Hand-Held Tactile Biofeedback as a Cuing Mechanism to Elicit and Generalize Correct /R/: A Case Study

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Abstract
The current study examined the clinical effectiveness of a tactile biofeedback device in the treatment of misarticulated American English /r/ in a single, treatment-naïve, neurotypical child. The device provided a direct tactile model of the retroflection of the tongue in the production of /r/ and was the primary cuing mechanism within a short-duration, traditional articulation therapy regimen. After four hours of direct therapy, the participant was able to demonstrate a remediation response, and generalized therapy gains, as measured ten weeks post-treatment. Results provide initial evidence for the clinical utility of this tactile biofeedback device in the treatment of American English /r/. Implications of results are discussed in detail.

The article author, Gordy Rogers, is the Chief Scientific Officer of Articulate Technologies, Inc., a company which has developed and patented a licensed technology trademarked as the Speech Buddies ®. The author has the following financial disclosures: intellectual property rights, patent on equipment and ownership interest. This article will focus exclusively on Speech Buddies ® and will not include information on other or similar products.

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Learning Objectives

1) Describe the theoretical underpinnings of tactile biofeedback in treating misarticulated /r/.
2) Explain the results reported in this study in a broader context of expected treatment outcomes in articulation disorders in children.
3) Identify whether any clients on their caseloads would benefit from the addition of tactile biofeedback into treatment

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Speech sound disorders affect as much as 7.5% of the school-age population (Shriberg & Kwiatkowski, 1994) and can negatively impact teacher perceptions of students with reduced speech intelligibility (Overby, Carrell, & Bernthal, 2007) as well as inter-peer relationships among school-age children (Crowe Hall, 1991). Despite evidence that traditional and phonological approaches to treating speech sound disorders can be effective, Jacoby, Lee, Kummer, Levin and Creaghead (2002) found that, broadly speaking, treatment resulted in no measurable progress for approximately 28% of the 234 pre-school and school-age children they analyzed over a two-year period. Given the size of this treatment-resistant cohort and the documented social and academic burden of speech sound disorders, it is incumbent upon researchers and clinical practitioners in the field to not only continue to develop improved treatment methods, but also to test these methods through rigorous treatment studies.

One persistent clinical problem facing researchers and clinicians is the American English /r/ sound (Bernthal, Bankson, & Flipsen, 2009; Secord, 1981). This speech sound can be persistently resistant to treatment (Flipsen, Shriberg, Karlsson, Weismer & McSweeny, 2001; Shriberg, 1980; Shuster, Ruscello & Smith, 1992), and accounts for the majority of residual speech errors, or errors that persist in a child's sound system into adolescence (Ruscello, 1995). For these reasons, it may be particularly important for researchers and clinical practitioners to continue to develop and test novel approaches to treating specifically the American /r/ sound.

Indeed, one of the principal reasons /r/ presents such difficulty in treatment is that its position in the word affects how it is produced. For example, when /r/ occurs before a vowel, it is called prevocalic or consonantal /r/; when it occurs after a vowel in a word it is termed vocalic /r/. Elbert and McReynolds (1975) found significant generalization across these two classes of /r/; when one class was explicitly trained, the other class showed gains in accuracy. However more recently, from both an articulatory and an acoustic standpoint, there is evidence that these two versions of /r/ are in fact distinct (McGowan, Nittrouer & Manning). Furthermore, Gick & Goldstein (2002) have found differences in the timing of the necessary articulatory gestures for both vocalic and consonantal /r/. This would suggest that both versions of American English /r/ need to be separately considered and targeted in treatment. In the current study, both consonantal and vocalic /r/ were targeted in separate blocks in each study treatment session.

More recently, researchers have begun to test a variety of novel treatment approaches to provide treatment alternatives for treatment-resistant children. Many of these approaches to treatment generally fall under the term sensory biofeedback. Sensory biofeedback utilizes specialized instrumentation to facilitate increased awareness of the target behavior in the client (McAllister, Byun, & Hitchcock, 2012). Sensory biofeedback works by providing an alternate visual representation of the target behavior (i.e., visual biofeedback) or by presenting a physical target for the participant to touch (i.e., tactile biofeedback) to achieve the target behavior (Shuster, Ruscello, & Toth, 1995). Examples of these approaches, which target the client's visual perceptual system, are electropalatography (EPG) and ultrasound. Sensory biofeedback provides an external focus of directed attention to the task of remediating misarticulated speech. This external focus is said to aid the retention of a newly acquired motor skill such as speech (Wulf, 2007).

The theoretical underpinnings of specifically tactile biofeedback have become the focus of recent studies. These studies have highlighted the strong connection between auditory and tactile or somatosensory feedback in speech perception and production (Tremblay, Shiller, & Ostry, 2003; Gick & Derrick, 2009; Champoux, Shiller, & Zatorre, 2011). Indeed, leading psycholinguistic models of the speech production mechanism, such as Guenther's DIVA model (Guenther & Vladusich, 2012) necessarily include an active somatosensory feedback control subsystem. This subsystem is thought to include specific, distinct somatosensory goals during speech production. These researchers have posited that aberrant speech production may be the result of an underlying impairment in the development of this somatosensory feedback control subsystem, and, by extension, fine-tuning a speaker's somatosensory acuity during speech production may be one of the principal underlying goals of speech intervention (Ghosh, Matthies, Maas, Hanson, Tiede, Menard, Guenther, Lane, & Perkell, 2010).

