Introduction

Although treatment for apraxia of speech (AOS) has been evaluated positively in the recent experimental literature (Wambaugh, Duffy, McNeil, Rogers, & Robin; 2006a, b), the weight of the evidence is light and the array of validated treatments is sparse. One recently reported treatment technique suggested that on-line visual feedback of lingual movements transduced with the electromagnetic articulograph (EMA) improved articulatory accuracy in an individual with AOS (Katz, Bharadwaj, & Carstens, 1999). That study used 100% feedback, a condition reported to increase rate of skill acquisition but diminish generalization and maintenance effects. To further investigate the efficacy and frequency of EMA-mediated feedback, the present study sought to determine if there were acquisition, generalization, and maintenance effects for erred productions under frequent (100%) and infrequent (50%) feedback conditions in a single individual with AOS.

Methods and Procedures

Participant

The participant (AOS1) was a 63 year old, right-handed male with 23 years of formal education. He was approximately two and one-half years post-onset from a left hemisphere infarct resulting in mild aphasia and mild to moderate severity AOS. Enrollment followed 12 months of treatment directed at improving his auditory comprehension, auditory memory skills, and production of multi-syllabic words at various levels of complexity. Initial assessment data are reported in Table 1. He demonstrated all of the primary speech characteristics consistent with AOS as proposed by McNeil, Robin and Schmidt (1997) and adopted by the Academy of Neurological Communication Disorders and Sciences practice guidelines working group (Wambaugh et al; 2006a, 2006b), consisting of: overall slow speech rate, increase segment and intersegment durations, prosodic abnormality and sound distortions. Other non-diagnostic characteristics included sound substitutions, self-corrections and multiple target attempts.

Procedures

Treatment was sequentially administered to nine phonemic targets that were determined to be challenging to the participant during extensive pretreatment evaluation. Each target was in the word medial position and was produced in a semantically meaningful phrase varied by preceding vowel environment. As shown in Figure 1, the treatment targets were (in chronological order of intervention): "pi**ll**ow", "co**l**or", "craw**l**ing", re**l**ic", "ru**st**ic", "fea**st**ing", "war**bl**er", "si**bl**ings" and "lec**tu**re". The first three targets were the /**l**/, the fourth and fifth targets were the /**st**/ blend, the sixth and seventh targets were the /**bl**/ blend and the final was the unvoiced /**t**ʃ/ sound. Generalization to words varying in phonetic contexts (constrained by AOS1's individual error patterns) was evaluated in 27 untreated stimuli that were both systematically baselined pre-treatment and probed throughout treatment. Frequent (100%) feedback was provided for treated /**l**/ and unvoiced /tʃ/ target words and infrequent (50%) feedback to /**st**/ and /**bl**/. The percentage of perceptually and kinematically accurate productions for the untreated targets (labeled along the ordinate) are displayed in Figure 1; Panels 10-36.

During treatment AOS1 sat in a sound treated booth with his head positioned within the EMA triangulated magnetic field. A calibrated sensor was glued at midline on tongue, approximately 6 mm from the tip. While AOS1 produced the target sound in a word in isolation until the target sound was perceptually and kinematically correct, the target zone for accurate productions was determined and marked on the computer graphic. AOS1 viewed a computer monitor that displayed the target zone and online tracing of his tongue movement and position. His goal was to use only the visual information to move his tongue into the target zone. Stimuli were presented live voice by the experimenter and visual reinforcement for a correct production (both correct tongue placement and auditory perceptually correct production) was provided. He produced a total of 40 correct productions of the target during each treatment session. EMA and sensor placement, extensive baselines and probes, along with treatment delivery typically took about 1.5 hours per session. Baselines and treatment to criteria (three consecutive sessions with an auditory perceptual accuracy on the treatment probes $\geq$ 80%) for all 9 treated targets required a total of 77 treatment sessions.

Results

Inter-rater perceptual judgments of the data displayed in Figure 1 (treatment, generalization and maintenance) were calculated and yielded 97% point-to-point agreement for two judges.

