AJSLP

Supplement

Select Papers From the 41st Clinical Aphasiology Conference

Acquired Apraxia of Speech: The Effects of Repeated Practice and Rate/Rhythm Control Treatments on Sound Production Accuracy

Julie L. Wambaugh,[a,b] Christina Nessler,[a] Rosalea Cameron,[a,b] and Shannon C. Mauszycki[a,b]

Purpose: This investigation was designed to elucidate the effects of repeated practice treatment on sound production accuracy in individuals with apraxia of speech (AOS) and aphasia. A secondary purpose was to determine if the addition of rate/rhythm control to treatment provided further benefits beyond those achieved with repeated practice.
Method: A single-subject design was employed with 10 speakers with chronic AOS and aphasia. Articulation accuracy served as the dependent measure. Participants received repeated practice treatment until a plateau in performance was observed or high levels of accuracy were achieved. If performance criterion was not reached, rate/rhythm control was added to the treatment to determine if additional gains would be made.
Results: For 8 of the participants, improvements were evident for all applications of repeated practice treatment, and positive response generalization was observed in most cases. When rate/rhythm control treatment was applied, modest additional gains were apparent for the majority of the applications. The 2 participants who did not benefit from repeated practice treatment also did not show improvements with rate/rhythm control treatment.
Conclusions: Repeated practice treatment resulted in improved articulation for the majority of participants. The amount of improvement varied within and across participants. Rate/rhythm control appeared to have limited additional benefits for some participants.

Key Words: apraxia, treatment, articulation

Acquired apraxia of speech (AOS) is generally defined as a "disorder of learned volitional actions associated with breakdown in the planning or programming of the movements needed for speech" (Miller & Wambaugh, 2011, p. 431). Lexical processing and phonological assembly are considered to be intact in AOS, with the difficulty being translation of well-formed phonological specifications into commands for articulatory execution (McNeil, Robin, & Schmidt, 2009). AOS is characterized by slowed rate of speech, difficulties in sound production, and disrupted prosody (McNeil et al., 2009). The presentation of AOS varies in accordance with its severity and may range from a complete inability to speak to relatively fluent but slow speech with infrequent, minor sound distortions.

There is limited information concerning the prevalence of AOS, with no frequency data pertaining to severity. Duffy (2005) reported that AOS was the primary communication disorder in 7.6% of 6,101cases of neurologic motor speech disorders. AOS is almost always accompanied by aphasia, with "pure" AOS being a rare occurrence. Stroke is the most common etiology for AOS (Duffy, 2005), and damage to cortical and/or subcortical areas of the language-dominant hemisphere have been associated with AOS (Wambaugh & Shuster, 2008). Debates concerning the specific brain regions implicated in AOS remain unresolved (Dronkers, 1996; Hillis et al., 2004; Ogar et al., 2006).

Research concerning the treatment of AOS has progressed steadily, but relatively slowly, since the recognition of AOS as a unique clinical entity almost 40 years ago. The AOS Treatment Guidelines Committee of the Academy of Neurologic Communication Disorders and Sciences (ANCDS) reviewed and critically evaluated the extant, English-language literature pertaining to treatment for AOS (Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006a, 2006b) and reported that although the evidence base for AOS treatment was lacking

[a]VA Salt Lake City Health Care System, UT
[b]University of Utah, Salt Lake City
Correspondence to Julie Wambaugh: Julie.wambaugh@health.utah.edu

Editor: Swathi Kiran
Associate Editor: Diane Kendall
Received August 15, 2011
Accepted November 16, 2011
DOI: 10.1044/1058-0360(2011/11-0102)

in terms of the quantity and quality of the evidence, there was sufficient support for the statement that "individuals with AOS can be expected to make improvements in speech production as a result of treatment, even when AOS is chronic" (Wambaugh et al., 2006b, p. lxiii). The committee categorized the 59 reports included in the guidelines into four general approaches to treatment: (a) articulatory–kinematic treatments, (b) rate/rhythm control treatments, (c) intersystemic facilitation/reorganization treatments, and (d) alternative and augmentative communication treatments (Wambaugh et al., 2006a).

All of the treatments that have been developed for AOS have consisted of a combination of techniques (Wambaugh et al., 2006b). Only recently have investigators begun to examine the individual components of treatment (e.g., Austermann Hula, Robin, Maas, Ballard, & Schmidt, 2008) or to compare treatments (Brendel & Ziegler, 2008; Rose & Douglas, 2006).

An element of treatment that is common to all AOS therapies, regardless of general approach, is repeated practice (Wambaugh et al., 2006b). Repeated practice has been demonstrated to be a critical aspect of nonspeech motor learning (Schmidt & Lee, 2005) and is likely to be crucial in the rehabilitation of individuals with AOS. If we are to move forward in the development of a technology of treatment for AOS, it is important to understand the relative contribution of different elements of treatment as well as factors that must be controlled in comparative treatment investigations. Because repeated practice underlies all AOS treatments, it would be a logical first step to understand the effects of repeated practice alone.

In our own research with an articulatory–kinematic treatment (e.g., Wambaugh, Kalinyak-Fliszar, West, & Doyle, 1998) and with rate/rhythm control treatment (e.g., Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000), we have not attempted to isolate the most potent treatment factors. Consequently, it is possible that the positive treatment effects that we reported could have been achieved with only repeated practice. This criticism applies to the majority of the AOS treatment literature in that there have been only a few efforts that have isolated and examined the effects of potentially crucial aspects of treatment (Austermann Hula et al., 2008; Knock, Ballard, Robin, & Schmidt, 2000; Maas, Barlow, Robin, & Shapiro, 2002; Rubow, Rosenbek, Collins, & Longstreth, 1982).

For this reason, we undertook this investigation to examine the effects of repeated practice treatment with limited use of other techniques such as modeling and feedback. In this study, we defined repeated practice as producing a target item five times after a single model with general feedback provided after the group of productions. In addition, this procedure was repeated three times within a single treatment session for all target items, allowing for 15 productions of an item per session.

We chose to examine the effects of treatment on sound production accuracy, which has been the focus of the majority of AOS treatment investigations. Additionally, articulatory accuracy has been shown to improve without direct intervention/instruction (Brendel & Ziegler, 2008; Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000) and was deemed likely to be responsive to this type of intervention.

We anticipated that repeated practice treatment would have positive but limited effects on participants' sound production accuracy. That is, we expected that participants' sound production accuracy would improve, but a substantial number of sound errors would remain. Consequently, we chose an experimental design that would allow us to apply a second treatment technique if and when repeated practice treatment effects were exhausted.

Articulatory–kinematic treatment approaches have substantially more evidence documenting their effects than do the other AOS treatment approaches; more than half of the investigations reviewed for the AOS guidelines (Wambaugh et al., 2006a, 2006b) employed articulatory–kinematic techniques. The majority of the AOS treatment investigations that have been published since the ANCDS review, which included investigations published through 2003, have also employed articulatory–kinematic techniques (Wambaugh & Mauszycki, 2010). Despite the preponderance of articulatory–kinematic treatments, there is no evidence to suggest that articulatory–kinematic approaches should be the treatment of choice for individuals with AOS (Wambaugh et al., 2006b). A recent investigation by Brendel and Ziegler (2008) indicated that a rate/rhythm control treatment, metrical pacing therapy (MPT), had benefits that exceeded those of a control treatment that included articulatory–kinematic strategies.

In the current investigation, we chose to use a rate/rhythm control treatment following application of repeated practice treatment because of our own positive findings with metronomic pacing (Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000) as well as those of Brendel and Ziegler (2008). Additionally, in keeping with single-subject design constraints, it was determined to be important to vary as few aspects of treatment across treatment phases and participants as possible. Rate/rhythm control treatment could be applied relatively uniformly across participants, with rate being the only factor that was expected to differ across speakers.

Treatments designed to control the rate and/or rhythm of a person's speech production have been shown to have positive effects for people with AOS (Wambaugh et al., 2006b). Techniques have included metronomic pacing (Dworkin & Abkarian, 1996; Dworkin, Abkarian, & Johns, 1988; Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000), computer pacing of oral reading (Southwood, 1987), metrical frame pacing (Brendel & Ziegler, 2008; Brendel, Ziegler, & Deger, 2000), and use of a pacing board (McHenry & Wilson, 1994).

There is a relatively small evidence base supporting the use of rate/rhythm treatments. A likelihood rating of *possibly effective* was provided for rate/rhythm treatments in the ANCDS AOS guidelines (Wambaugh et al., 2006b), and it was recommended that such approaches be considered as treatment "options." A higher rating and stronger recommendation could not be provided because the evidence base at that time consisted of only a few single-subject experimental investigations and several case studies. Since publication of the AOS guidelines, two additional investigations have provided support for the use of rate/rhythm techniques to treat AOS (Brendel & Ziegler, 2008; Mauszycki & Wambaugh, 2008).

Metronomic pacing has been used in several investigations with participants ranging widely in the severity of their AOS (Dworkin & Abkarian, 1996; Dworkin et al., 1988; Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000). With metronomic pacing, speech targets or movements are repeatedly practiced in time with the beat of a metronome, usually at a rate of one syllable or movement per beat. The metronomic rate has usually, but not always, been considerably slower than the typical speech production rate used by a speaker.

Metrical pacing is similar but more sophisticated than metronomic pacing. With metrical pacing, the metrical form or rhythm of the target utterance is used in the pacing (Brendel & Ziegler, 2008; Brendel et al., 2000), whereas with metronomic pacing, the pace is not modified to match the natural rhythm of the utterance. Brendel and Ziegler (2008) devised "metrical templates" for target utterances using the syllable onset times derived from waveforms of the utterances that were produced with natural prosody at a normal rate. The templates were used to keep the natural *relative distances* of the syllables of the utterance constant when presenting the pacing tones at different rates. Thus, the pacing tones corresponded to the natural rhythm of the utterances, regardless of the rate of production.

Brendel and Ziegler (2008) compared MPT to a control treatment in a crossover design with 10 speakers whose AOS severity ranged from mild to severe. Target items were devised for each participant, and metrical templates were developed for the utterances. The participants were provided with repeated models of the target utterances and were instructed to produce each target in synchrony with the pacing rhythm. Participants were asked to maintain fluent articulation while not attending closely to articulation. Treatment also included hand tapping and choral speaking. Rates of production were determined by baseline rates and were reduced and increased as needed. The control treatment included use of a variety of "conventional" techniques (e.g., phonetic placement, gestural facilitation, integral stimulation, minimal pair contrast, word derivation), but with no focus on rhythm or metrical features. Results revealed that both treatments resulted in significantly reduced numbers of sound errors, but only MPT resulted in a reduced proportion of disfluencies and changes in duration. Brendel and Ziegler's finding that MPT improved articulation without any specific articulation treatment was consistent with findings from metronomic pacing treatments that included no articulatory training (Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000).

The basic rationale for the use of rate and rhythm control in the treatment of AOS is that disturbances in aspects of the timing of speech production are evident in AOS, and rhythm is a fundamental component of the speech production process. The theorized mechanisms by which rate/rhythm control treatments may mediate improvements in speech production are many, varied, and untested. As such, the following hypothesized actions of rate/rhythm control on AOS must remain speculative.

Although speakers with AOS evidence a reduced speaking rate, additional slowing of speech production may provide additional time for motor planning and/or programming as well as for processing of sensory feedback. It has been hypothesized that rhythm control treatments for AOS may help re-establish temporal patterning (or metrical processing; Brendel & Ziegler, 2008; Brendel et al., 2000). It has also been theorized that central pattern generators (CPGs) may be disfunctional in AOS (Dworkin & Abkarian, 1996). Rhythmic treatments may serve to phase-lock movements, which may facilitate functioning of CPGs (Wambaugh & Martinez, 2000). Some investigators have suggested that provision of an external rhythmic source may affect attentional mechanisms that impact speech by either focusing attention on speech (Dworkin et al., 1988) or drawing attention away from speech (Brendel et al., 2000). Other investigators have speculated that the external rhythm generators serve as additional afference, which may positively impact speech production (Rubow et al., 1982).

Manipulations of rate of speech have long been considered to impact a person's speech motor programming (McNeil, Liss, Tseng, & Kent, 1990), which is believed to be disrupted in AOS. However, this logical link should not lead to the assumption that the changes in articulation that have been reported in previously described AOS pacing investigations were derived from the rate/rhythm components of the treatments. Specifically, all of the investigations employed relatively large amounts of repeated practice and did not control for this factor. As such, the changes in articulation may have been due to the practice. That is, repeated practice alone may have achieved the same effects in people with AOS in the absence of rate/rhythm control.