As a methodology, tactile biofeedback provides the participant with a lingual target inside the oral cavity that indicates, by feeling this target, where the tongue should be placed and how it should move in order to achieve correct production of misarticulated /r/. There has been a long history of tactile feedback devices in therapy for speech sound disorders (Ruscello, 1995). A notable study testing the effectiveness of such a device was reported by Clark, Schwarz, and Blakeley (1993). Their investigation focused on a specially fitted dental mold with an attached lingual target that was shown to be effective in treating misarticulated /r/, as compared to traditional approaches of articulation therapy.

Although sensory biofeedback approaches have shown clear clinical promise, particularly with treatment-resistant /r/ errors, the widespread applicability currently appears limited. For example, Adler-Bock, Bernhardt, Gick, and Bacsfalvi (2007) noted the relatively high cost of ultrasound instrumentation despite the promising clinical implications of the data they obtained supporting its use in remediating residual /r/ in adolescents. The tactile biofeedback device described in Clark et al. (1993) required individual fitting, was noted to have impeded saliva swallowing, anad was generally uncomfortable to study participants over extended use. The current study aims to provide preliminary evidence for a unique embodiment of tactile biofeedback that does not require specialized fitting, is generally well tolerated by clients, and would be available to clinicians at a fraction of the cost of other biofeedback tools.

Hypothesis

This study aims to examine the effectiveness of a specially designed tactile biofeedback tool that directly cues the retroflection necessary to produce American English /r/. Specifically, the author hypothesizes that the use of tactile biofeedback as the primary cuing mechanism for remediating /r/ will result in decreased time to achieve remediation as compared to industry norms. The tactile biofeedback device will be used as the primary cuing mechanism within a traditional articulation therapy framework, as described in Van Riper & Emerick (1984). Industry norm used for comparison are data gathered by Jacoby et al (2002), which describe the average treatment time for speech sound disorders for pre-school and early school-age children. These norms are based on data gathered from 149 children aged 3 to 6 who received treatment to address speech sound disorders; to the author's knowledge, no other set of data of a comparable sample size exists for the study participant's age group. Based on these data reported by Jacoby et al (2002), the average time to achieve one level of functional communication improvement, which corresponds to the study participant's misarticulation of /r/, was 14 hours of direct therapy. These normative data will be compared with the data gathered during this investigation at two separate time points: 1) at the conclusion of treatment; and, 2) at ten weeks following the conclusion of treatment. Should the study participant show maintenance of accuracy levels ten weeks post-treatment, this would suggest gains were generalized to the participant's everyday life. Remediation is defined as greater than 70% accuracy in words and words-in-sentences on a 50-item picture naming test, as per performance standards stipulated in Van Riper and Emerick (1984).

Methodology

In order to test the hypotheses listed above, a single, treatment-naïve male participant, A.R., age 8 years, 10 months, received eight therapy sessions of approximately 30 minutes each. During treatment, the primary means of eliciting correct American English /r/ was tactile biofeedback. The participant's baseline accuracy at producing /r/ was assessed pre-treatment and compared to accuracy immediately following the conclusion of treatment as well as ten weeks post-treatment, to assess generalization. The principal investigator (PI), who acted both as the study evaluator and therapist, obtained informed consent from A.R.'s mother as well as assent from A.R. himself, using IRB-approved forms.

Participant

At the time of enrollment, the study participant was 8 years, 10 months old and presented with misarticulated American English /r/ and /s/, as measured by 20% accuracy or less on picture naming tests focused on these phonemes. He was a monolingual native speaker of Standard American English. As per the results of the Comprehensive Evaluation of Language Fundamentals-4 Screening Test (CELF-4 Screening Test), A.R. was not at risk for a receptive or expressive language delay or disorder. As per an audiological screening using a recently calibrated Earscan 3 ® brand audiometer, A.R. presented with hearing function within normal limits at 500 Hz, 1000 Hz, and 5000 Hz, bilaterally. He had no consistent prior speech therapy targeting his misarticulated /r/ but underwent a brief therapy regimen of approximately four hours focused on production of /s/. The participant's mother reported no measureable improvement on accuracy of /s/ production as a result of this treatment and therapy to target /s/ was discontinued.

Test Article

The principal function of the test article is to aid the participant in achieving correct lingual placement and movement for the /r/sound, the primary task of the speaker (McAllister, Byun, & Hitchcock, 2012). Acoustically correct production of /r/ requires three distinct oral cavity constrictions as well as posterior lateral tongue bracing (Alwan, Narayana, & Haker, 1997; Gick, Iskarous, Whalen, & Goldstein, 2003). The first, most anterior constriction is commonly referred to as lip rounding and is particularly evident in word-initial, pre-vocalic /r/ (Bernhardt & Stemberger, 1998). The second constriction involves the tongue moving posteriorly to approximate the shape of the palate. This is generally accomplished by two means in the majority of speakers of American English: tongue retroflection or tongue retraction. The third, most posterior constriction involves the tongue moving toward the pharyngeal wall (Alwan et al., 1997). As described below, a combined visual and verbal cue was used to aid the client in achieving lip rounding for /r/. The test article targets the second of these constrictions, where the tongue moves to approximate the shape of the oral cavity.