The results of this intervention yielded evidence for both a treatment (acquisition) effect and generalization of learning to untreated speech targets along with sufficiently stable baselines to attribute the effects of the intervention to the treatment rather than any of the numerous other possible sources of change (e.g. physiological recovery, a Hawthorne Effect, general practice, motivation). Specifically, when the augmented kinematic biofeedback was directed to the movements that correspond to a perceptually correct /l/ sound, following an unstable baseline (Figure one, Panel 1), performance reached the 100% accuracy level following the first session (probed on the day following the initial treatment) and generally remained at that level. It can be seen that generalization to the untreated "color" target (Panel 2) occurred with a destabilization of this target, but with insufficient effect for it to reach criterion during this treatment phase. Likewise, generalization to the "sublet" target was realized and generalization to criterion was evidenced for the "gala" and "crouching" targets. It might also be argued that there was a stabilization of accuracy at the 100% level for the "future" target as well. Importantly, no generalization was evidenced for several targets (e.g. "relic", "rustic", "warbler", "siblings" and "lecture", among many others) during the treatment of the "pillow" target; offering the essential experimental control that the effects observed were due to the intervention rather than a general or unspecified change that would affect all speech production.

When treatment was initiated for the "color" target (Figure 1, Panel 2 shaded area), immediately following the fifth day of treatment directed to "pillow", it remained variable, fluctuating between 100% and 0% accuracy for five treatment sessions before reaching and remaining at 100% criterion. Generalization was evidenced untreated "crawling", "relic", "rustic", "lecture", "foolish", "glibly", "feisty", "coastal", "tastiest", "frosting", "nurture", and "oblate" (treatment criterion met). No effects beyond baseline or the previous phase were evidenced for several targets (e.g., "broiler", "squabbling", "sublet", etc.), providing sufficient experimental control for the establishment of a treatment effect.

It can be seen in the subsequent panels (Figure 1, Panels 3-9) that each treatment yielded an improvement in performance to criteria following the initiation of the intervention. It can also be seen for each intervention that generalization to selected untreated targets was evident, while some probes remained unchanged from baseline.

In general, three to eight sessions were necessary for criterion to be reached and maintained in the frequent (100%) feedback condition, while five to ten sessions were necessary for the 50% feedback condition. At the one-month follow-up (the final data point on all panels), two of the non-treated words fell below the achieved level at treatment termination. Both words were in the sound class that received 100% feedback.

Overall it can be seen that for this participant, intervention produced treatment and generalization effects with the manipulation of feedback frequency relative to perceptual and kinematic accuracy. These results suggest that feedback frequency is a relevant variable for speech motor control. While this treatment needs to be administered to more participants, these results support its efficacy for this clinical population. Results will be discussed relative to patterns of generalization, consistent and varied schedules of practice, and possible psychophysiological mechanisms for the observed effects.

