14	1268	-1.83	1878	0.03	610	1.69	1.48	2.13

Table 9
Acoustic data for *cried* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	2105	2.14	2608	1.71	503	-0.32	1.24	-0.88
2	F	9	–	–	–	–	–	–	–	–
3	F	10	1684	-0.36	2282	0.07	597	0.30	1.36	0.35
4	F	11	1672	0.23	2247	0.54	575	0.49	1.35	0.39
5	F	11	2093	3.86	2750	3.94	657	1.26	1.32	-0.05
6	F	11	1680	0.30	2320	1.04	640	1.09	1.38	0.89
7	F	12	1856	1.16	2355	0.27	498	-0.24	1.27	-0.42
8	F	13	1963	2.09	2499	1.81	637	0.38	1.27	-0.37
9	F	13	1727	0.42	2187	0.14	459	-0.31	1.27	-0.48
10	F	14	1753	1.25	2303	1.04	550	0.52	1.31	0.29
11	F	14	1809	1.87	2453	1.87	644	1.18	1.36	0.83
12	F	15	1563	-0.21	2063	1.04	500	1.35	1.32	1.28
13	M	9	1628	0.36	2058	-0.22	430	-0.67	1.26	-0.75
14	M	9	2148	4.02	2782	3.31	634	0.74	1.30	-0.43
15	M	10	1704	0.40	2270	0.48	566	0.23	1.33	0.11
16	M	10	2024	2.55	2746	2.73	722	1.15	1.36	0.34
17	M	11	1697	1.31	2380	1.98	683	1.23	1.41	0.80
18	M	11	1521	-0.14	2071	0.31	550	0.45	1.36	0.43
19	M	12	1349	-1.46	1990	-0.10	640	1.02	1.48	1.33
20	M	12	1461	-0.56	1988	-0.11	527	0.31	1.36	0.35
21	M	13	1444	0.42	1908	-0.10	464	-0.59	1.32	-0.75
22	M	13	1354	-0.31	2034	0.65	680	1.27	1.51	1.28
23	M	13	1628	1.94	2101	1.06	473	-0.52	1.29	1.10
24	M	13	1405	0.11	1848	-0.46	443	-0.78	1.32	-0.82
25	M	14	1504	0.17	2052	1.33	548	1.21	1.36	0.95
26	M	14	1341	-1.21	1977	0.77	636	1.89	1.48	2.05

Table 10
Acoustic data for *tried* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	2148	2.40	2697	2.19	548	0.06	1.26	-0.68
2	F	9	-	-	-	-	-	-	-	-
3	F	10	1637	-0.71	2402	0.53	765	1.06	1.47	1.22
4	F	11	1830	1.59	2355	1.27	524	0.01	1.29	-0.49
5	F	11	2178	4.60	2832	4.49	653	1.22	1.30	-0.27
6	F	11	1667	0.19	2281	0.77	614	0.85	1.37	0.75
7	F	12	-	-	-	-	-	-	-	-
8	F	13	1955	2.04	2720	2.99	765	2.39	1.39	1.31
9	F	13	1758	0.64	2320	0.85	563	0.61	1.32	0.29
10	F	14	1723	0.92	2247	0.73	524	0.34	1.30	0.17
11	F	14	1960	3.53	2777	3.66	817	2.38	1.42	1.57
12	F	15	1706	1.07	2140	1.75	434	0.70	1.25	0.35
13	M	9	1676	0.70	2091	-0.06	415	-0.77	1.25	-0.92
14	M	9	2268	4.87	2866	3.72	597	0.49	1.26	-0.76
15	M	10	1669	0.17	2306	0.64	634	0.65	1.39	0.66
16	M	10	2041	2.66	2990	3.41	849	1.90	1.42	0.87
17	M	11	-	-	-	-	-	-	-	-
18	M	11	1607	0.56	2161	0.80	554	0.47	1.35	0.29
19	M	12	1456	-0.60	2063	0.33	607	0.81	1.42	0.81
20	M	12	1454	-0.62	1976	-0.18	523	0.29	1.36	0.31
21	M	13	1478	0.71	1921	-0.02	443	-0.78	1.30	-0.99
22	M	13	1319	-0.60	1869	-0.33	550	0.15	1.42	0.34
23	M	13	1654	2.15	2140	1.29	486	-0.40	1.30	-1.03
24	M	13	1530	1.13	2032	0.64	503	-0.26	1.33	-0.67
25	M	14	1534	0.42	2234	2.71	700	2.39	1.46	1.86
26	M	14	1429	-0.47	1918	0.33	489	0.76	1.34	0.74