The test article is a tactile biofeedback device and is commercially known as the Speech Buddy® R device. The test article was designed by Articulate Technologies, Inc., a private company based in San Francisco, California. The device is hand-held, minimally invasive and sized to fit a wide range of sizes of the oral cavity. The hand-held embodiment allows it to be maximally controllable by the clinician while providing a direct tactile target for 1) the correct initial placement of the tongue tip via the positioning ridges described above; and 2) the correct tongue movement during production. The device was designed to minimally impede coarticulation, thus allowing the participant to correctly produce /r/ up to the word level in most phonetic contexts, with the device in place. Figure 1 depicts the key components of the test article as well as its placement and use within the oral cavity. The ridges between the end of the device neck and the body of the device coil provide tactile cue for the correct starting position of the tongue. The device coil itself represents the tactile cue for the movement phase of production. During feasibility testing conducted by the device manufacturer with over 50 children presenting with misarticulated /r/, the test article was able to elicit correct productions of both consonantal /r/ (as in "rack") and vocalic /r/ ("as in car").

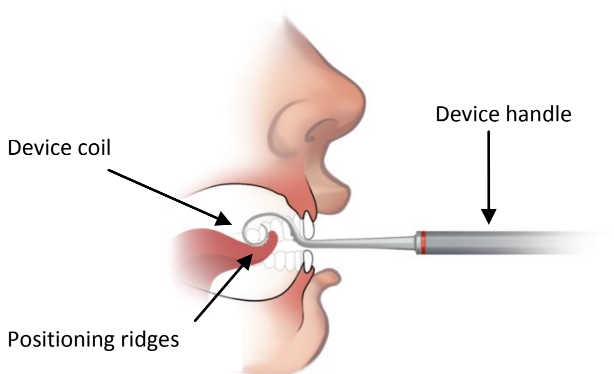


Figure 1. The key components, placement and use of the test article within the oral cavity

Eliciting correct production of /r/ with the test article requires two distinct phases: 1) the positioning phase, and 2) the movement phase. For the positioning phase, the speech-language pathologist (SLP) places the device directly behind the participant's upper dentition and holds it in this position. The SLP then instructs the participant to feel the positioning ridges with his tongue and hold his tongue in this correct starting position. The SLP would then have the participant confirm that he feels these ridges with a simple question (e.g. "can you feel those bumps?") that the participant would answer with a nod. Once the tongue is correctly placed for the positioning phase, the SLP instructs the participant to roll his tongue back by uncoiling the device coil while saying an extended /a/ low, back vowel. This low back vowel is thought to cue posterior vocal tract constriction (Kent & Read, 2002), the third of the vocal tract constrictions. The participant should feel the coil fully unroll to confirm the necessary retroflection of the tongue. The SLP would then cue, via a simple visual cue and one-step verbal directive, a slightly rounded and protruded lip posture (e.g. "Look at my lips and try to make an 'O' with your lips like I am doing."). This rounded lip posture represents the most anterior of the three vocal tract constrictions described in this section above.

The tip of the device, which provides the tactile biofeedback, is made of a soft thermoplastic elastomer that has passed appropriate biocompatibility and toxicity testing required by International Organization for Standardization (ISO) standards and U.S. Food and Drug Administration (FDA) guidance. The material is soft enough to prevent deformation or pain when bitten down upon, yet is sturdy enough to retain its shape when manipulated by the tongue.

Therapy

A.R. received eight individual treatment sessions over a period of seven weeks. The study PI attempted to schedule two weekly sessions over four weeks. However, taking into account scheduling conflicts (e.g. vacation and illness), seven weeks was allotted to complete all eight sessions.

Therapy featured tactile biofeedback delivered via the test article as the primary cuing mechanism. This primary tactile biofeedback cue was supported by verbal instructions to correctly manipulate the tool with the tongue as well as auditory cues to aid the participant to auditorily perceive correct vs. incorrect production of /r/. In addition, since lip rounding represents a secondary, necessary vocal tract constriction in American English /r/ (Bernhardt & Stemberger, 1998), a separate and combined visual and verbal cue was used to elicit this lip rounding. This cue involved a visual demonstration of this lip configuration, supported by the verbal instruction, "watch my lips make an "O" shape and try to do the same thing when you say /r/." No external cues, in the form of another device or other instrumentation (e.g., a mirror) were used during the study. Each of the eight treatment sessions consisted of exactly 55 stimulus items, taking approximately 25 minutes to complete. The first six items trained were "warm-up" items with /r/ presented in isolation and in CV and VC syllables (e.g. "ra" and "ar"). After completing the "warm-up" items, the remaining 49 items trained consonantal, pre-vocalic /r/ in words in initial position (22 items), vocalic /r/ in medial position (seven items), and vocalic /r/ final position (20 items). For all study sessions, stimulus items were trained in blocks according to word position, with the 22 word-initial items trained first, followed by the seven items in medial position, and the 20 word-final items. Stimulus words featured both vocalic and consonantal /r/ only in singletons (i.e. not in clusters) and generally in stressed syllables when stimulus items were polysyllabic.

Items were chosen to generally feature /r/ in stressed syllables and only as a singleton, not in consonant clusters. Items were chosen to represent a wide range of vocalic and consonantal contexts. All "warm-up" items with /r/ in isolation and in CV and VC syllables used the intra-oral tactile biofeedback device. In addition, every other item was trained with the intra-oral tactile biofeedback device, with 25 of the 49 total items trained with the device. Appendix A provides a sample therapy session, including randomly selected stimulus items. Given the random nature of the stimulus item selection, certain items appeared in duplicate in a given session.

A.R.'s therapy regimen was tracked by the PI using a dedicated trial binder consisting of all relevant study information. Each binder consisted of executed parent and student consent forms; all pre-treatment, during-treatment, and post-treatment assessments; and, all therapy session logs.