References

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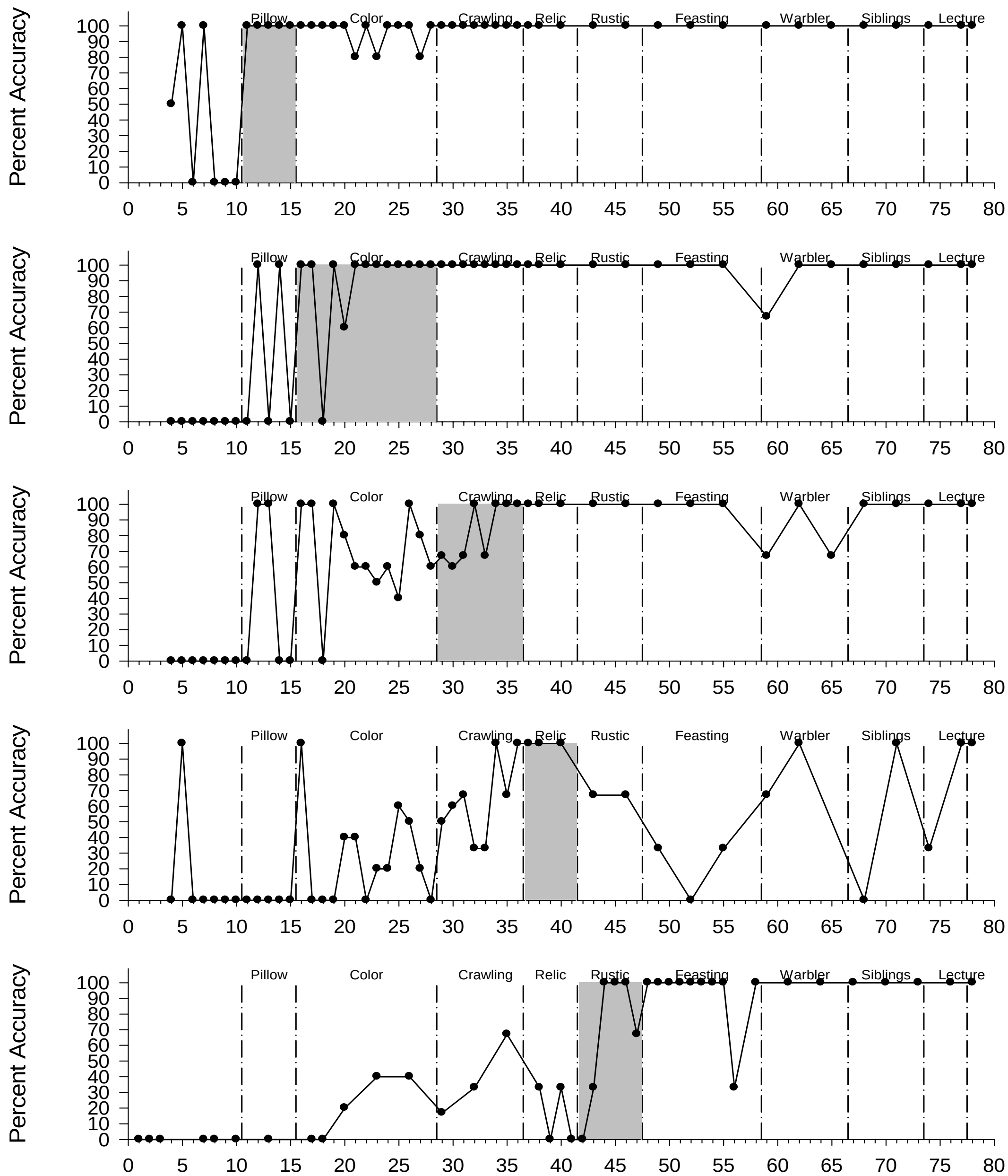