Table 11
Acoustic data for *crude* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1944	1.15	2396	0.54	451	-0.75	1.23	-0.95
2	F	9	2240	2.96	2755	2.51	516	-0.21	1.23	-0.99
3	F	10	1740	0.05	2333	0.27	593	0.28	1.34	0.27
4	F	11	1345	-2.59	2221	0.37	876	3.30	1.65	4.75
5	F	11	1778	1.15	2798	4.27	1020	4.65	1.59	3.80
6	F	11	1730	0.73	2359	1.30	629	0.99	1.37	0.77
7	F	12	1504	-0.95	2320	0.18	817	0.64	1.55	0.85
8	F	13	1843	1.24	2539	2.02	696	1.79	1.38	1.13
9	F	13	1676	0.06	2329	0.90	653	1.41	1.39	1.29
10	F	14	1702	0.69	2299	1.02	597	0.85	1.35	0.77
11	F	14	1646	0.07	2570	2.51	924	3.13	1.56	3.42
12	F	15	1474	-1.00	2178	2.10	704	3.38	1.49	3.67
13	M	9	1555	-0.15	2217	0.55	662	0.93	1.43	0.91
14	M	9	1971	2.78	2578	2.31	607	0.55	1.31	-0.29
15	M	10	1650	0.04	2221	0.24	572	0.26	1.35	0.26
16	M	10	1753	0.73	2922	3.56	1169	3.80	1.67	3.18
17	M	11	-	-	-	-	-	-	-	-
18	M	11	1542	0.03	1908	-0.56	366	-0.64	1.24	-0.59
19	M	12	1233	-2.39	1990	-0.10	756	1.75	1.62	2.47
20	M	12	1402	-1.03	2084	0.45	682	1.28	1.50	1.53
21	M	13	1413	0.17	1955	0.18	543	0.08	1.39	-0.04
22	M	13	1448	0.46	2041	0.69	593	0.52	1.42	0.28
23	M	13	1418	0.21	1938	0.08	520	-0.11	1.37	-0.26
24	M	13	1461	0.56	1916	-0.05	456	-0.67	1.31	-0.86
25	M	14	1379	-0.89	1891	0.12	511	0.93	1.37	1.02
26	M	14	1199	-2.42	1912	0.28	713	2.49	1.60	3.27