Assessments and Measures

A.R.'s speech was qualitatively assessed to be highly intelligible, despite his misarticulation of /s/ and /r/. Due to this, the PI made the judgment that standardized assessments such as the Goldman-Fristoe Test of Articulation or percentage consonants correct (PCC) that would assess A.R.'s whole speech sound system would not be sufficiently specific measures for the purposes of this investigation. Therefore, to assess A.R.'s pre-treatment vs. post-treatment accuracy in producing /r/, the PI developed a 50-item picture-naming test consisting of words and words-in-sentences containing only the /r/ phoneme in various word positions and phonetic contexts used. This test was constructed to contain vocabulary items expected to be found in the lexicon of a school-age child without expressive lexical deficits. In order to mitigate any learning effect for the assessment items, no assessment item was used as a stimulus item during therapy. The same 50-item picture-naming test was used for the pre-treatment assessment, the post-treatment assessment, and the generalization assessment. The generalization assessment was administered ten weeks after the post-treatment assessment. A list of assessment battery stimulus items and results of each of the study's three evaluations (pre-treatment, post-treatment, and ten weeks post-treatment) can be found in Appendix B.

All data were recorded by the primary investigator (PI), a New York State-licensed, ASHA-certified clinical speech-language pathologist. The PI also acted as the sole study clinician. Accuracy judgments made by the PI when acting as the study evaluator are reported in the Results section below. Assessments were audio and video recorded. Audio and video recordings were captured using a JVC Everio GZ-MS120BU brand digital camcorder. The camcorder microphone had an audio sampling rate of 40 kHz, considered adequate for recording the entire acoustic signal of human speech, and particularly for capturing the acoustic signal of both consonantal and vocalic /r/ (Kent & Read, 2002).

In order to establish the inter-rater reliability of the study evaluator, the recorded post-treatment data were converted to a digital format and electronically mailed to a leading researcher in the field of speech sound disorders with over 30 years of clinical and research experience (please see Acknowledgements section below). Under his supervision, three graduate student clinicians took part in a dedicated training session led by this supervising researcher to distinguish between correct versus incorrect consonantal and vocalic /r/ using 30 token items via a Marantz Digital Recorder Model PMD 671 free field in a quiet room. These 30 token items differed from the study stimulus items. After this training session, the three graduate student clinicians made independent judgments of the sample of the recorded items spoken by the study participant. Results of this inter-rater reliability testing are reported below.

Results

A.R. demonstrated little difficulty in using the test article to effect the retroflex tongue movement necessary to produce correct consonantal and vocalic /r/. In addition, he easily incorporated the secondary, combined visual and verbal cue to achieve correct lip rounding during production. With these cues, A.R. showed correct productions of both consonantal and vocalic /r/ in all word positions during the first therapy session. Based on the baseline assessment data reported below, A.R.'s production of consonantal /r/ in initial position and vocalic /r/ in medial position of words was emerging at the beginning of therapy. He had begun to manifest correct production of both classes of /r/ in limited contexts, suggesting that he was likely stimulable for producing correct consonantal and vocalic /r/. Figure 2 summarizes the change in accuracy of both consonantal and vocalic /r/ across all positions, combining words and words-in-sentences. Figure 3 illustrates the change in accuracy according to word position, aggregating words and words-in-sentences.

Figure 2. Pre-treatment vs. post-treatment change in accuracy: all items

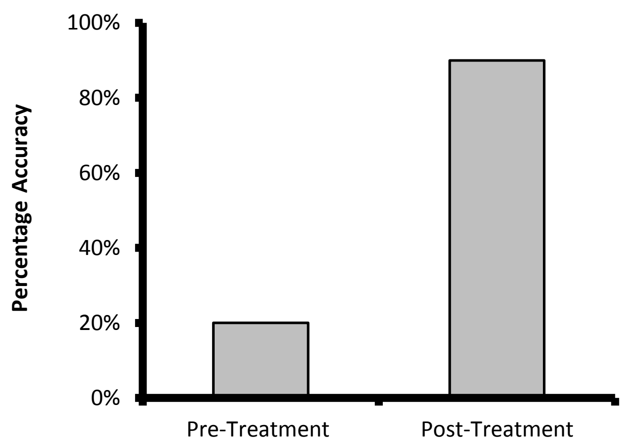
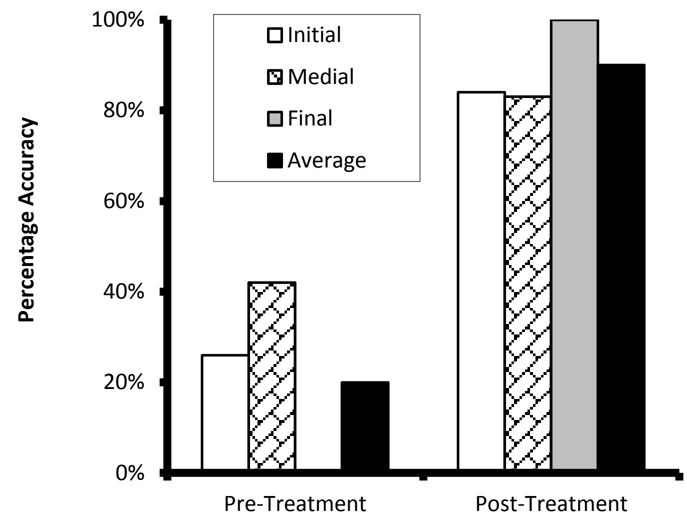


Figure 3 – Pre-treatment vs. post-treatment change in accuracy by word position.