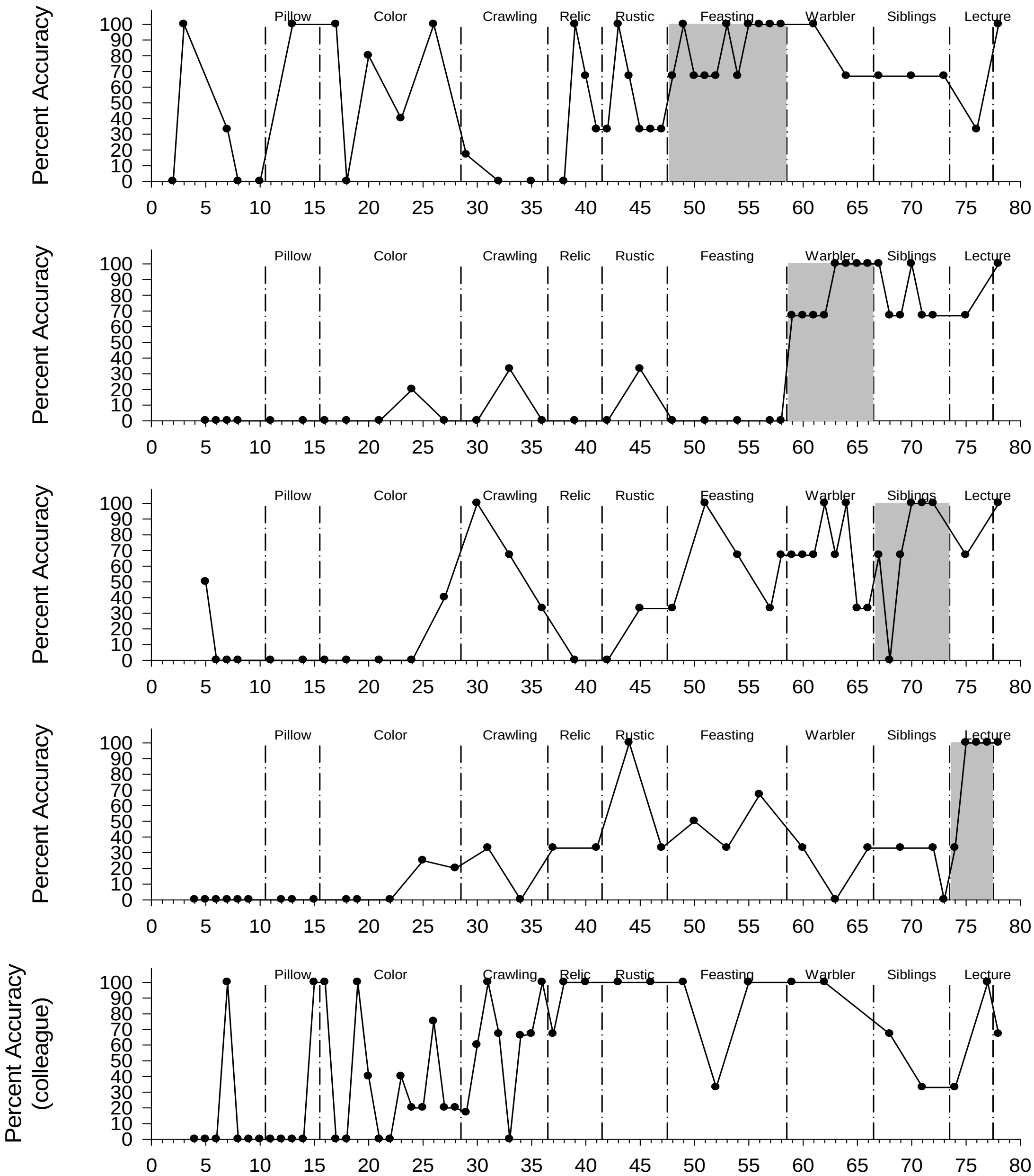
Table 1. AOS1 Descriptive Speech, Language and Cognitive Performance