Consequently, we designed this investigation to elucidate the effects of repeated practice treatment on sound production accuracy in individuals with AOS and aphasia. A secondary purpose was to determine if the addition of rate/rhythm control to treatment provided further benefits beyond those achieved with repeated practice. The specific questions addressed in this investigation were as follows:

- Will repeated practice treatment result in increased accuracy of sound production in trained and untrained utterances for speakers with AOS and aphasia?
- Will repeated practice *plus* rate/rhythm treatment result in increased accuracy of sound production in trained and untrained utterances beyond that achieved with repeated practice?

Method

Participants

Ten adults with chronic AOS and nonfluent, agrammatic aphasia served as study participants. According to existing medical records, each of the participants' AOS and aphasia resulted from a single-episode stroke. At the time of this investigation, the participants were between 1 and 19 years post stroke.

All of the participants were native English speakers and lived at home. Each passed a pure-tone audiological screening and demonstrated performance within normal limits on a test of nonlinguistic intelligence. All had negative histories for alcohol or substance abuse, psychological disorders, and neurological conditions other than stroke. None was receiving any other speech/language treatment

during the course of this study. The participants were not compensated for their participation in this investigation other than reimbursement for travel.

Participant characteristics are shown in Table 1; pretreatment assessment results are shown in Table 2.

The diagnosis of AOS was made on the basis of criteria established by McNeil, Robin, and Schmidt (1997) and McNeil et al. (2009). The participants were asked to provide speech samples in response to the following elicitation tasks:

- Increasing Word Length and Repeated Trials subtests of the Apraxia Battery for Adults—2nd Edition (ABA–2; Dabul, 2000)
- Narrative and procedural discourse tasks described by Nicholas and Brookshire (1993)
- Assessment of Intelligibility of Dysarthric Speech (Yorkston & Beukelman, 1981)
- consonant production probe (Wambaugh, Kalinyak-Fliszar, et al., 1998)
- sentence repetition (Wambaugh, West, & Doyle, 1998)
- multisyllabic word repetition (Mauszycki & Wambaugh, 2008)

The behaviors designated as necessary for the diagnosis of AOS were evidenced by all of the participants: slow rate of speech production, sound errors that were relatively consistent in type and location across repeated trials, sound errors that were predominately sound distortions, and prosodic abnormalities. No specific quantified criteria were attached to any specific task for demonstration of these behaviors because it is recognized that the AOS symptoms are likely to manifest differently for each study participant (thus, the variety of tasks).

As seen in Table 2, all of the participants were diagnosed with Broca's aphasia. Overall percentile scores on the Porch Index of Communicative Ability (PICA; Porch, 2001) ranged from the 40th to the 71st percentile. None of the participants displayed symptoms of dysarthria as described by Duffy (2005).

Experimental Design

We used a combined single-subject experimental design (McReynolds & Kearns, 1983), which included an ABCA component (Barlow & Hersen, 1984), a multiple probe across behaviors component (Horner & Baer, 1978), and a multiple baseline across participants component (McReynolds & Kearns, 1983).

The *ABCA* component was used to allow for examination of the effects of repeated practice versus repeated practice plus rate/rhythm control. The *A* phase of the design was the baseline period in which the primary dependent measures (articulation of target items) were measured repeatedly in probe sessions. In the *B* phase, treatment consisted of repeated practice treatment applied to target items. This phase was continued until at least 10 sessions were conducted and five consecutive probe sessions revealed no changes in the dependent measures under treatment (i.e., a plateau in performance). Then, in the *C* phase, treatment was modified to add rate/rhythm control to the repeated practice, with the treatment termination criterion being the same as for the *B* phase. The remaining *A* phase represented withdrawal of treatment.

The *multiple probe across behaviors* component involved measuring several behaviors concurrently, with treatment being applied sequentially to those behaviors. The multiple probe design is a variant of the multiple baseline design. It employs a reduced probing schedule in comparison to a standard multiple baseline design. For the behavior not immediately under treatment, behaviors were probed in baseline, then at scheduled intervals, and then in increased numbers before the application of treatment. Thus, baselines are still extended, but the probing schedule is reduced. This reduced probing schedule was desired to (a) reduce the effects of repeated exposure on baseline performance and (b) reduce the possibility that repeated, incorrect productions would inadvertently be reinforced (because of no feedback), thus increasing the difficulty of instantiating behavior change in those items. The multiple behaviors in this investigation were five lists of speech stimuli.

The *multiple baseline across participants* component entailed conducting an increasing number of baseline measurements across participants; five baseline sessions were designated as the minimum.

Additional design elements related to the multiple baselines were included to control for several potential confounding factors. Of the five lists of speech stimuli, two of the lists

TABLE 1. Participant characteristics.

Participant	Gender	Etiology	CVA location/type	Age (in years)	Months post onset of stroke	Years of education	Premorbid handiness
P1	Female	CVA	L MCA ischemic	48	38	12	R
P2	Male	CVA	L ACA hemorrhagic	49	212	12	Ambidextrous
P3	Female	CVA	L MCA ischemic	42	27	12+	R
P4	Female	CVA	L MCA ischemic	58	54	13+	R
P5	Male	CVA	L MCA ischemic	37	32	16	L
P6	Male	CVA	R MCA ischemic	60	124	14	L
P7	Male	CVA	L MCA ischemic	54	35	12	R
P8	Male	CVA	L MCA ischemic	33	15	16+	R
P9	Male	CVA	L MCA ischemic	56	28	21	L
P10	Male	CVA	L Basal ganglia hematoma	52	234	14	R

Note. CVA = cerebrovascular accident, L = left, MCA = middle cerebral artery, R = right, ACA = anterior cerebral artery.

TABLE 2. Participant pretreatment assessment results.

Participant	RCPM	AIDS word intelligibility	WAB aphasia quotient	PICA overall percentile score	WAB aphasia type
P1	30/36	70%	43.0	49	Broca's
P2	30/36	92%	67.0	65	Broca's
P3	35/36	82%	77.0	71	Broca's
P4	36/36	96%	78.0	60	Broca's
P5	36/36	38%	42.4	64	Broca's
P6	23/36	88%	51.6	47	Broca's
P7	27/36	76%	64.8	55	Broca's
P8	25/36	70%	24.8	40	Broca's
P9	36/36	68%	73.7	66	Broca's
P10	25/36	72%	40.6	43	Broca's

Note. RCPM = Raven's Coloured Progressive Matrices (Raven, Raven, & Court, 1998); AIDS = Assessment of Intelligibility of Dysarthric Speech (Yorkston & Beukelman, 1981); WAB = Western Aphasia Battery (Kertesz, 1982); PICA = Porch Index of Communicative Ability (Porch, 2001).

were designated for treatment to be applied in the ABCA fashion described earlier (with one list having delayed treatment application and an extended baseline phase in keeping with the multiple baseline design across behaviors). Beyond the two treatment lists, one list was designated for pre-, interim-, and posttreatment measurement only. This limited probing schedule was deemed necessary because repeated attempts at production were considered to have the potential to result in improved performance that could be mistaken for treatment effects. Another list was also designated as a "no treatment" list but was scheduled for more frequent probing (i.e., probing occurring on the same schedule as the treated lists). Although, as just noted, changes in performance with this list could potentially be due to repeated exposure, there were several reasons for including this list: (a) Changes in untreated lists might be transient and therefore not detected with limited probing, and (b) generalization effects may be related to exposure to items. The remaining list was submitted to repeated practice treatment throughout the course of the investigation (i.e., AB only). This list was included because of concern that gains occurring during the rate/rhythm treatment (C phases) could be due merely to the effect of additional treatment sessions. For this reason, the C phase was not initiated until a plateau in performance was evident in the B phase, but this list provided additional control.

In summary, we designed the investigation so that each participant's performance was measured with five lists of experimental stimuli in the baseline phase. After baseline, two lists (L1, L2) were simultaneously submitted to repeated practice treatment (B). During this first B phase, production of items in the two treated lists was measured before every treatment session along with a third, untreated list. Production of the remaining two lists was measured on a limited basis during this phase. Following a plateau in probe performance with L1 (designated a priori), repeated practice plus rate/rhythm control (C) was applied to that list, and repeated practice treatment (B) continued with L2 and probing continued as described. After a plateau in performance was reached with L1, the list in the C phase, treatment was discontinued with that list and additional probing was conducted with the next list designated for treatment (L3). Treatment (B) was then applied to the new list while repeated practice treatment (B) continued with L2. The C phase was then applied to L3 after a plateau was reached in the B phase. Following completion of treatment with L3, all treatment was terminated, and posttreatment probes were conducted immediately following treatment and at 4- and 8-week posttreatment intervals.

The design described above was planned for all of the participants. However, some modifications were made to the design for six of the participants. The specific variations will be described in the Results section; in all cases, experimental control was maintained due to the flexibility of the designs. The changes were necessitated primarily because of high levels of accuracy of production achieved during repeated practice treatment. We decided that if a participant reached ≥85% accuracy of production *in probes* for items that received repeated practice treatment, then repeated practice plus rhythm/rate control treatment would not be applied. Such high levels of accuracy left very little room for evidencing improvement from repeated practice plus rate/rhythm control treatment.

Experimental Stimuli

Stimuli were developed for each participant individually to correspond to the level of production at which sound errors became most evident. As part of the pretreatment assessment, each participant was asked to produce items ranging from monosyllabic words to multisyllabic words in sentences, with multiple exemplars of all English consonants represented at each level (see the Participants section). Performance during these assessments was used to guide the selection of stimulus items. It was desired that treatment items be in the range of difficulty of 0% to 40% accuracy when measured in baseline probes.

Five lists of items were developed for each participant. These stimuli served as the probe items for measuring the acquisition and response generalization effects of treatment. Acquisition stimuli were those lists that were submitted to treatment and were then used to evaluate the effects of treatment as measured during probe sessions. Response generalization lists were those items that were similar to the treatment

items but were not submitted to treatment and were used to measure generalization across lists. The items in the lists were selected to be comparable in terms of difficulty for the participant. The lists were also devised to be similar in composition in terms of factors such as syllable length and syllable structure. Additionally, the lists were structured so that generalization across the lists receiving treatment concurrently would not be likely (as determined by the nature of the participant's errors). The lists designated as untreated did not contain any exemplars of trained lists but were designed to contain items that were similar in structure to all of the treated lists; consequently, generalization may have been possible.

All experimental stimuli used with each participant are shown in the online supplemental materials (Experimental stimuli: Treatment/acquisition stimuli). A general description of the stimuli used with each participant is shown in the Appendix. As described in the Appendix, single words served as the stimuli for all participants except Participant 4, whose stimuli were words in sentences. Each of the lists of stimuli included 20 items except in the case of Participant 4. Participant 4's lists contained only 12 items each, but these stimuli were sentences rather than individual words. More sentences per list were planned for Participant 4. However, when the items were first presented in baseline probes, it became apparent that there were too many items for probes and treatment to be completed in a realistic amount of time. Consequently, the number of sentences for Participant 4 was reduced to 12 per list.

Dependent Variables

The dependent variable was accuracy of sound production in experimental words/stimuli produced during probes with two scoring methods employed. A binary scoring system was used for daily probes in which each item was scored as *correct* or *incorrect* for production of the target word(s) (sounds). For Participants 1 and 8, production of specific target sounds in the experimental words was scored for accuracy. These sounds are underlined in the experimental words in the online supplemental materials. For the other participants, production of the entire target word was scored. That is, all sounds were required to be produced accurately in order for the word to be scored as correct. An overall percentage of accuracy score was calculated for each list for each probe. These data were used for making determinations regarding continuation or cessation of treatment on a daily basis.

In addition to the binary scoring, the percentage of consonants correct (PCC) was calculated for each item for selected probe sessions (i.e., the final three "true baseline" probes and probes at the end of each phase of treatment). PCC was included as an additional indicator of sound production accuracy to reflect more fine-grained changes. That is, the binary scoring may have masked some improvements in the participants' sound production. The PPC scoring was not used on a daily basis due to its labor-intensive nature.

The research speech-language pathologists (SLPs) who administered the probes scored the productions as accurate or inaccurate online. All speech samples were recorded using high-quality recording equipment (i.e., Zoom H4next digital recorder). The recordings were used to verify the online scoring after each session, to complete the PCC scoring, and to conduct reliability analyses.

Probing schedule and conditions. The dependent variables were measured repeatedly across all phases of the investigation, with procedures for conducting probes being identical across all phases. Productions of the probe stimuli were elicited through repetition. The research SLP provided a verbal model and asked the participant to provide one repetition of that model. No feedback concerning the accuracy of production was provided during the probes, but minimal encouragers, such as "you're trying hard," were allowed. The items within each experimental list were randomized, and the order of presentation of the lists was randomized for every probe session.