Pre-Treatment vs. Post-Treatment

Pre-treatment data suggest that A.R.'s consonantal (initial) and medial vocalic /r/ were emerging at the time of assessment. Final, vocalic /r/ was not accurate in any context and was not stimulable at the outset of treatment. Post-treatment, A.R. was 90% accurate in all positions in both words and words-in-sentences, above the generally accepted 70-80% accuracy range for remediation (Van Riper & Emerick, 1984). Table 1 and Table 2 below summarize the participant's pre-treatment vs. post-treatment accuracy of /r/ for words (Table 1) and words-in-sentences (Table 2) for all assessment items.

Table 1. Pre-treatment vs. post-treatment accuracy: Words

	Initial	Medial	Final	Total
Pre-Treatment	27% (4/15)	45% (5/11)	0% 0/14	23% (9/40)
Post-Treatment	80% (12/15)	91% (10/11)	199% (14/14)	90% (36/40)

Table 2. Pre-treatment vs. post-treatment accuracy: Words-in-Sentences

	Initial	Medial	Final	Total
Pre-Treatment	25% (1/4)	0% (0/2)	0% (0/4)	10% (1/10)
Post-Treatment	100% (4/4)	50% (1/2)	100% (4/4)	90% (9/10)

Pre-Treatment vs. Ten Weeks Post-Treatment

Table 3 summarizes A.R.'s accuracy in producing /r/ ten weeks after the conclusion of treatment, as compared to pre-treatment accuracy. These data show that A.R. generalized correct consonantal /r/ in initial position and vocalic /r/ in medial position beyond the treatment period in both words and words-in-sentences. That he was able to generalize production accuracy in these word positions suggests that this short-duration therapy regimen was sufficient for contexts in which he had begun to show emerging competence. However, generalization did not occur for vocalic /r/ in final position in either words (57% accuracy) or words-in-sentences (25% accuracy). This suggests that in contexts in which A.R. showed no baseline competence or stimulability, this short-duration was sufficient to achieve a remediation response, as assessed immediately post-treatment, but that additional therapy was likely required to yield a generalization response for word-final vocalic /r/. Considering all positions of words, A.R. generalized correct production of consonantal and vocalic /r/ according to the 70-80% accuracy range for remediation only for words (75% accuracy) but not for words-in-sentences (60% accuracy), as per Van Riper and Emerick, (1984). Table 3 and Table 4 below summarize the participant's pre-treatment vs. ten weeks post-treatment accuracy of /r/ for words (Table 3) and words-in-sentences (Table 4) for all assessment items.

Table 3. Post-treatment vs. ten weeks post-treatment accuracy: Words

	Initial	Medial	Final	Total
Post-Treatment	80% (12/15)	91% (10/11)	100% (14/14)	90% (45/40)
10 weeks Post-treatment	80% (12/15)	91% (10/11)	57% (8/14)	75% (30/40)
Change in Accuracy	0%	0%	-43%	-15%

Table 4. Post-treatment vs. ten weeks post-treatment accuracy: Words-in-sentences

	Initial	Medial	Final	Total
Post-Treatment	100% (4/4)	50% (1/2)	100% (4/4)	90% (9/10)
10 Weeks Post-Treatment	100% (4/4)	50% (1/2)	25% (1/4)	60% (6/10)
Change in Accuracy	0%	0%	-75%	-30%

Post-Treatment vs. Ten-Weeks Post-Treatment

In the ten-week period between the conclusion of treatment and the generalization assessment (i.e. "ten weeks post-treatment" assessment), the data above show that A.R. was able to maintain improvements in accuracy achieved during the therapy period for initial, consonantal /r/ and for medial, vocalic /r/ in words and words-in-sentences. However, accuracy in A.R.'s production of vocalic /r/ in final position of words did show a decay of 15 percentage points to 75% accuracy; and, a decay of 30 percentage points to 60% accuracy in word-final vocalic /r/ in words-in-sentences. Table 5 and Table 6 below summarize the participant's post-treatment vs. ten weeks post-treatment accuracy, as well as any observed decay in accuracy, of /r/ for words (Table 5) and words-in-sentences (Table 6) for all assessment items.

Table 5. Pre-treatment vs. ten weeks post-treatment accuracy: words

	Initial	Medial	Final	Total
Pre-Treatment	27% (4/15)	45% (5/11)	0% (0/14)	23% (9/40)
10 weeks Post-treatment	80% (12/15)	91% (10/11)	57% (8/14)	75% (30/40)

Table 6. Post-treatment vs. ten weeks post-treatment accuracy: Words-in-Sentence

	Initial	Medial	Final	Total
Post-Treatment	25% (1/4)	0% 0/2)	0% (0/4)	10% (1/10)
10 weeks Post-treatment	100% (4/4)	50% (1/2)	25% (1/4)	60% (6/10)

In summary, Figure 4 depicts A.R.'s change in accuracy over all time points, from pre-treatment, through post-treatment to ten weeks post-treatment. Figure 5 depicts these data according to word position. In both depictions, data for words and words-in-sentences are aggregated.