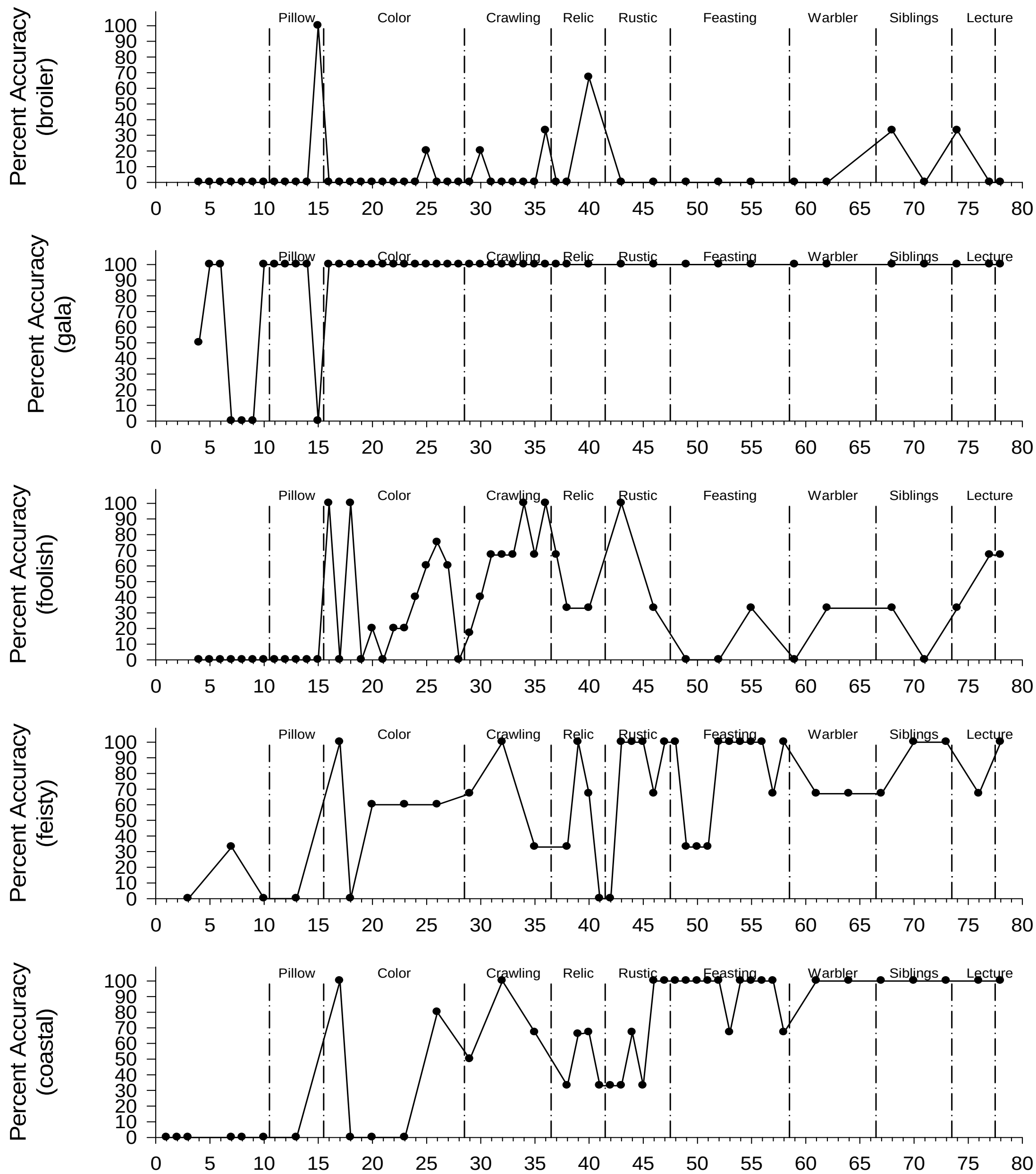
Assessment Measure	**Score**
Computerized- Revised Token Test (CRTT) McNeil & Pratt (In Development)	Overall Mean: 13.78; 87th Percentile *
Coloured Progressive Matrices (CPM) Raven (1965)	Percentile: 63**
Story Retell Procedure (SRP) McNeil, et al (In Press)	Mean %IU: 22.08
Arizona Battery for Communication Disorders of Dementia (Immediate and Delayed Story Retell Subtest) Bayles & Tomoeda (1993)	Ratio: 1.00***
Assessment of Intelligibility of Dysarthric Speech Yorkston and Beukelman (1984)	Intelligibility: 95%
Word intelligibility task Kent, Weismer, Kent, & Rosenbek (1989)	Intelligibility: 88%