Table 12
Acoustic data for *prude* produced by 26 typically speaking adolescents

ID	Sex	Age	F2	z F2	F3	z F3	F3-F2	z F3-F2	F3/F2	z F3/F2
1	F	9	1627	-0.80	2191	-0.59	564	0.19	1.36	0.59
2	F	9	2011	1.56	2621	1.78	610	0.58	1.31	-0.04
3	F	10	1607	-0.93	2273	0.03	666	0.61	1.42	0.82
4	F	11	1370	-2.37	2181	0.10	811	2.69	1.59	3.91
5	F	11	1805	1.38	2782	4.16	978	4.25	1.56	3.41
6	F	11	1697	0.45	2385	1.47	688	1.54	1.41	1.34
7	F	12	1504	-0.96	2251	0.01	747	0.46	1.50	0.64
8	F	13	1792	0.88	2483	1.72	692	1.75	1.39	1.29
9	F	13	1676	0.05	2379	1.17	704	1.85	1.42	1.74
10	F	14	1611	-0.31	2230	0.64	619	1.00	1.39	1.25
11	F	14	1534	-1.16	2454	1.87	920	3.10	1.60	3.91
12	F	15	1405	-1.61	2054	0.96	648	2.83	1.47	3.40
13	M	9	1624	0.33	2174	0.34	550	0.16	1.34	-0.02
14	M	9	1912	2.36	2637	2.60	725	1.37	1.38	0.41
15	M	10	1560	-0.57	2269	0.48	709	1.08	1.46	1.24
16	M	10	1680	0.24	2788	2.93	1108	3.44	1.66	3.11
17	M	11	1530	-0.08	2587	3.08	1057	3.43	1.69	3.19
18	M	11	1568	0.24	2032	0.10	464	-0.06	1.30	-0.10
19	M	12	1273	-2.07	1972	-0.21	699	1.38	1.55	1.96
20	M	12	1311	-1.77	2141	0.79	830	2.21	1.63	2.62
21	M	13	1354	-0.32	1982	0.34	629	0.82	1.46	0.83
22	M	13	1405	0.11	2058	0.80	653	1.04	1.47	0.85
23	M	13	1392	0.00	1848	-0.46	456	-0.67	1.33	-0.69
24	M	13	1412	0.17	1831	-0.56	418	-0.99	1.30	-1.04
25	M	14	1422	-0.53	1895	0.16	473	0.64	1.33	0.62
26	M	14	1173	-2.63	1801	-0.55	627	1.83	1.54	2.66

Figures 1–12. Z Scores For F2 And F3

● male ○ female

Figure 1. *bird*

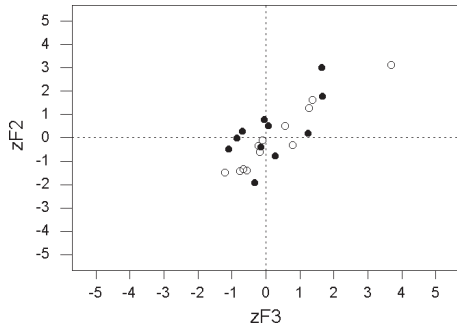


Figure 2. *burg*

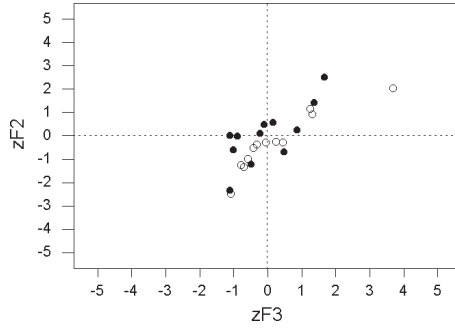


Figure 3. *burr*

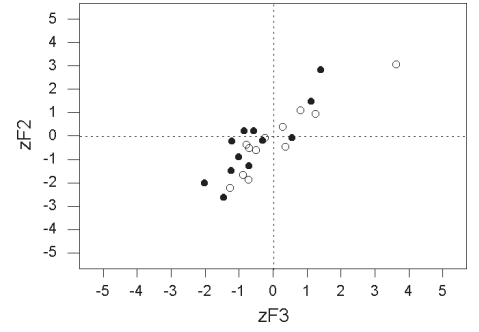


Figure 4. *ride*

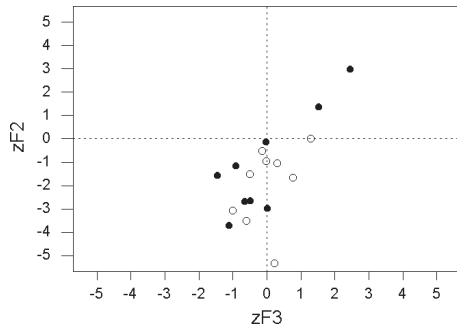


Figure 5. *rude*

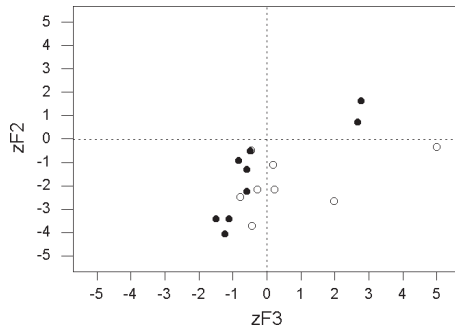


Figure 6. *rebel* (noun)