Baseline phase. A minimum of five baseline probes were conducted with each participant to measure the primary dependent variable before the start of treatment. It was planned that the number of probes would be extended across participants, from five to six, seven, and eight sessions, and then that sequence would be repeated across subsequent participants. However, performance criteria were also applied to the determination of the number of baseline probes. Specifically, each participant's performance on the final three probes preceding the scheduled initiation of treatment could not vary by more than 10% across those probes and could not be increasing. Because of these constraints, the numbers of baseline probes ranged from five to nine. Baseline probes were completed on a schedule that approximated the schedule that was employed in treatment (i.e., three times per week).

Treatment phases. During the treatment phases, the probing schedule varied for each list and was dependent on the function served by the list. Only the two lists currently under treatment and the exposure/no treatment list were probed on a daily session basis. The remaining two lists were probed at the end of the phase of treatment. Following completion of treatment with the first list of items (i.e., after both treatment applications or behavioral criterion was met), the next list designated for repeated practice treatment and repeated practice plus rate/rhythm treatment was probed repeatedly to ensure stability of responding before the initiation of treatment.

Maintenance and follow-up phases. After treatment was withdrawn from a list, that list was then probed at the end of treatment for the new treated list. After all treatment was completed, all lists were probed at 4 and 8 weeks after treatment.

Treatment

Treatment was provided three times per week by a research SLP who was certified by the American Speech-Language-Hearing Association (i.e., the first three authors). Treatment times were determined primarily by each participant's availability. Treatment was always preceded by the administration of probes, and total daily contact with participants was ~1¼ to 1½ hr. Treatment was conducted in the participant's home or in the research SLP's office in the research laboratory, with location scheduled according to the participant's preference.

Each participant received treatment for two lists of stimuli during all treatment phases. That is, each treatment session consisted of treatment applied to one list of items followed by treatment applied to a second list of items, with a 10- to 20-min break between treatments. Due to fatigue, Participants 4 and 9 sometimes could complete only one treatment list in a session, and Participant 7 consistently could complete only one list per session. In these cases, the remaining list received treatment in the following treatment session.

Immediately following the baseline phase, each treated list received repeated practice treatment (B phase). If a plateau was reached with the designated list, then repeated practice plus rate/rhythm treatment was applied to that list while the other list continued to receive repeated practice treatment. Consequently, depending on the phase of treatment, the participant may have been receiving two applications of repeated practice treatment (one per list) or one application of repeated practice treatment and one application of repeated practice plus rate/rhythm treatment per session. The order of treatment for the lists was alternated across treatment sessions.

The criteria for determining the duration of treatment was originally set at a minimum of six treatment sessions, with termination to occur upon a plateau (no additional gains) across five probe sessions. However, upon the first application of treatment with Participant 1, there was an obvious plateau with one treated list but a great deal of variability in the second treated list at the same time. Following this observation, it was determined that in order to give the treatment an adequate amount of time for effects to be evident, treatment would be applied for a minimum of 10 sessions. After the 10-session criterion was met, a determination was made on a session by session basis as to whether to continue treatment. If increases in accuracy were observed in probe sessions, then treatment was continued until ≥90% accuracy was achieved in two of three consecutive probe sessions. If no gains were observed in probes for five consecutive sessions following the highest achieved accuracy score, then treatment was stopped with the designated list (i.e., a plateau of six probe sessions that occurred over approximately a 2-week period). For example, if a participant achieved the scores of 80%, 75%, 80%, 70%, 75%, and 80% in consecutive probe sessions, then his or her treatment would be terminated for that phase with that list. Six sessions were selected to reflect a plateau because this number of probes approximated the number of baseline sessions obtained to reflect pretreatment stability.

Repeated practice treatment. Each item in the designated treatment list was presented one at a time in random order. The research SLP provided a verbal model of the item and asked the participant to repeat the item five times in succession. Only general feedback about the accuracy of the grouped productions was provided after the five productions were completed (e.g., *those all sounded perfect, there were a few sound errors, most of the sounds were correct, there were a lot of sound mistakes, the middle one was the best,* etc.). No specific feedback concerning the articulation errors was provided, even when the participants asked for more information. A repetition of the verbal model was provided upon participant request. The choice of repeating an item five times was made to minimize the number of verbal models provided by the research SLP and to limit the amount of feedback. Additionally, our previous experience with AOS treatment suggested that most AOS speakers could produce a maximum of five repetitions without additional modeling or instruction being required to maintain an accurate production.

One treatment application consisted of three trials of the treatment items, resulting in 300 word productions for Participants 1, 2, 3, 5, 6, 7, 8, and 9 and 180 sentence productions for Participant 4. A break was provided following completion of the three trials, and then treatment (repeated practice treatment or repeated practice plus rate/rhythm treatment) was applied to the next list.

Repeated practice plus rate/rhythm treatment. Repeated practice plus rate/rhythm treatment entailed the addition of hand-tapping in time to the beat of a digital metronome to the repeated practice treatment. The metronome was set to a rate that approximated a 50% reduction in the participant's typical rate of syllable production. Rate of production was determined by measuring the durations of baseline productions and determining the average rate of syllable production.

As with repeated practice treatment, each treatment item was presented one at a time, and five repetitions were requested. Feedback was the same as described previously, and three trials of all of the items were completed per session.

Reliability

Ten percent of all probes were randomly selected for rescoring by a research SLP who had not provided treatment. The audio-recorded samples were used for this purpose. Point-to-point agreement was calculated for scoring of each item, and percentage of agreement was calculated for each list. Agreement across lists ranged from 83% to 97%, with the average being 91%. Reliability scores for each participant are provided in the online supplemental materials (Online Table 1).

Results

Data representing correctly articulated targets (binary scoring) produced during *probes* of production of the experimental stimuli are shown in Figures 1–10 for Participants 1–10, respectively. Within each figure, the separate graphs represent the accuracy of production for each experimental list. Baseline phases are designated as A, repeated practice treatment phases are designated as B, and repeated practice plus rate/rhythm treatment phases are designated as C. Maintenance and follow-up phases are labeled separately. Vertical lines and arrows indicate changes in the phases of treatment (vertical lines are shown for behaviors that were under treatment; arrows are shown for behaviors that were not treated). Effect sizes (*d* index; Bloom, Fischer, & Orme, 2003; Cohen, 1988; see equation that follows) are shown on the figures in the corresponding phases of treatment. Effect sizes for treated lists are also displayed in the online supplemental materials (Online Table 2), and cumulative effect sizes for List 2

FIGURE 1. Participant 1 - Accuracy of productions of experimental stimuli on probes.

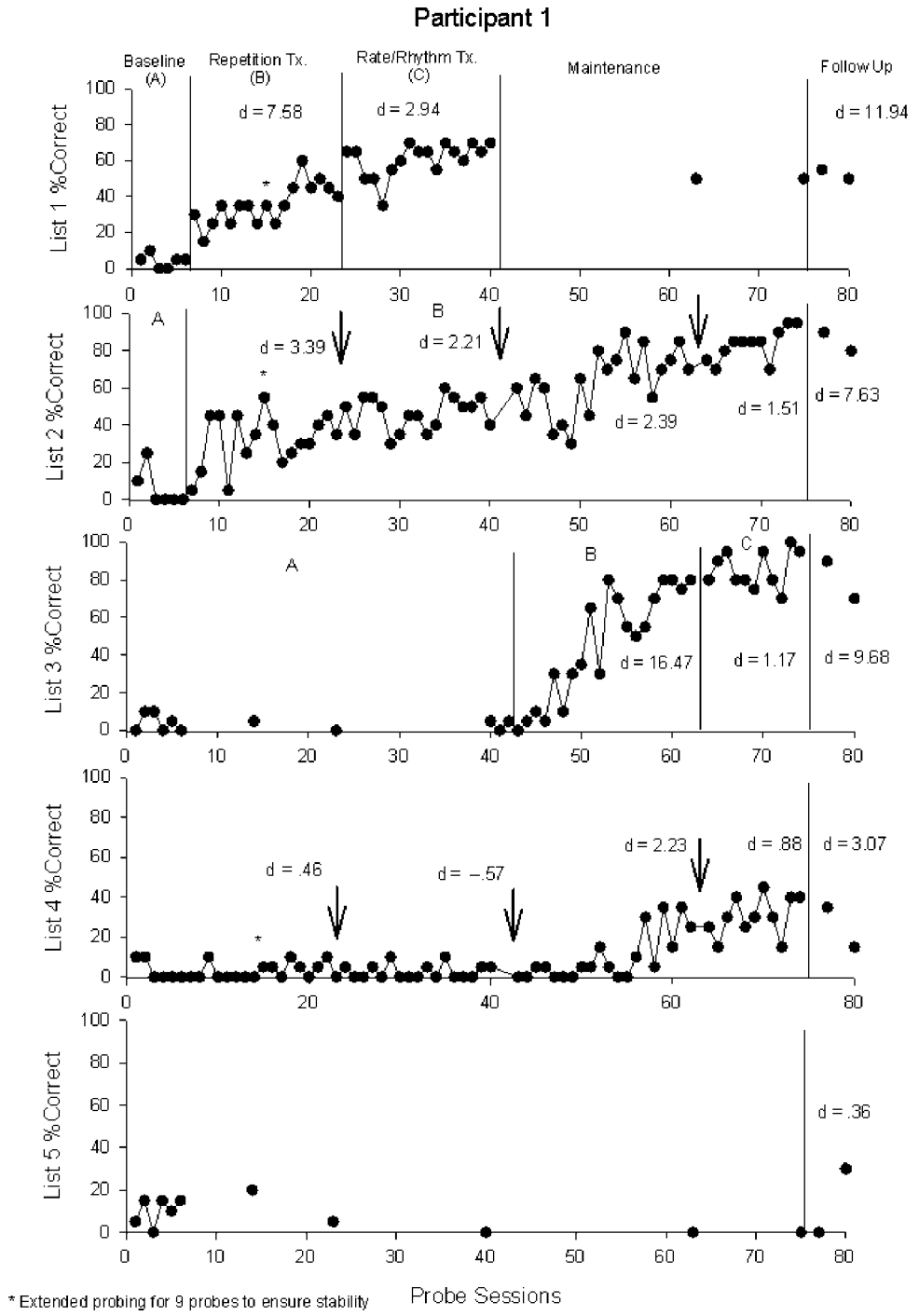


FIGURE 2. Participant 2 - Accuracy of productions of experimental stimuli on probes.

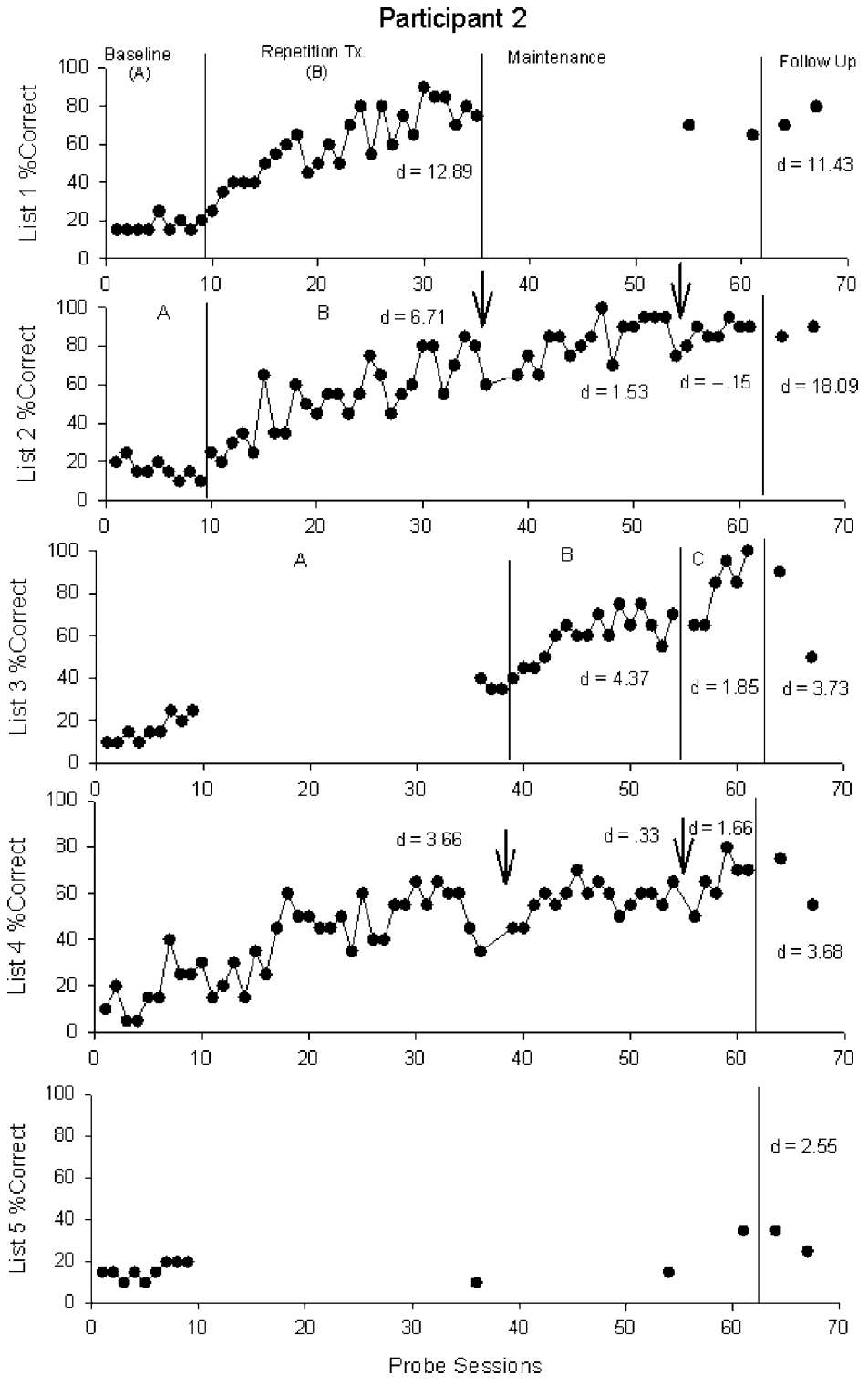


FIGURE 3. Participant 3 - Accuracy of productions of experimental stimuli on probes.