Figure 4. Pre-treatment, post-treatment vs. ten weeks post-treatment change in accuracy: all items

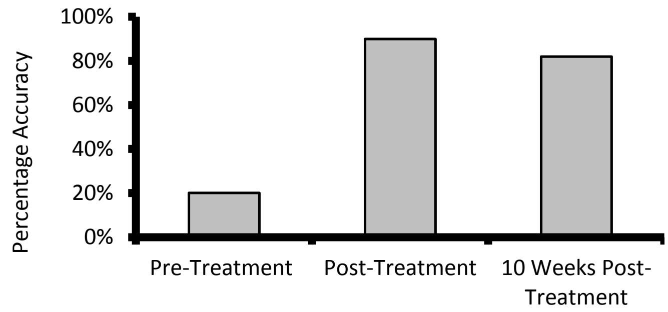
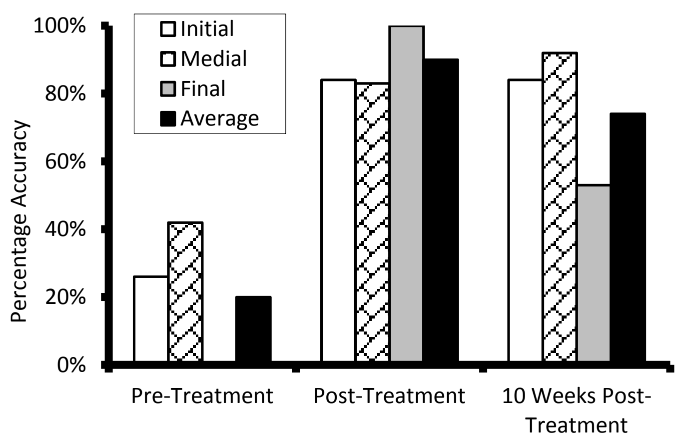


Figure 5. Pre-treatment, post-treatment vs. ten weeks post-treatment change in accuracy by word position: all items



Inter-Rater Reliability

As described above, three separate, supervised graduate student clinicians acted as judges, who made independent judgments of A.R.'s accuracy of production based on audio recordings of the data. These judges' responses were tabulated and compared to accuracy judgments made by the study evaluator. Table 7 below summarizes the judgments of accuracy made by these judges, as compared to those of the study evaluator. Analysis revealed 83% correspondence with the study evaluator among the judges for all items. This inter-rater correspondence is considered sufficient to consider the study evaluator a reliable judge of /r/ accuracy, as per the standards presented in McCauley and Swisher (1984).

Table 7. Summary of Evaluator and Reliability Judges' Accuracy: Post-Treatment and 10 Weeks Post-Treatment Data

	Study Evaluator	Judge #1	Judge #2	Judge #3
Post-Treatment	90% (45/50)	94% (47/50)	96% (48/50)	88% (44/50)
10 weeks Post-treatment	74% (37/50)	62% (31/50)	82% (41/50)	58% (29/50)

Discussion

The results above suggest that the therapy regimen described above enabled the test participant to remediate his misarticulated /r/ during a short-duration therapy regimen of four hours. Based on the performance standards outlined in Van Riper and Emerick (1984), the accuracy achieved by A.R. would suggest an overall remediation response for combined words and words-in-sentences at both of the study's separate time points: upon final assessment immediately following the conclusion of treatment, as well as ten weeks following the conclusion of treatment. The author concludes that the study's hypothesis was met at both time points. It is important to note however that word-final vocalic /r/ in words decayed to overall 57% accuracy, and word-final vocalic /r/ in words-in-sentences decayed to 25% accuracy ten weeks post-treatment, both below the 70-80% accuracy threshold as per Van Riper and Emerick (1984). This would indicate that some additional therapy may have been necessary to generalize treatment gains to these two specific contexts. As will be discussed in more detail below, the four hours required to achieve overall remediation was measurably better than the mean time to achieve a similar level of functional improvement, as reported in Jacoby et al. (2002).

As a case study design clinical investigation, this study did not use a concurrent control. Jacoby et al. (2002) have provided a comprehensive description of the mean treatment units required to achieve functional change in communication. These authors used the functional communication measures (FCMs) rubric from the ASHA National Outcomes Measurement System (NOMS), which was designed to systematically describe and track communicative functioning and its change over time (NOMS, 1997; NOMS, 1999). This rubric uses seven levels of functioning to describe a child's communication effectiveness; level one represents the lowest level of functioning and seven the highest. Descriptions of the FCM levels from the ASHA NOMS are listed in Appendix C.

Before treatment, A.R. was classified by the study PI as FCM level six. For articulation and intelligibility, FCM level six is described as "compared to chronological peers, child's connected speech is consistently intelligible to unfamiliar listeners. Child's speech occasionally calls attention to itself more than would be expected of chronological peers, and this rarely affects participation in adult-child, peer, and directed group activities" (p. 380). A.R.'s mother reported to the study PI that this description accurately reflects her son's communicative functioning; she reported no adverse social consequences of his speech sound disorder. After treatment and at the assessment conducted ten weeks post treatment, A.R. was classified as FCM level seven, described as "child's connected speech rarely calls attention to itself more than would be expected of chronological peers, and participation in adult-child, peer, and directed group activities is not limited by speech intelligibility" (p. 380). A.R.'s mother again reported agreement with this description.