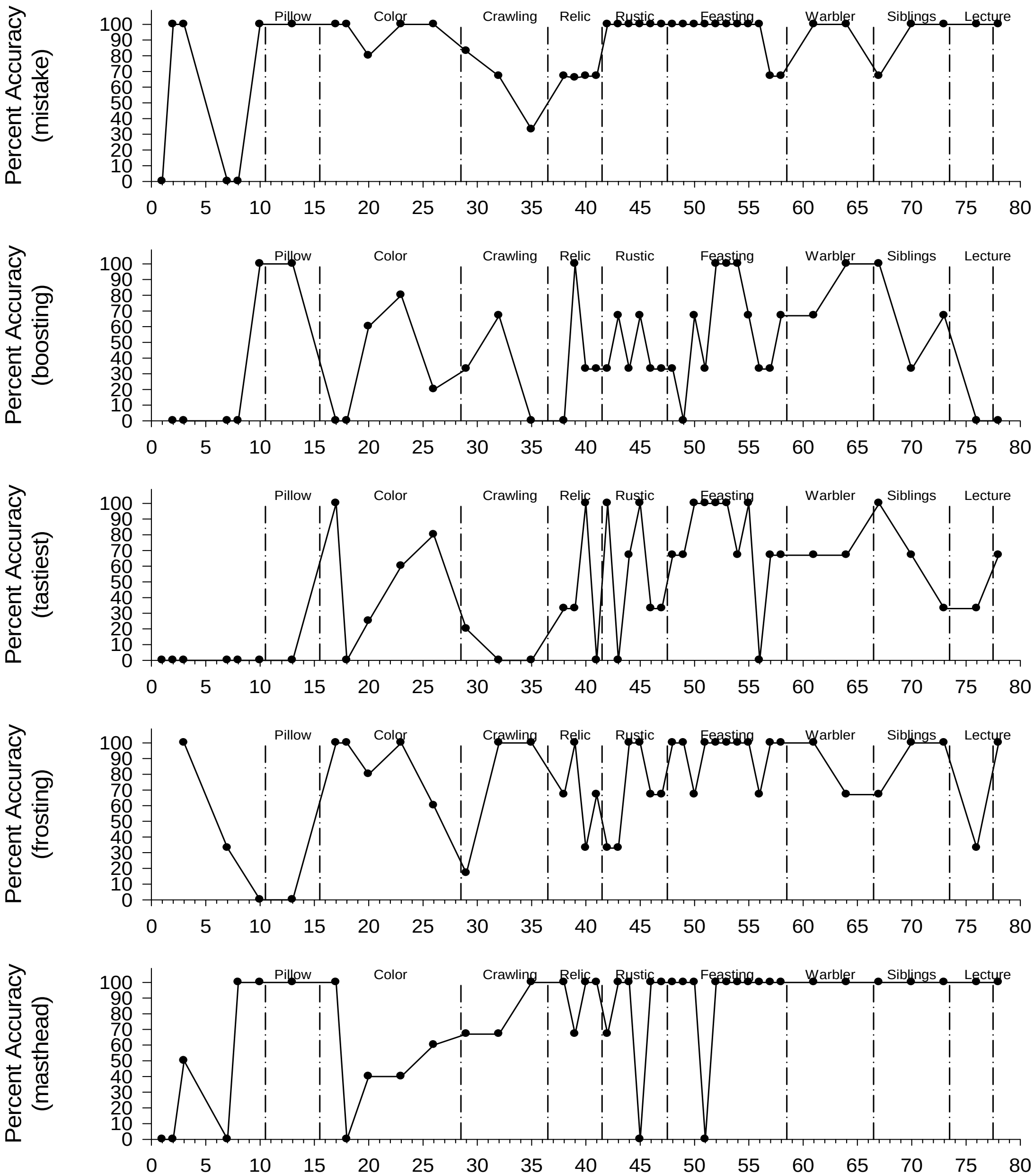
Note: * = Approximate percentile based on normative data for persons with aphasia obtained from the *Revised Token Test* (McNeil & Prescott, 1978). Note: ** = Approximate percentile based on normative data from non-brain-damaged participants.
Note: *** = Ratio of the delayed retell compared to the initial retell (the delayed recall/ immediate recall X 100) on the *Story Retelling Test* of the *Arizona Battery for Communication Disorders of Dementia*.