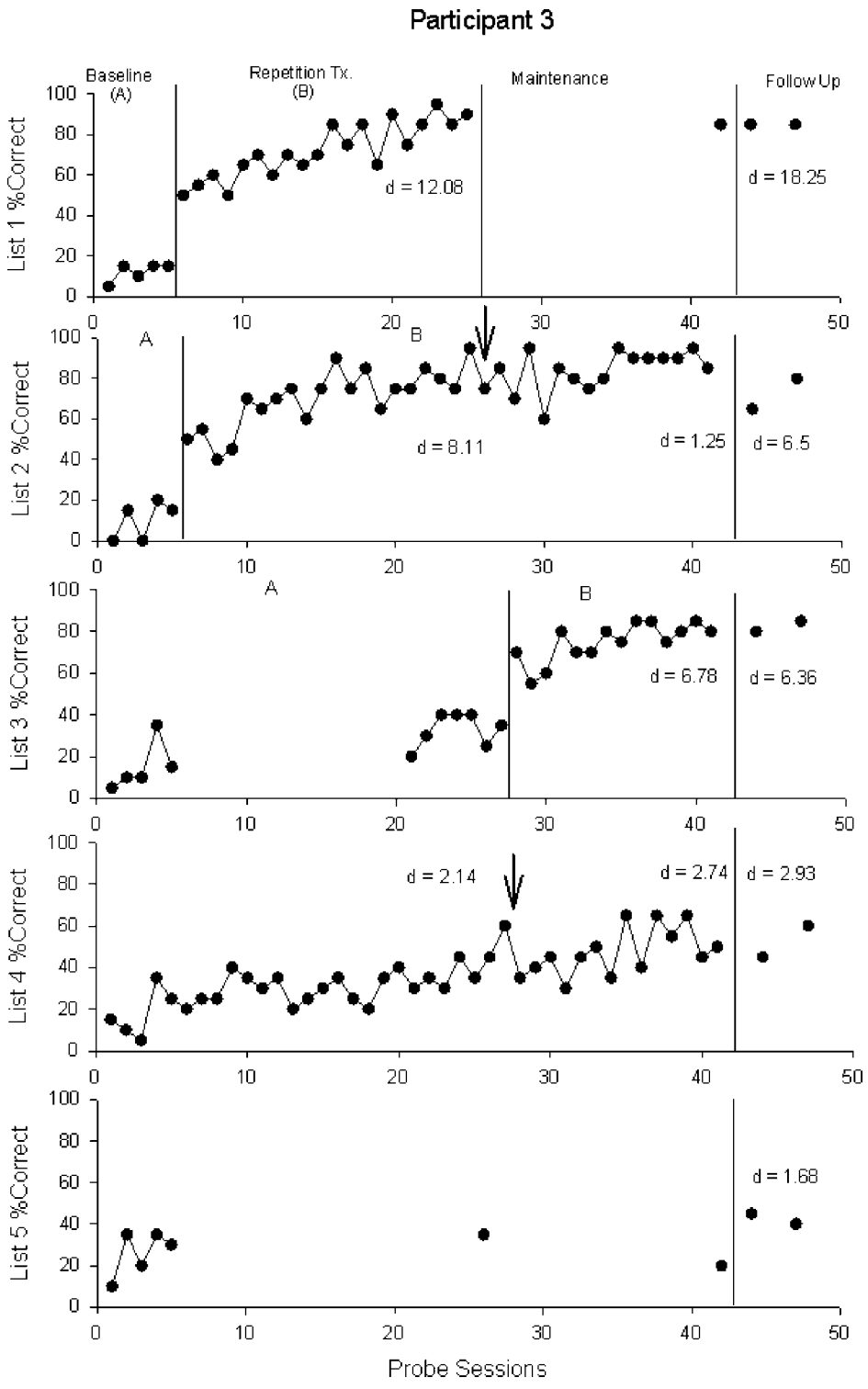


FIGURE 4. Participant 4 - Accuracy of productions of experimental stimuli on probes.

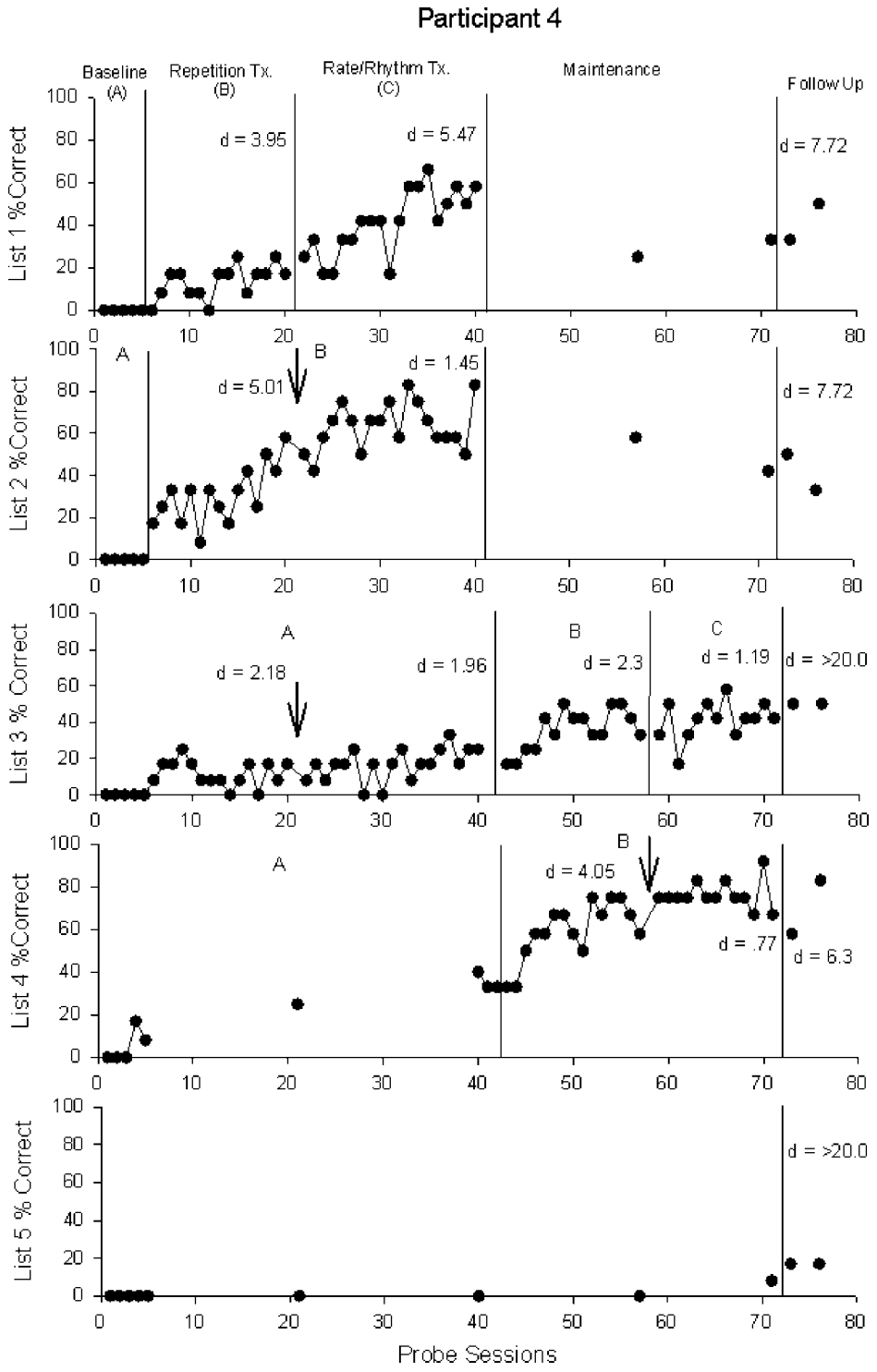


FIGURE 5. Participant 5 - Accuracy of productions of experimental stimuli on probes.

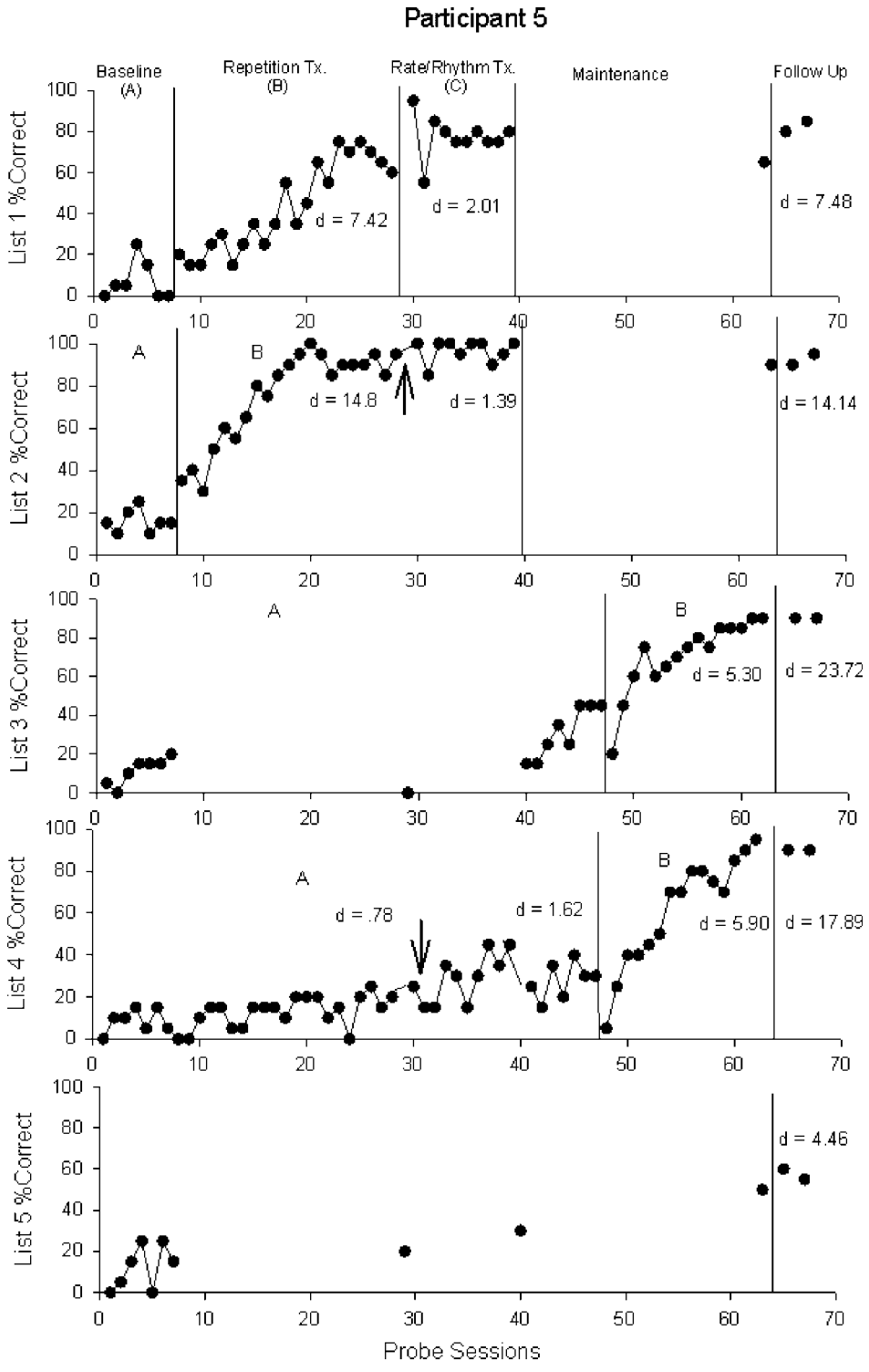


FIGURE 6. Participant 6 - Accuracy of productions of experimental stimuli on probes.