For all participants in their articulation/intelligibility data set, Jacoby et al. (2002) reported a mean of 55.4 treatment units (SD 2.1) required to achieve one level of FCM improvement (n=149). A treatment unit is defined as fifteen minutes of direct intervention. For six year olds, the age group that most closely matches A.R., Jacoby et al. reported a mean of 56.9 treatment units (SD 2.2) to achieve one level of FCM improvement (n=17). With tactile biofeedback via the test article as the primary cuing mechanism, A.R. required 16 treatment units to achieve one level of FCM improvement. As per Jacoby et al. (2002), this would equate to 37.4 fewer treatment units, or approximately nine fewer hours of therapy, to achieve comparable treatment gains.

As the generalization assessment revealed, administered ten weeks after the conclusion of treatment, A.R. showed some decay producing word-final vocalic /r/. Although he scored 100% accuracy in producing word-final vocalic /r/ in the post-treatment assessment administered immediately following the conclusion of therapy, it appears that a limited amount of additional therapy was likely necessary. One noteworthy finding is the stability of consonantal word-initial as well as vocalic word-medial /r/ in the generalization assessment. For these word positions, A.R. had shown emerging stimulability. This observation would support the findings of Miccio, Elbert, and Forrest (1999), who concluded that stimulable phonetic contexts undergo the most change in accuracy and may be the most resistant to decay after treatment. Conversely, at the outset of treatment, A.R. was not stimulable for word-final vocalic /r/. While he experienced a treatment response in therapy via the test article, particularly as measured by the post-treatment assessment, the initial non-stimulability of this phonetic context would justify extended treatment, specifically focused on vocalic /r/ in word-final position. This would lend further support to recent evidence (e.g. Preston, Brick & Landi, 2013) that the generalization process is more protracted among less stimulable phonetic contexts and may be limited between vocalic and consonantal /r/.

As noted above, previous investigations into the clinical utility of sensory biofeedback have shown this methodology's potential for treating treatment-resistant speech sound errors. The current study provides preliminary evidence of the utility of sensory biofeedback in a single, treatment-naïve participant. The experimental use of treatment-naïve participants has the advantage of eliminating the effect of prior treatment on observed results (He, Deng, Li, Chen, Jiang, Wang, Huang, Collier, Gong, Ma, Zhang, & Li, 2012). Since A.R. was naïve to therapy to treat /r/, the improvement observed in A.R.'s /r/ accuracy was likely a direct consequence of therapy he received. In addition, that A.R. was a treatment-naïve participant for /r/ would suggest that the treatment program used here could be indicated at the outset of therapy.

An additional advantage of the test article used in this study is that its simple design and fabrication process enable it to be comparatively low cost compared to other sensory biofeedback instrumentation. Despite the growing body of evidence in support of ultrasound as an effective treatment tool, Adler-Bock et al. (2007) noted the high cost of ultrasound equipment as the primary factor inhibiting its more widespread application in the field; Clark et al. (1993) noted that their dental retainer embodiment for tactile biofeedback necessarily required costly individual fitting by an orthodontist. The test article used here was a single extruded piece of thermoplastic elastomer that through extensive feasibility testing was sized to fit a wide range of oral cavity sizes, thus preventing the need for individual fitting. This would allow clinical practitioners to provide the benefit of tactile biofeedback to a variety of clients in a comparatively cost-effective manner.

Despite the results reported above, caution is indicated. The single-participant, case study design would limit the wider applicability of results. The pre-treatment assessment showed that A.R.'s production of word-initial and word-medial /r/ was emerging at the onset of therapy. Given this and his apparent initial stimulability for producing correct /r/, we cannot rule out a similar treatment response would have been achieved had a traditional, phonetic-based approach or phonological approach been used. In addition, A.R. presented as a neurotypical, hearing child, who was reported to excel academically and was not reported to be socially or emotionally affected by his misarticulation of /r/. Additional studies incorporating larger participant samples would further validate this approach to treating misarticulated /r/. Further research also is required to determine the extent to which these results may apply to other treatment populations, such as those presenting with hearing impairment or cognitive deficits. ◆

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"Missith Thmith...a bunch of uth got together before clath and dethided that YOU are the one with the thpeech problem."

Appendix A. Sample Therapy Session

One of eight sessions lasting approximately 25 to 30 minutes. Total therapy was 4 hours.

Therapy Items 1 – 6. "Warm-up" in isolation and syllables

Instruct the participant: "*I am going to say the /r/ sound in isolation or in a syllable. Please repeat each sound after me*."

	Stimulus Item	Position	Consonantal (C) or Vocalic (V)	Correct (√) or Incorrect (/)
1	Rrr	Isolation	V	
2	Rrr	Isolation	V	
3	Rah	Initial	C	
4	Rah	Initial	C	
5	Arr	Final	V	
6	Arr	Final	V	

Therapy Items 7 – 55. Words and words in sentences

Instruct the participant: "*I am going to say a word or a word in a sentence that has the /r/ sound in them. Please repeat what I say*."