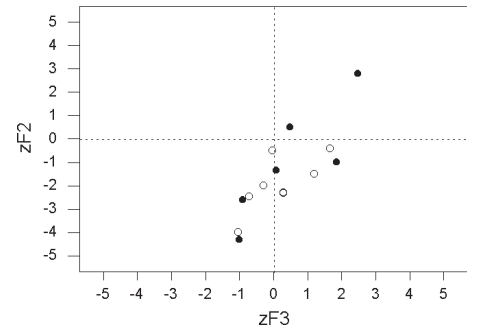


Figure 7. *rebel* (verb)

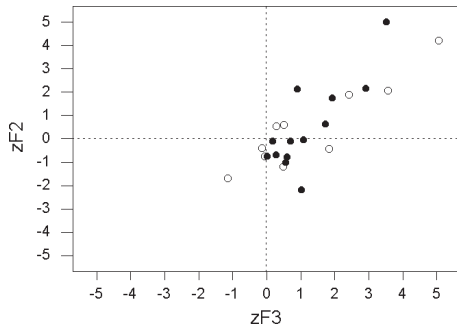


Figure 8. *pried*

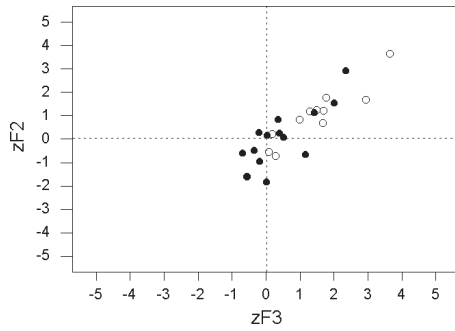


Figure 9. *cried*

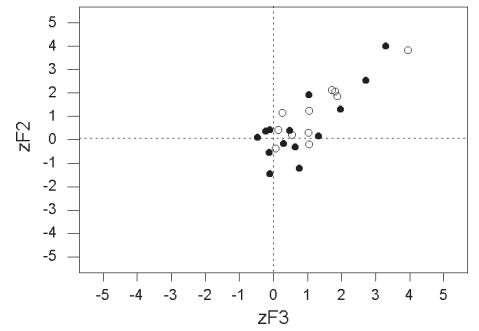


Figure 10. *tried*

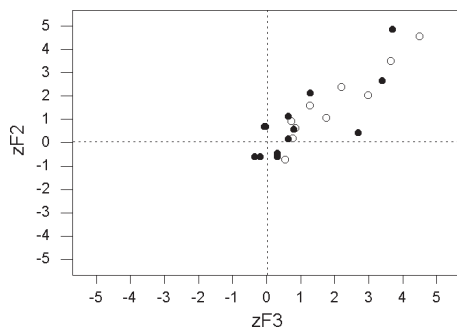


Figure 11. *crude*

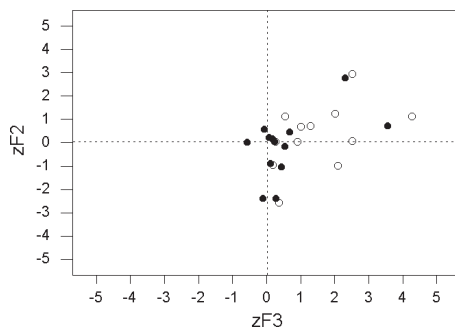


Figure 12. *prude*