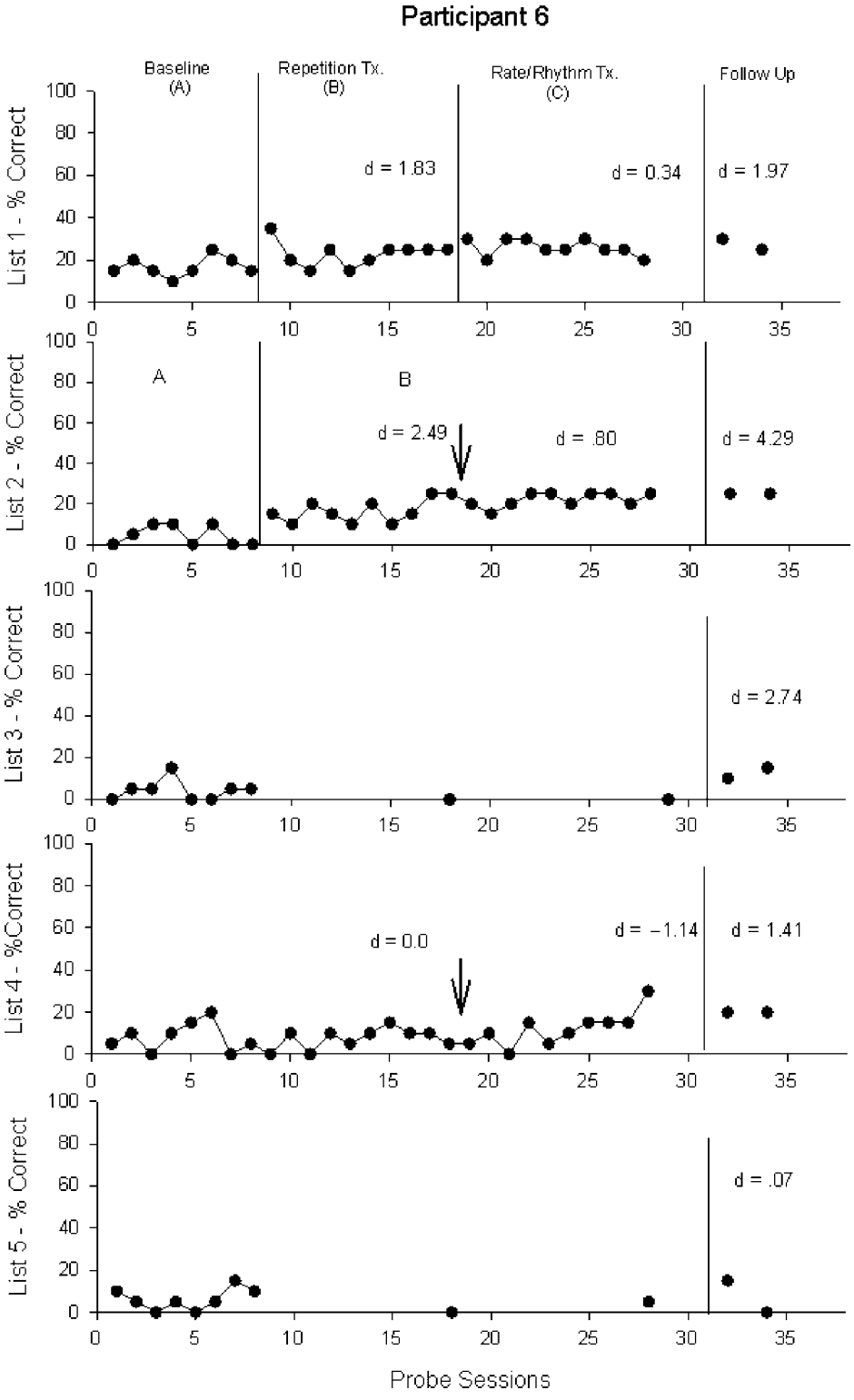


FIGURE 7. Participant 7 - Accuracy of productions of experimental stimuli on probes.

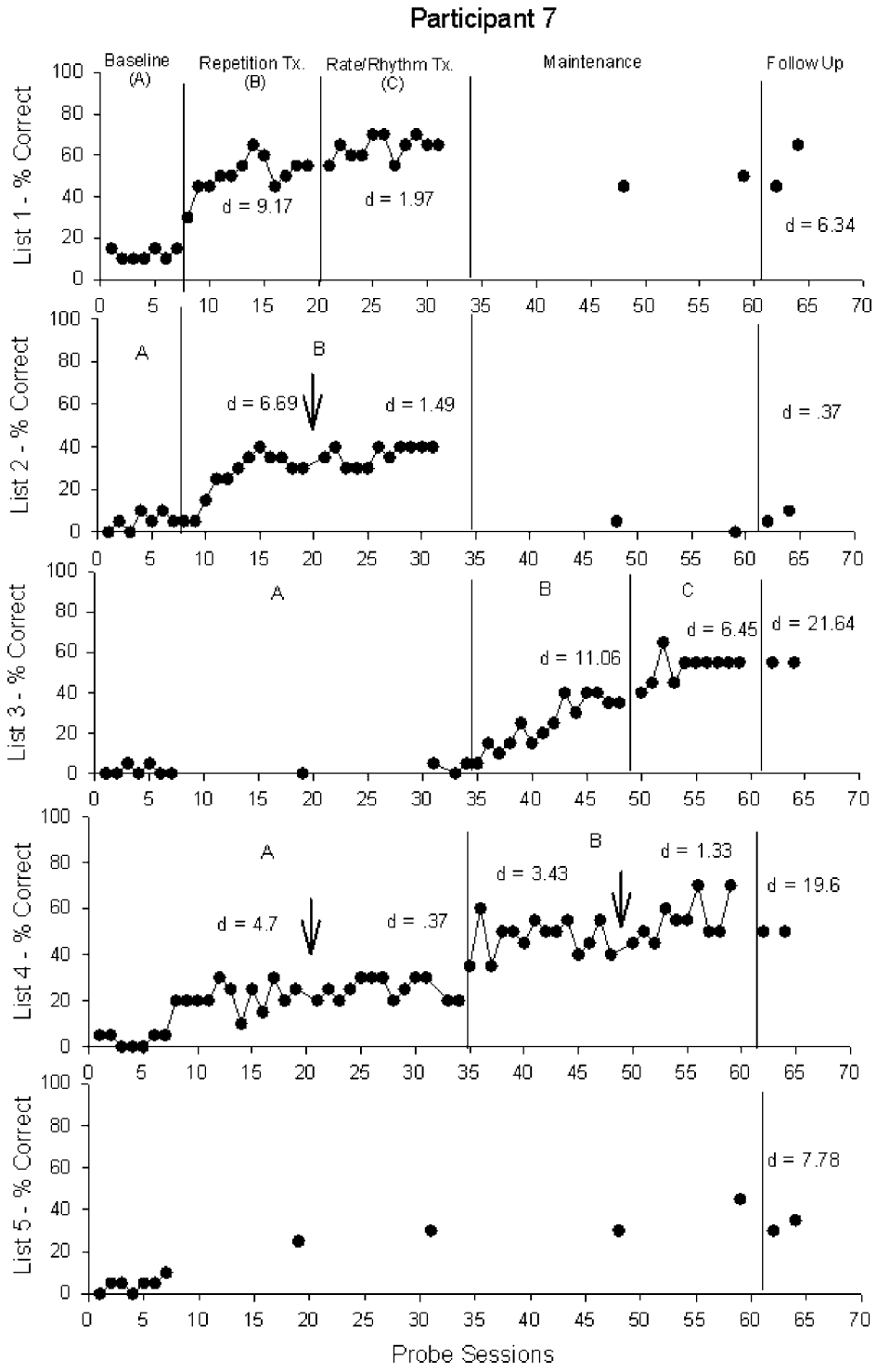


FIGURE 8. Participant 8 - Accuracy of productions of experimental stimuli on probes.

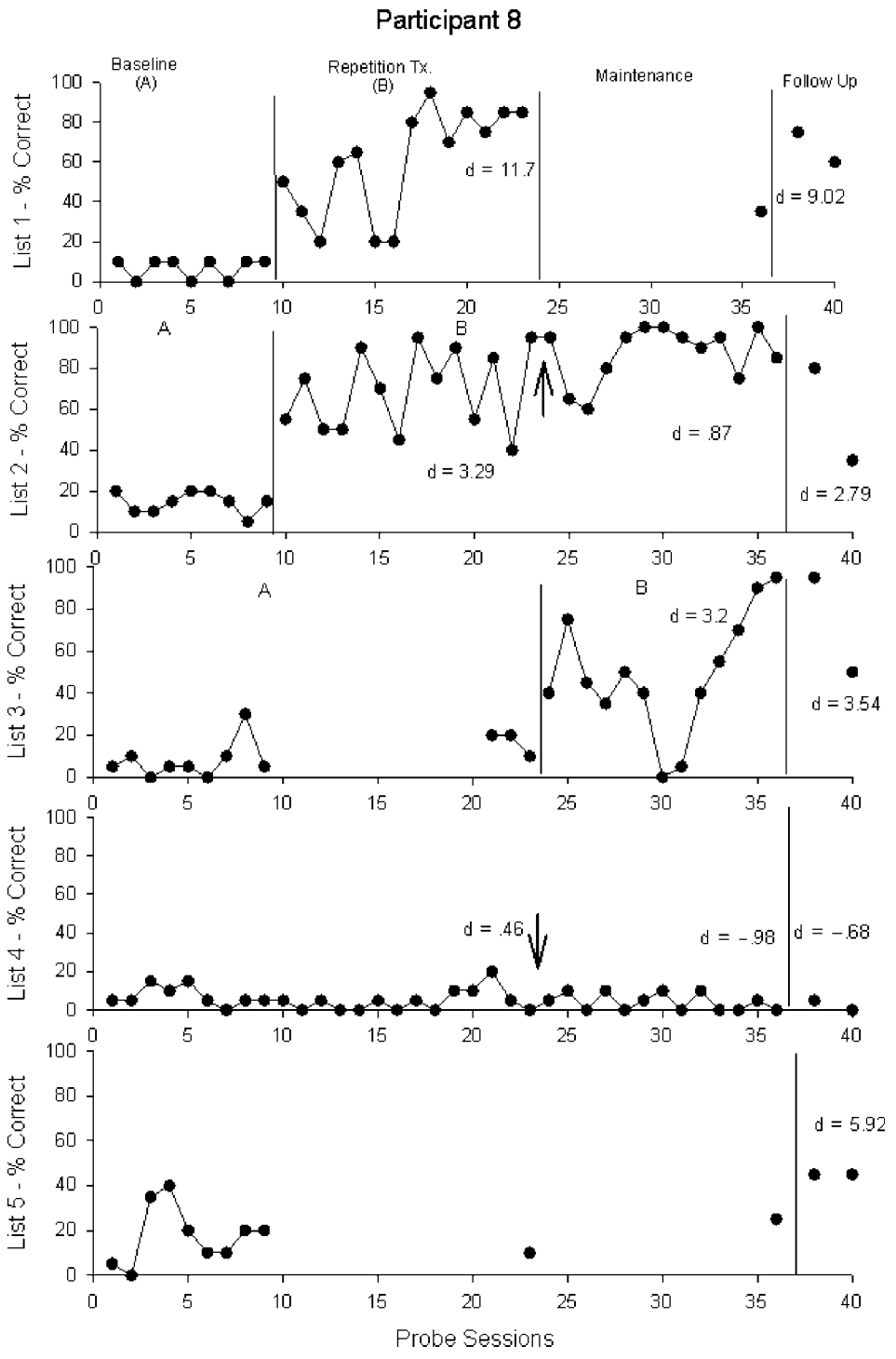


FIGURE 9. Participant 9 - Accuracy of productions of experimental stimuli on probes.