	Stimulus Item	Position	Consonantal (C) or Vocalic (V)	Correct (√) or Incorrect (/)
7	Race	Initial	C	
8	Rook	Initial	C	
9	Rail	Initial	C	
10	Raid	Initial	C	
11	Rob	Initial	C	
12	Wrist	Initial	C	
13	Roll	Initial	C	
14	Rig	Initial	C	
15	Rod	Initial	C	
16	Riddle	Initial	C	
17	Rack	Initial	C	
18	Rum	Initial	C	
19	Rust	Initial	C	
20	Wrestle	Initial	C	
21	Rid	Initial	C	
22	Ref	Initial	C	
23	Riddle	Initial	C	
24	Risk	Initial	C	
25	Rum	Initial	C	
26	Ref	Initial	C	
27	Wreck	Initial	C	
28	Rind	Initial	C	
29	Furry	Medial	V	
30	Bury	Medial	V	

31	Very	Medial	V
32	Referee	Medial	V
33	Carry	Medial	V
34	Very	Medial	V
35	Ferry	Medial	V
36	Core	Final	V
37	Jar	Final	V
38	Clear	Final	V
39	Fire	Final	V
40	Tire	Final	V
41	Store	Final	V
42	Pier	Final	V
43	Fire	Final	V
44	Core	Final	V
45	Steer	Final	V
46	Shore	Final	V
47	Fire	Final	V
48	Shore	Final	V
49	Mare	Final	V
50	Wear	Final	V
51	Score	Final	V
52	Blur	Final	V
53	Jar	Final	V
54	Tar	Final	V
55	Core	Final	V

Appendix B. Assessment Battery Stimulus Items with Results

Assessment Items 1 – 40. /r/ in Words
Instruct the participant: "*I am going to show you some pictures of words that have the /r/ sound in them. Please just name what's in the picture. If you don't know what something is, just tell me and I will give you a hint.*"
Indicate whether the participant's response was correct or incorrect

	Item	Position	Pre-Treatment	Post-Treatment	10 Weeks Post-Treatment
			Correct (√) or Incorrect (/)		
1	Rat	Initial	/	/	√
2	Rake	Initial	/	/	/
3	Red	Initial	/	/	/
4	Rainbow	Initial	√	√	√
5	Radish	Initial	/	√	√
6	Rice	Initial	√	√	√
7	Raccoon	Initial	√	√	√
8	Rooster	Initial	√	√	√
9	Robot	Initial	/	√	/
10	Ruler	Initial	/	√	√
11	Rug	Initial	/	√	√
12	Road	Initial	/	√	√
13	Robe	Initial	/	√	√
14	Rope	Initial	/	√	√
15	Roof	Initial	/	√	√
16	Factory	Medial	/	√	√
17	Barrel	Medial	√	√	√
18	Blueberries	Medial	/	√	√
19	Celery	Medial	√	√	√
20	Parrot	Medial	√	√	√
21	Arrow	Medial	√	√	√
22	Cherry	Medial	/	/	/
23	Carriage	Medial	/	√	√
24	Camera	Medial	/	√	√
25	Siren	Medial	√	√	√
26	Carrot	Medial	/	√	√
27	Ear	Final	/	√	√
28	Door	Final	/	√	√
29	Bear	Final	/	√	√
30	Pear	Final	/	√	√
31	Guitar	Final	/	√	/
32	Hair	Final	/	√	√
33	Floor	Final	/	√	/
34	Car	Final	/	√	/

35	Deer	Final	/	√	/
36	Star	Final	/	√	/
37	Square	Final	/	√	√
38	Four	Final	/	√	/
39	Tear	Final	/	√	√
40	Flower	Final	/	√	√

Assessment Items 41 – 50. /r/ in words in sentences

Instruct the participant: "*I am going to show you some pictures of words that have the /r/ sound in them. I am also going to say a sentence that has that word in it. Please repeat the whole sentence and make sure you do your best to say that word that has the /r/ in it*."

Indicate whether the participant's response was correct or incorrect.

	Item	Position	Pre-Treatment	Post-Treatment	10 Weeks Post-Treatment
			Correct (√) or Incorrect (/)		
41	Someone who has lots of money is **rich**.	Initial	/	√	√
42	A tool that helps you loosen or tighten things is a **wrench**.	Initial	/	√	√
43	A vessel that floats on water is called a **raft**.	Initial	√	√	√
44	Something pretty you tie around a present is a **ribbon**.	Initial	/	√	√
45	The food group that contains milk and cheese is **dairy**.	Medial	/	√	√
46	Something that shows your reflection is a **mirror**.	Medial	/	/	/
47	Someone who keeps people healthy is a **doctor**.	Final	/	√	√
48	Twelve months make up a **year**.	Final	/	√	/
49	This person is a **skier**.	Final	/	√	/
50	The house isn't near, it's very **far**.	Final	/	√	/

Appendix C. Functional Communication Measures (FCM) rating scale for articulation/intelligibility.

This measure was developed by and is the property of the American Speech-Language and Hearing Association (ASHA).

LEVEL	Description of Rating
Level 1	Speech cannot be understood even by familiar listeners.
Level 2	Child's production of simple words and short phrases is rarely intelligible to familiar listeners. Child's speech is unintelligible to unfamiliar listeners.
Level 3	Child is occasionally intelligible in connected speech to familiar listeners. Child's production of simple words and phrases is rarely intelligible to unfamiliar listeners.
Level 4	Child's connected speech is usually intelligible to familiar listeners but only occasionally intelligible to unfamiliar listeners.
Level 5	Compared to chronological peers, child's connected speech is consistently intelligible to familiar listeners and is usually intelligible to unfamiliar listeners. Child's speech usually calls attention to itself more than would be expected of chronological peers, and this occasionally affects participation in adult-child, peer, and directed group activities.
Level 6	Compared to chronological peers, child's connected speech is consistently intelligible to unfamiliar listeners. Child's speech occasionally calls attention to itself more than would be expected of chronological peers, and this rarely affects participation in adult-child, peer, and directed group activities.
Level 7	Child's connected speech rarely calls attention to itself more than would be expected of chronological peers, and participation in adult-child, peer, and directed group activities is not limited by speech intelligibility.