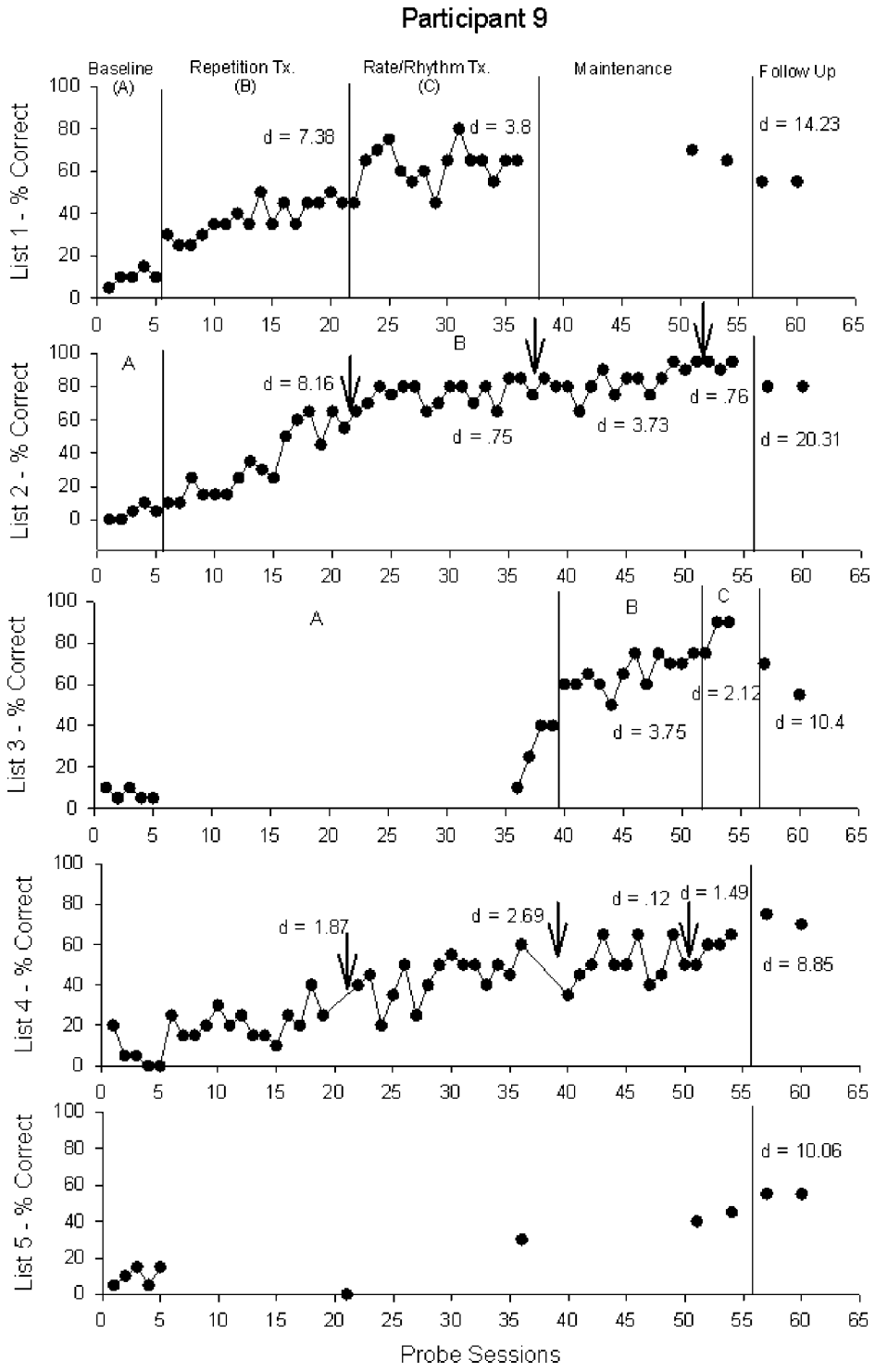
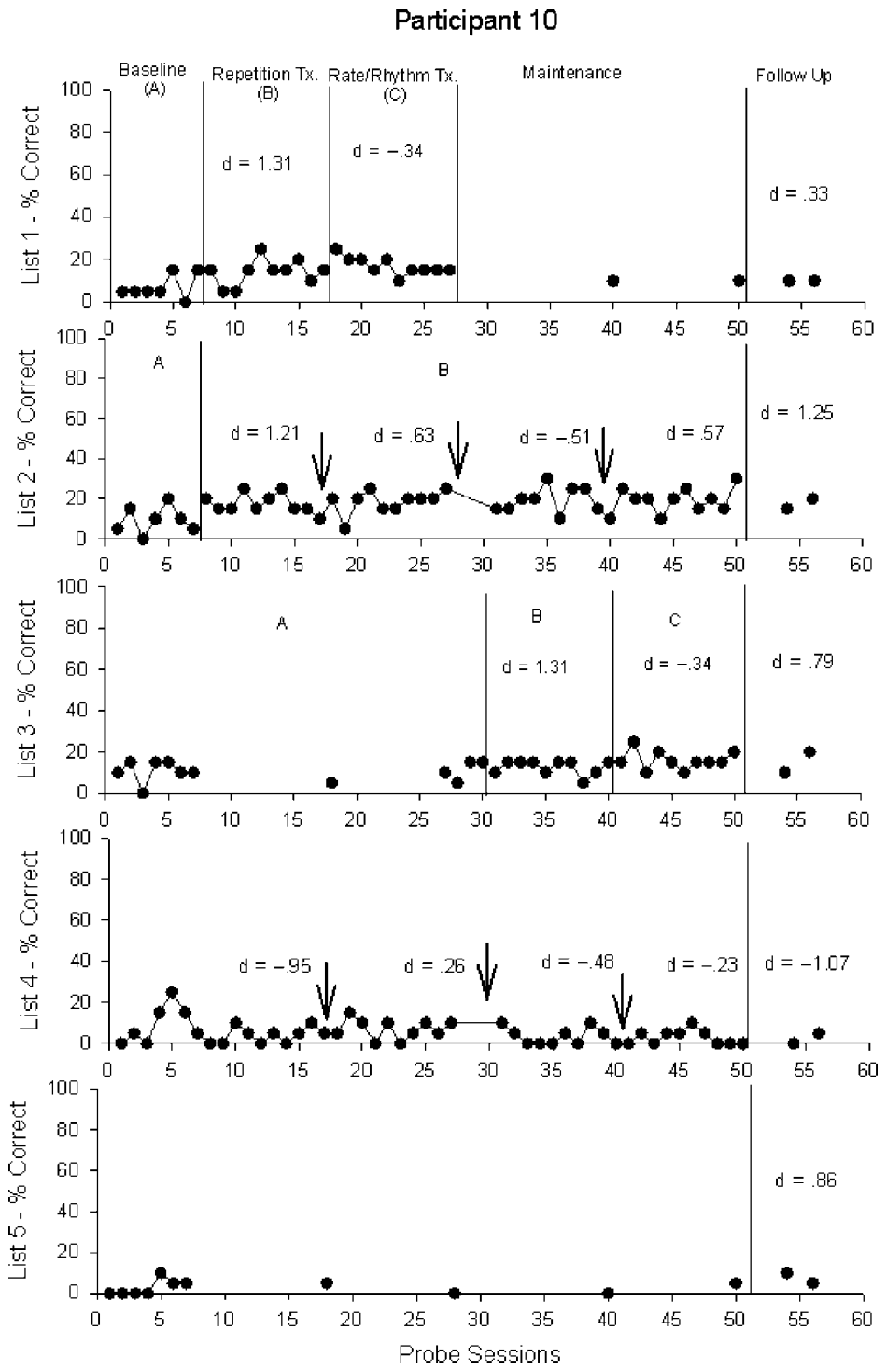


FIGURE 10. Participant 10 - Accuracy of productions of experimental stimuli on probes.



(which has effect sizes separated by phases in the figures) are included as well.

$$d = \frac{M_1 - M_2}{SD_{pooled}} \qquad \text{where} \qquad SD_{pooled} = \sqrt{\frac{(SD_1^2 + SD_2^2)}{2}}$$

For effect-size calculations associated with changes occurring in the treatment phases, the five data points immediately preceding the onset of treatment and the last five data points at the end of the treatment phase were used. For effect-size calculations associated with changes occurring in the follow-up phases, the last five "true baseline" data points and the two follow-up data points were used.

PCC data are displayed in Table 3 for each list for all participants across all phases of the study. Findings will be discussed with participants grouped according to similar response patterns.

TABLE 3. Percentage of consonants correct for each participant on each list across all phases of the study.

Participant	List	Baseline	Baseline	Final baseline	Post rep-1	Post RRT-1	Post rep-2	Post RRT-2
P1	1	53	45	48	69[a]	79[b]	69	71
	2	46	45	52	58[a]	66[a]	82[a]	90[a]
	3	51	44	51	51	50	84[a]	91[b]
	4	42	46	51	51	77	52	62
	5	61	45	55	63	47	45	52
P2	1	66	68	52	90[a]	No RRT	89	90
	2	71	65	73	78[a]		94[a]	94[a]
	3	58	72	67	77		89[a]	88[b]
	4	62	66	62	84		92	91
	5	56	64	65	70		73	80
P3	1	68	76	67	94[a]	No RRT	99	
	2	80	80	79	98[a]		92[a]	
	3	79	59	85	89		97[a]	No RRT
	4	88	74	78	88		96	
	5	77	73	84	XX		85	
P4	1	71	75	85	88[a]	96[b]	94	93
	2	57	78	79	93[a]	96[a]	97	93
	3	83	79	95	92	93	97[a]	99[b]
	4	73	73	81	87	92	92[a]	99[a]
	5	83	82	85	84	85	90	88
P5	1	58	63	60	85[a]	92[b]	96	
	2	57	57	64	93[a]	98[a]	95	
	3	61	62	58	68	70	97[a]	No RRT
	4	58	58	60	66	55	95[a]	
	5	59	62	64	71	74	82	
P6	1	46	24	22	32[a]	22[b]		
	2	27	13	16	25[a]	18[a]		
	3	16	8	22	0	8		
	4	24	16	23	24	25		
	5	15	28	27	0	6		
P7	1	41	47	59	78[a]	84[b]	66	70
	2	43	31	37	57[a]	69[a]	51	61
	3	28	36	27	41	42	59[a]	78[b]
	4	36	43	48	51	54	58[a]	78[a]
	5	36	50	41	44	64	63	63
P8	1	9	18	27	67[a]	No RRT	27	
	2	30	15	22	65[a]		59[a]	
	3	3	5	16	21		64[a]	No RRT
	4	15	0	13	28		24	
	5	18	9	23	23		14	
P9	1	44	54	46	89[a]	89[b]	95	79
	2	62	56	62	88[a]	83[a]	96[a]	98[a]
	3	51	64	61	83	60	93[a]	97[b]
	4	49	48	61	81	86	87	92
	5	47	52	56	63	62	81	70
P10	1	70	57	66	80[a]	67[b]	71	55
	2	60	43	54	59[a]	65[a]	65[a]	69[a]
	3	67	56	63	68	81	73[a]	65[b]
	4	59	61	52	49	65	49	43
	5	67	56	69	57	55	55	43

Note. Rep = repeated practice treatment. RRT = rate/rhythm treatment.

[a]List received repeated practice treatment, [b]List received rate/rhythm control treatment.

Participants 3 and 8: No Rate/Rhythm Treatment Required

Participants 3 and 8 displayed strong positive responses to repeated practice treatment alone. As seen in Figures 3 and 8, both participants reached high levels of correct responses for the three lists that were submitted to repeated practice treatment. Effect sizes for the treated lists ranged from 6.78 to 12.08 and from 3.2 to 11.7 for Participants 3 and 8, respectively.

Because accuracy levels exceeding 85% correct were reached, rate/rhythm treatment was not applied. Participant 8 exhibited minimal changes in untrained lists above baseline levels. However, Participant 3 demonstrated increases in accuracy for the untrained, repeatedly probed list of ~20% (List 4; $d = 2.93$ at follow-up). Follow-up probes revealed that Participant 3 maintained accuracy levels similar to those achieved during treatment (i.e., follow-up phase *d*-index values ranging from 6.36 to 16.25). In contrast, Participant 8 exhibited decreases in performance at 8 weeks after treatment, but with accuracy remaining above baseline levels (follow-up phase *d*-index values for treated items ranging from 2.79 to 9.02).

Participants 2 and 5: One Application of Rate/Rhythm Treatment Required

As depicted in Figures 2 and 5, Participants 2 and 5 also achieved high levels of performance with repeated practice treatment alone for all treated lists. Although each participant achieved at least 85% correct responding to one treated list with repeated practice treatment, they did not reach 85% accuracy with the other list. Consequently, both received one application of rate/rhythm treatment. Participant 2 reached a plateau of ~70% correct with List 3 with repeated practice treatment. Upon the addition of rate/rhythm treatment, he achieved higher levels and reached performance criterion. Participant 5 achieved a maximum score of 70% with List 1 and then plateaued. When rate/rhythm treatment was implemented, his performance increased and stabilized at a slightly higher level.

Effect sizes for repeated practice treatment lists ranged from 4.37 to 12.89 for Participant 2 and from 5.3 to 14.8 for Participant 5. Effect sizes for the rate/rhythm treatment were 1.85 and 2.01 for Participants 2 and 5, respectively.

Both participants demonstrated improved performance with the untrained, repeatedly probed list (Lists 4). Following the first phase of repeated practice treatment, an effect size of 3.66 was achieved for List 4 for Participant 2. Slight additional gains were observed for List 4 when rate/rhythm treatment was applied to List 3 ($d = 1.66$). For Participant 5, limited gains were observed with List 4 following repeated practice treatment ($d = .78$), but were greater when rate/rhythm treatment was applied to List 2 ($d = 1.62$). Gains exceeding baseline levels were also noted for the untrained, limited exposures list (List 5) for both participants (Participant 2, $d = 2.55$; Participant 5, $d = 4.46$). Participants 2 and 5 demonstrated strong maintenance effects at follow-up probing, with Participant 2 exhibiting a slight decrease for one treated list and the untreated, exposed list at 8 weeks after treatment. Participant 5 had expressed a desire to terminate treatment with List 2 (which had reached very high accuracy levels) and therefore received treatment applied to List 4 when treatment was extended to List 3. Consequently, he provided an additional replication of the effects of repeated practice treatment. Follow-up phase effect sizes for treated lists ranged from 3.73 to 18.09 for Participant 2 and from 7.48 to 23.72 for Participant 5.

Participants 1, 4, 7, and 9: Two Applications of Rate/Rhythm Treatment Required

Four participants received applications of both treatments with two lists of stimuli: Participants 1, 4, 7, and 9. As seen in Figures 1, 4, 7, and 9, all of these participants displayed a positive response to repeated practice treatment but did not achieve 85% accuracy levels before reaching a plateau in performance. When rate/rhythm treatment was applied, modest additional gains were achieved in all but one instance. Although Participant 4 demonstrated increased accuracy levels with List 1 when rate/rhythm treatment was applied, she did not evidence gains with List 4 when rate/rhythm treatment was applied. Effect sizes for repeated practice treatment were as follows: Participant 1, 3.39–16.47; Participant 4, 2.3–5.01; Participant 7, 3.43–9.17; and Participant 9, 3.75–8.17. Effect sizes for the rate/rhythm treatment ranged from 1.17 to 5.47 across participants. Modest changes in the untreated, repeatedly exposed lists (List 4) were seen for all of these participants, with changes associated with both types of treatment (see Figures 1, 4, 7, and 9 for effect-size values). Maintenance of treatment gains was evident for all treated lists with the exception of one list for Participant 7. Follow-up phase effect sizes ranged from .37 to 21.64 across participants.

Participants 6 and 10: No or Minimal Response to Treatments

As seen in Figures 6 and 10, Participants 6 and 10 demonstrated no changes in accuracy of production in response to both treatments. Participant 6 was discontinued from treatment after the first application of both treatments due to lack of progress and lack of compliance with the treatment protocol (discussed later). Participant 10 received a second application of both treatments and the lack of positive effects was replicated.

Effect sizes for all participants for the treated lists are summarized in the online supplemental materials (Online Table 2).

The PCC data (Table 3) appeared to accurately reflect the graphed data, which were based on binary scoring. That is, the binary scoring did not mask additional gains.

Discussion

The primary purpose of this investigation was to examine the effects of repeated practice alone on the accuracy of sound production in speakers with AOS. More specifically, the study was designed to determine if repeated practice treatment would result in increased accuracy of sound

production in trained and untrained utterances. A secondary goal of the investigation was to determine if repeated practice plus rate/rhythm treatment would result in additional gains beyond that achieved with repeated practice alone.

Repeated practice treatment was applied to 32 different lists of experimental stimuli across the 10 participants. Increases in production accuracy were evident for eight speakers for all lists. Given that repeated practice is a ubiquitous component of almost all AOS treatments, it was expected that positive changes in sound production would be found. However, it was not expected that maximal changes would be achieved with repeated practice treatment alone, as was the case with several of the participants. We had anticipated that additional treatment (rate/rhythm control) would be warranted with the majority of the participants, but high levels of production accuracy prohibited the application of rate/rhythm treatment completely with two participants and partially with two other participants.

The degree of improvement associated with repeated practice treatment varied within and across speakers. For example, Participant 1 achieved increases of 25% over the highest baseline probe with List 1 and 70% with Lists 2 and 3 (effect sizes ranging from *d* index = 7 to *d* index = 16). Other participants, such as Participant 2, demonstrated more similar increases across lists, with increases of 65%, 60%, and 50% over the highest baseline probes for Lists 1, 2, and 3, respectively.

It is likely that within-subject performance variability was related, at least in part, to the stimuli. Efforts were made to ensure similarity across lists in terms of the composition of the stimulus items. Of special concern were the levels of performance accuracy in baseline. That is, it was desired that the ranges of baseline probe values be similar for each list selected for each participant. As seen in the figures, baseline performance appeared to be stable and similar across lists for all participants. The degree of baseline variability did not appear to be related to treatment responsiveness. It was speculated that very low levels of accuracy during baseline probes may have masked differences in the difficulty levels of the lists. However, as in the cases of Participants 4 and 8 (who had very low levels of accuracy in baseline), the lists did not appear to respond much differently.

The tentative conclusion that differences in difficulty of the experimental lists contributed to treatment performance variability was drawn for several reasons. The simultaneous application of the same treatment to two different lists was particularly useful for addressing this issue. It was unlikely that an uncontrolled factor (e.g., participant fatigue) would affect only one treated list during the same time period. Thus, a difference in gains achieved with Lists 1 and 2 could be attributed to differences in the lists.

Potential explanations for differences in gains achieved with an earlier treated list versus a later treated list could include previous exposure to the treatment, which might enhance performance or be detrimental to performance with the later treated list (e.g., boredom). Participant 4 demonstrated greater increases with List 3 (later list) than with List 1 (initial list). But, she also showed greater gains with List 2 than with List 1 (treated during the same time period). Additionally, Participant 4 received repeated practice treatment for List 4 simultaneously with List 3 and evidenced gains with List 4 that were similar to gains with List 1. Thus, her performance appeared to vary with list rather than time period. Participant 1 demonstrated somewhat better performance for List 2 than List 1 during the initial treatment period but then showed much larger gains when treatment was applied to List 3. When treatment was applied to List 3, she showed additional gains with List 2 (which had received continued repeated practice treatment) and improvements in the untreated, exposure list. It appeared that time/exposure may have contributed to better performance later in the investigation for Participant 1, but differences in lists likely contributed to initial performance differences as well.

Variability in responding to the same treatment within participants has been observed with our previous research with other AOS treatments (e.g., Wambaugh et al., 1998, Wambaugh & Martinez, 2000; Wambaugh & Nessler, 2004) and was evident in the literature reviewed in the AOS treatment guidelines project (Wambaugh et al., 2006b). Speakers with AOS experience more or less difficulty with particular sounds/stimuli. It is to be expected that when stimuli are grouped by similar characteristics, speakers may have a better response with one set of stimuli versus another even when the stimuli are balanced and equated for difficulty in baseline.

This conclusion has implications for the design of treatment investigations for speakers of AOS. Researchers should be cautious in using within-subject effects (e.g., effect sizes) in single-subject designs to ascribe a stronger or weaker treatment effect to one treatment in comparison to another. That is, it is apparent that the same treatment can result in substantially different effect sizes within the same speaker with stimuli that have been carefully balanced. If one wishes to compare AOS treatments within a speaker using designs such as multiple baseline designs, it is suggested that each treatment's effects be replicated; one application of each treatment should not be considered sufficient to determine a treatment's effects.

Response generalization effects of repeated practice treatment were also of interest. During the first application of repeated practice treatment to Lists 1 and 2, the three remaining untreated lists offered the opportunity to measure response generalization. Two of the lists (Lists 3 and 5) were probed only at the end of repeated practice treatment, and List 4 was probed on the same schedule as the treated lists (i.e., before every treatment session). Thus, generalization could be measured to items that had frequent exposure and to items with limited exposure.

Of the eight participants who demonstrated a positive response to treatment, six demonstrated increases in accuracy of production of items in the untreated list that had been exposed frequently (Participants 2, 3, 5, 7, 9). Additionally, Participant 1 demonstrated an increase in accuracy with the untrained, exposed list that was delayed until treatment was extended to a third list. Although Participant 8 achieved large increases in accuracy with the treated lists, no response generalization was evident (even when his PCC data were examined). Interestingly, Participant 8 displayed the lowest

accuracy levels during baseline with respect to his PCC. This would suggest that his stimuli may have been more challenging, which may relate to the ability to generalize.

Changes in the limited exposure lists (List 5) were either absent or minimal for all participants. It may be argued that the single probe conducted with the limited exposure lists "missed" possible generalization. However, subsequent probes confirmed the limited change in performance.

The changes in the untrained, exposed list were not always of the magnitude of the changes that were seen in the trained lists, although for a few participants, generalization effects equaled acquisition effects. It is possible that the changes were due to repeated production of or exposure to the items in the probe. Similar improvements with repeated exposure have been reported in the word-retrieval literature (Nickels, 2002), and such findings served as the rationale for our inclusion of a limited exposure probe list. The act of repeating untrained items in response to the examiner's model during probes may have served as a weaker form of treatment. An alternate or perhaps complementary explanation may be that generalization effects were dependent on exposure. That is, perhaps a degree of familiarity or continual production attempts is necessary for generalization to occur. Severity of AOS may have been a factor related to degree of generalization, but a metric of severity is needed to evaluate this issue in the future.

As noted previously, the rate/rhythm control treatment was not applied to all lists because maximal gains had been achieved with repeated practice treatment alone. There were 13 opportunities to observe these effects. For the majority of the applications of repeated practice plus rate/rhythm control, slight additional gains in accuracy of production of the trained lists were evident.

The purpose of this investigation was not to examine the magnitude of change that could be achieved with rate/rhythm treatment, but to determine if additional gains could be achieved after maximal change had occurred with repetition treatment. Because the addition of rate/rhythm treatment always followed repeated practice treatment, there was less room for making gains in comparison to the initial phases of treatment. The 85% criterion for not instituting rate/rhythm treatment was used to try to avoid ceiling effects. However, there were obviously fewer items with which to effect change by the time rate/rhythm control was applied. Additionally, stimulus items that had not been correctly articulated with repeated practice treatment may have been more difficult and/or may have become resistant to treatment.

Conversely, the effects of repeated practice treatment may have facilitated the effects of rate/rhythm control in this investigation (i.e., positive order effects). This appears unlikely on the basis of previous rate/rhythm control investigations that did not employ repeated practice alone first (Brendel & Ziegler, 2008; Mauszycki & Wambaugh, 2008; Wambaugh & Martinez, 2000).

This investigation was not designed to compare repeated practice treatment and rate/rhythm control treatment. The examination of rate/rhythm control treatment without repeated practice would appear to be very difficult to accomplish, if not impossible. That is, application of rate/rhythm in the context of treatment would seem to necessitate practice, as would most other AOS treatments.

Although the majority of participants in this investigation responded positively to treatment, two participants did not evidence gains. We examined individual participant characteristics to determine if any were associated with the poor response to treatment. The eight participants who demonstrated positive responses to repeated practice treatment reflected a relatively wide range of characteristics. The two participants who did not achieve gains fell within the range of characteristics of the positive responders for all available descriptive and speech/language data, with the exception of site of lesion. Participant 6 had a right-hemisphere lesion, and Participant 10 had a lesion of the left basal ganglia. It is possible that site of lesion was a factor in the lack of response to treatment. There were behavioral factors, which may have been associated with site of lesion, that were likely related to the poor responses of Participants 6 and 10.

Participant 6 failed to comply satisfactorily with the treatment protocol. He frequently would not attempt production of items and often would not complete repeated productions of the items. Although he expressed the desire to participate in the treatment, his motivation to improve/succeed was questionable. Behaviorally, he did not achieve the high number of repetitions of stimuli that were completed by the other participants. In contrast, Participant 10 was an enthusiastic participant who complied completely with the protocol. Although participants were not asked to provide feedback concerning their awareness of their errors, most of the participants spontaneously indicated such awareness. Anecdotally, Participant 10 indicated almost no awareness of the accuracy or inaccuracy of his productions. Unfortunately, we did not conduct any formal measures of self-monitoring. However, Participant 10 was judged to have extremely poor self-monitoring skills.

Repeated practice treatment involved no instruction and very limited feedback concerning articulation. It was speculated that changes in articulation derived from two main sources: (a) improved access to or reestablishment of motor programs through repeated production attempts and (b) increased accuracy due to articulatory adjustments from prearticulatory or postarticulatory self-monitoring. Participant 6 may not have achieved a sufficient number of production attempts to improve motor program access, and Participant 10 may not have had sufficient self-monitoring resources to improve productions. Of course, the preceding explanations are speculative.

It is clear that repeated practice treatment resulted in improved articulation for most of the study participants. Although the gains achieved with the addition of rate/rhythm control were modest, they may warrant the comparison of repeated practice plus rate/rhythm control to repeated practice alone. If repeated practice plus rate/rhythm treatment had been applied immediately to a list of stimuli (instead of following repeated practice treatment), it is possible that gains may have been greater than gains from repeated practice alone.

The difficulty in separating the effects of repeated practice from another treatment factor applies to the majority of the AOS treatment evidence base. One might question the

necessity of additional treatment techniques if repeated practice alone has robust effects. In this investigation, all participants had at least a few errors that remained that were not likely to change with any amount of repeated practice treatment (or repeated practice plus rate/rhythm treatment). It was obvious in the treatment process that there were errors that the participants did not know how to remediate. Participants and the research SLPs were at times frustrated by the prohibition of articulatory instruction; requests for articulatory instruction to remediate errors often occurred, particularly in the initial phases of treatment. Several participants displayed dissatisfaction with the lack of specific feedback about sound errors (i.e., which sounds were in error and the nature of the errors). As with rate/rhythm control, articulatory–kinematic treatments (or other approaches) in combination with repeated practice may result in stronger or more rapid effects than repeated practice alone.

Factors associated with the organization of repeated practice and the consequating of practice results are also important considerations for maximizing treatment effects. Preliminary findings have suggested that some speakers with AOS may benefit from principles of motor learning applied to practice in AOS treatment (Austermann Hula et al., 2008; Knock et al., 2000; Maas et al., 2002). In addition, treatment schedule or intensity of practice is likely to influence outcomes, as has been demonstrated with childhood AOS (Edeal & Gildersleeve-Neumann, 2011). A discussion of the numerous factors that may impact the effects of repeated practice is beyond the scope of this report.

This investigation represents an initial attempt to clarify the effects of repeated practice treatment on sound production accuracy in speakers of AOS and to specify the additional benefits of rate/rhythm control. The degree of improvement achieved with repeated practice alone (with limited feedback concerning accuracy) was not anticipated but highlights the importance of this treatment technique. The findings do not negate the need for other treatments, but they do underscore the need to consider and control the factor of repeated practice.

Acknowledgment

This research was supported by the Department of Veterans Affairs, Rehabilitation Research and Development.

References

Austermann Hula, S. N., Robin, D. A., Maas, E., Ballard, K. J., & Schmidt, R. A. (2008). Effects of feedback frequency and timing on acquisition, retention, and transfer of speech skills in acquired apraxia of speech. *Journal of Speech, Language, and Hearing Research, 51,* 1088–1113.

Barlow, D. H., & Hersen, M. (1984). *Single case experimental designs: Strategies for studying behavior change*. New York, NY: Pergamon Press.

Bloom, M., Fischer, J., & Orme, J. G. (2003). *Evaluating practice—Guidelines for the accountable professional* (4th ed.). Boston, MA: Allyn & Bacon.

Brendel, B., & Ziegler, W. (2008). Effectiveness of metrical pacing in the treatment of apraxia of speech. *Aphasiology, 22*(1), 1–26.

Brendel, B., Ziegler, W., & Deger, K. (2000). The synchronization paradigm in the treatment of apraxia of speech. *Journal of Neurolinguistics, 13,* 241–327.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Dabul, B. L. (2000). *Apraxia Battery for Adults* (2nd ed.). Austin, TX: Pro-Ed.

Dronkers, N. F. (1996). A new brain region for coordinating speech articulation. *Nature, 384*(6605), 159–161.

Duffy, J. R. (2005). *Motor speech disorders. Substrates, differential diagnosis, and management* (2nd ed.). St. Louis, MO: Elsevier Mosby.

Dworkin, J. P., & Abkarian, G. G. (1996). Treatment of phonation in a patient with apraxia and dysarthria secondary to severe closed head injury. *Journal of Medical Speech-Language Pathology, 2,* 105–115.

Dworkin, J. P., Abkarian, G. G., & Johns, D. F. (1988). Apraxia of speech: The effectiveness of a treatment regime. *Journal of Speech and Hearing Disorders, 53,* 280–294.

Edeal, D. M., & Gildersleeve-Neumann, C. E. (2011). The importance of production frequency in therapy for childhood apraxia of speech. *American Journal of Speech-Language Pathology, 20,* 95–110.

Hillis, A. E., Work, M., Barker, P. B., Jacobs, M. A., Breese, E. L., & Maurer, K. (2004). Re-examining the brain regions crucial for orchestrating speech articulation. *Brain, 127,* 1479–1487.

Horner, R. D., & Baer, D. M. (1978). Multiple-probe technique: A variation of the multiple baseline. *Journal of Applied Behavior Analysis, 11,* 189–196.

Kertesz, A. (1982). *The Western Aphasia Battery*. New York, NY: Grune & Stratton.

Knock, T. R., Ballard, K. J., Robin, D. A., & Schmidt, R. A. (2000). Influence of order of stimulus presentation on speech motor learning: A principled approach to treatment for apraxia of speech. *Aphasiology, 14*(5/6), 653–668.

Maas, E., Barlow, J., Robin, D., & Shapiro, L. (2002). Treatment of sound errors in aphasia and apraxia of speech: Effects of phonological complexity. *Aphasiology, 16*(4/5/6), 609–622.

Mauszycki, S. C., & Wambaugh, J. L. (2008). The effects of rate control treatment on consonant production accuracy in mild apraxia of speech. *Aphasiology, 22*(7/8), 906–920.

McHenry, M., & Wilson, R. (1994). The challenge of unintelligible speech following traumatic brain injury. *Brain Injury, 8*(4), 363–375.

McNeil, M. R., Liss, J. M., Tseng, C., & Kent, R. D. (1990). Effects of speech rate on the absolute and relative timing of apraxic and conduction aphasic sentence production. *Brain and Language, 38*(1), 135–158.

McNeil, M. R., Robin, D. A., & Schmidt, R. A. (1997). Apraxia of speech: Definition, differentiation, and treatment. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 311–344). New York, NY: Thieme.

McNeil, M. R., Robin, D. A., & Schmidt, R. A. (2009). Apraxia of speech: Definition, differentiation, and treatment. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (2nd ed., pp. 249–268). New York, NY: Thieme.

McReynolds, L. V., & Kearns, K. P. (1983). *Single-subject experimental designs in communicative disorders*. Baltimore, MD: University Park Press.

Miller, N., & Wambaugh, J. (2011). Acquired apraxia of speech. In I. Papathanasiou, P. Coppens, & C. Potogas (Eds.), *Aphasia and related neurogenic communication disorders* (pp. 431–457). Burlington, MA: Jones and Bartlett Learning.

Nicholas, L. W., & Brookshire, R. H. (1993). A system for quantifying the informativeness and efficiency of the connected speech of adults with aphasia. *Journal of Speech and Hearing Research, 36,* 338–350.

Nickels, L. A. (2002). Improving word-finding: Practice makes (closer to) perfect? *Aphasiology, 16,* 1047–1060.

Ogar, J., Willock, S., Baldo, J., Wilkins, D., Ludy, C., & Dronkers, N. (2006). Clinical and anatomical correlates of apraxia of speech. *Brain and Language, 97,* 343–350.

Porch, B. (2001). *Porch Index of Communicative Ability (Vol. 2). Administration, scoring and interpretation* (4th ed.). Albuquerque, NM: PICA Programs.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Coloured Progressive Matrices*. Oxford, England: Oxford Psychologist Press.

Rose, M., & Douglas, J. (2006). A comparison of verbal and gesture treatments for a word production deficit resulting from acquired apraxia of speech. *Aphasiology, 20*(12), 1186–1209.

Rubow, R. T., Rosenbek, J. C., Collins, M. J., & Longstreth, D. (1982). Vibrotactile stimulation for intersystemic reorganization in the treatment of apraxia of speech. *Archives of Physical Medicine Rehabilitation, 63,* 150–153.

Schmidt, R., & Lee, T. (2005). *Motor control and learning: A behavioural emphasis* (4th ed.). Champaign, IL: Human Kinetics.

Southwood, H. (1987). The use of prolonged speech in the treatment of apraxia of speech. In R. H. Brookshire (Ed.), *Clinical Aphasiology Conference Proceedings* (pp. 277–287). Minneapolis, MN: BRK.

Wambaugh, J. L., Duffy, J. R., McNeil, M. R., Robin, D. A., & Rogers, M. (2006a). Treatment guidelines for acquired apraxia of speech: A synthesis and evaluation of the evidence. *Journal of Medical Speech-Language Pathology, 14*(2), xv–xxxiii.

Wambaugh, J. L., Duffy, J. R., McNeil, M. R., Robin, D. A., & Rogers, M. (2006b). Treatment guidelines for acquired apraxia of speech: Treatment descriptions and recommendations. *Journal of Medical Speech-Language Pathology, 14*(2), xxxv–lxvii.

Wambaugh, J. L., Kalinyak-Fliszar, M. M., West, J. E., & Doyle, P. J. (1998). Effects of treatment for sound errors in apraxia of speech. *Journal of Speech, Language, and Hearing Research, 41,* 725–743.

Wambaugh, J., & Martinez, A. (2000). Effects of rate/rhythm control treatment on consonant production accuracy in apraxia of speech. *Aphasiology, 14*(8), 851–871.

Wambaugh, J. L., & Mauszycki, S. C. (2010). Application of the WHO ICF to management of acquired apraxia of speech. *Journal of Medical Speech-Language Pathology, 18*(4), 133–140.

Wambaugh, J. L., & Nessler, C. (2004). Modifications of sound production treatment for aphasia: Generalization effects. *Aphasiology, 18*(5/6/7), 407–427.

Wambaugh, J. L., & Shuster, L. (2008). The nature and management of neuromotor speech disorders accompanying aphasia. In R. Chapey (Ed.), *Language intervention strategies in aphasia and related neurogenic communication disorders* (5th ed., pp. 1009–1042). Philadelphia, PA: Lippincott Williams & Wilkins.

Wambaugh, J. L., West, J. E., & Doyle, P. J. (1998). Treatment for apraxia of speech: Effects of targeting sound groups. *Aphasiology, 12,* 731–743.

Yorkston, K. M., & Beukelman, D. R. (1981). *Assessment of Intelligibility of Dysarthric Speech*. Austin, TX: Pro-Ed.

Appendix

Description of Experimental Stimuli by Participant

Participant 1: monosyllabic words containing word-initial clusters (e.g., *freeze, plot, green*) and bisyllabic words containing sounds that were difficult for her (i.e., word-medial /θ/, /dʒ/ and /ŋ/ (e.g., *author, wager, ringer*) and word-final /k/ and /g/ (e.g., *iceberg, attic*).
Participant 2: trisyllabic words with word-initial clusters (e.g., *granola, spatula*) or word-initial vowels (e.g., *abrasion, electric*).
Participant 3: bi- and trisyllabic words with word-initial /s/ clusters (e.g., *strategic, squeegee*). Each list included trisyllabic words with word-medial /ʃ/, /tʃ/, /dʒ/, /ʒ/, or ŋ (e.g., *crescendo, hatchery, drudgery, visual, bungalow*), with half of those words beginning with vowels (e.g., *anchovy, official*).
Participant 4: words in sentences that contained the following: 1) 4–6 words, 2) 9–10 syllables, 3) at least one, 3–4 syllable word, and 4) no words longer than 4 syllables (e.g., *Leo usually likes lemonade.*).
Participant 5: mono- and bisyllabic words with several target sounds were included in each list (e.g., word-initial /z/, word-medial /tʃ/ and /dʒ/, /or/, /s/ clusters, /r/ clusters, etc.) (e.g., *zipper, kerchief, mammoth, spring*).
Participant 6: trisyllabic words with clusters (e.g., *flexible, tragedy*) and bisyllabic words with word-final fricatives/affricates (e.g., *concave, bandage*).
Participant 7: same as Participant 6.
Participant 8: mono- and bisyllabic words with word-initial and word-final "difficult" sounds (e.g., *visa, rocking*).
Participant 9 & Participant 10: same as Participant 3.