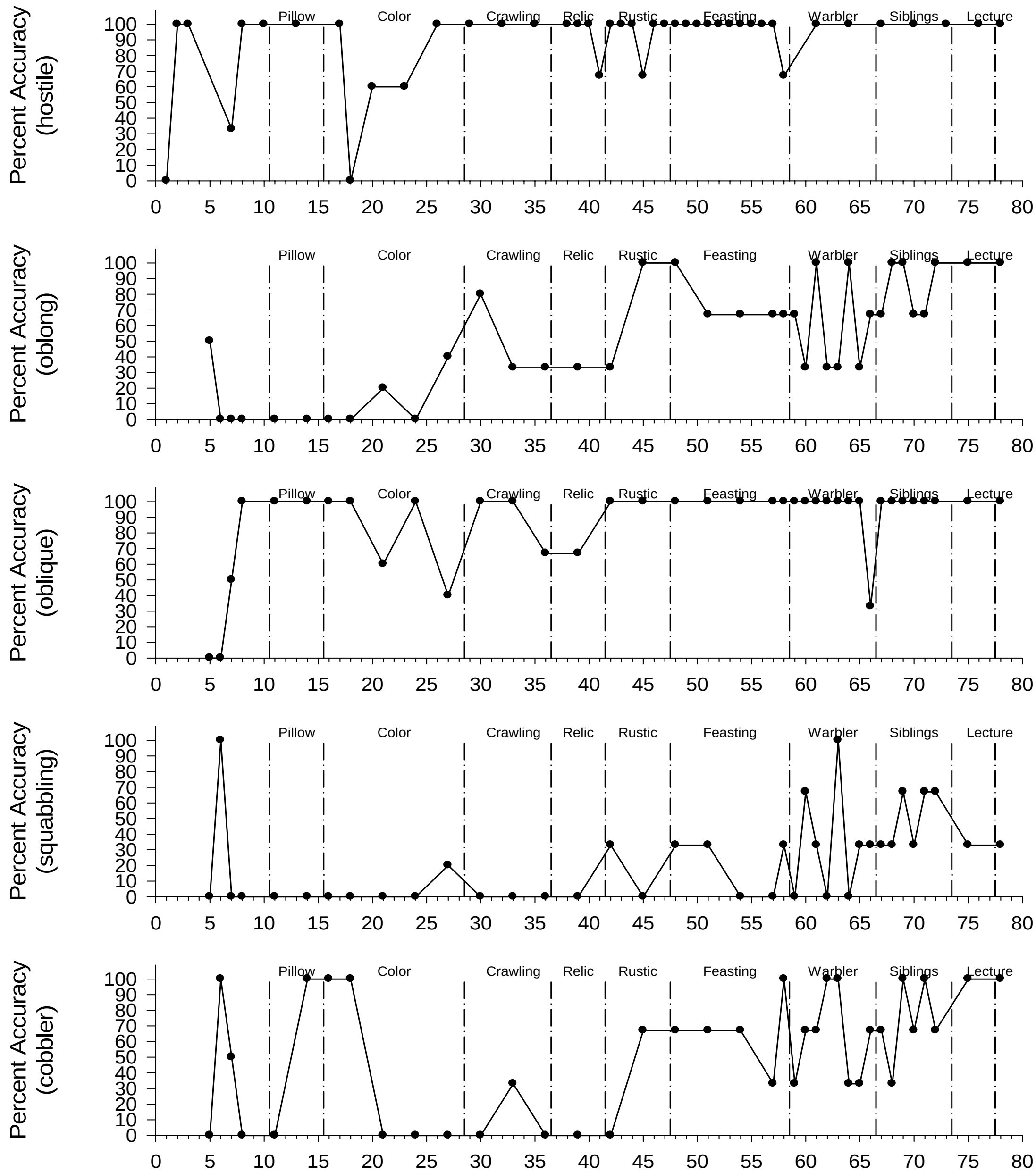
Figure 1

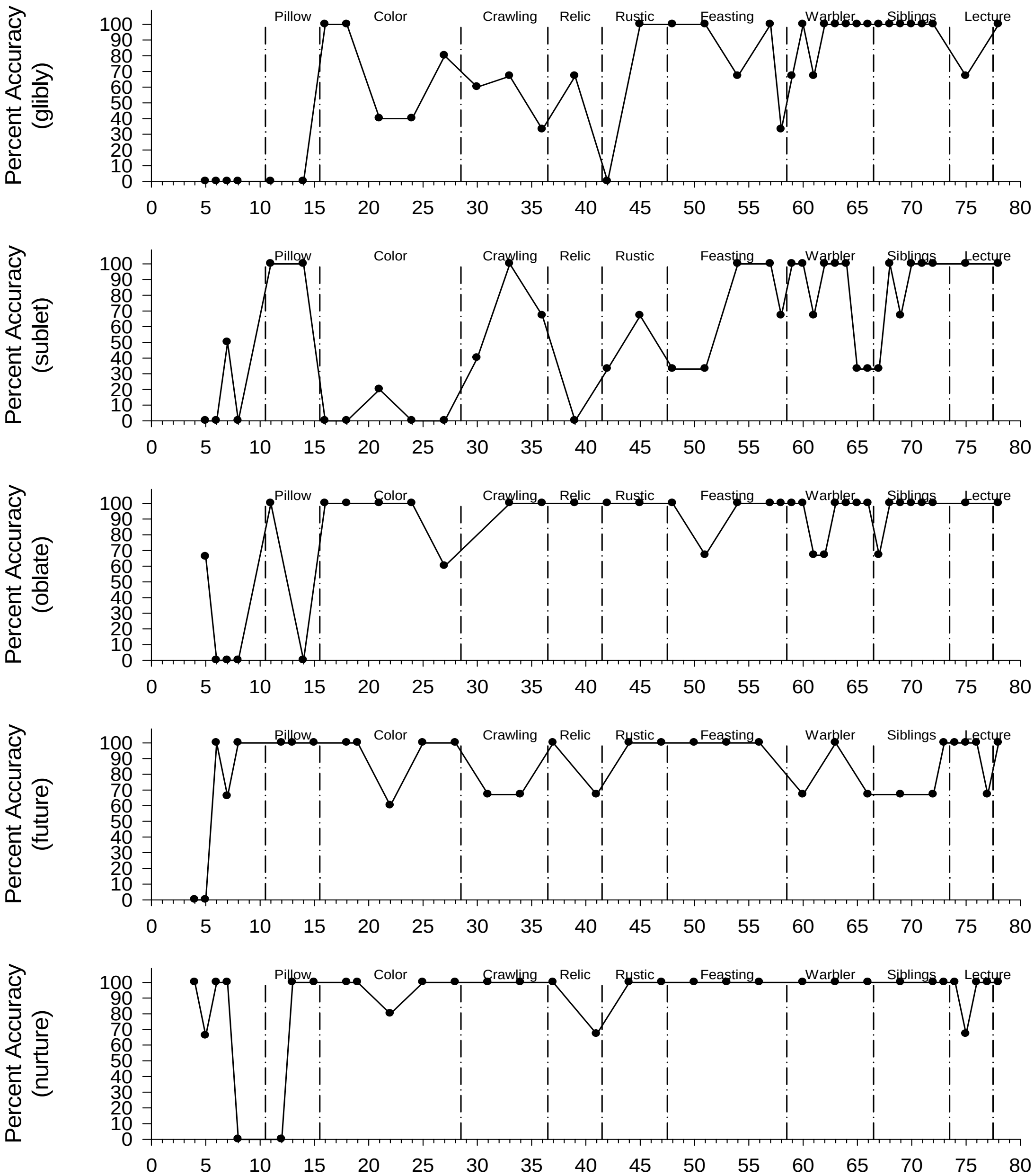

Percent Accuracy
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

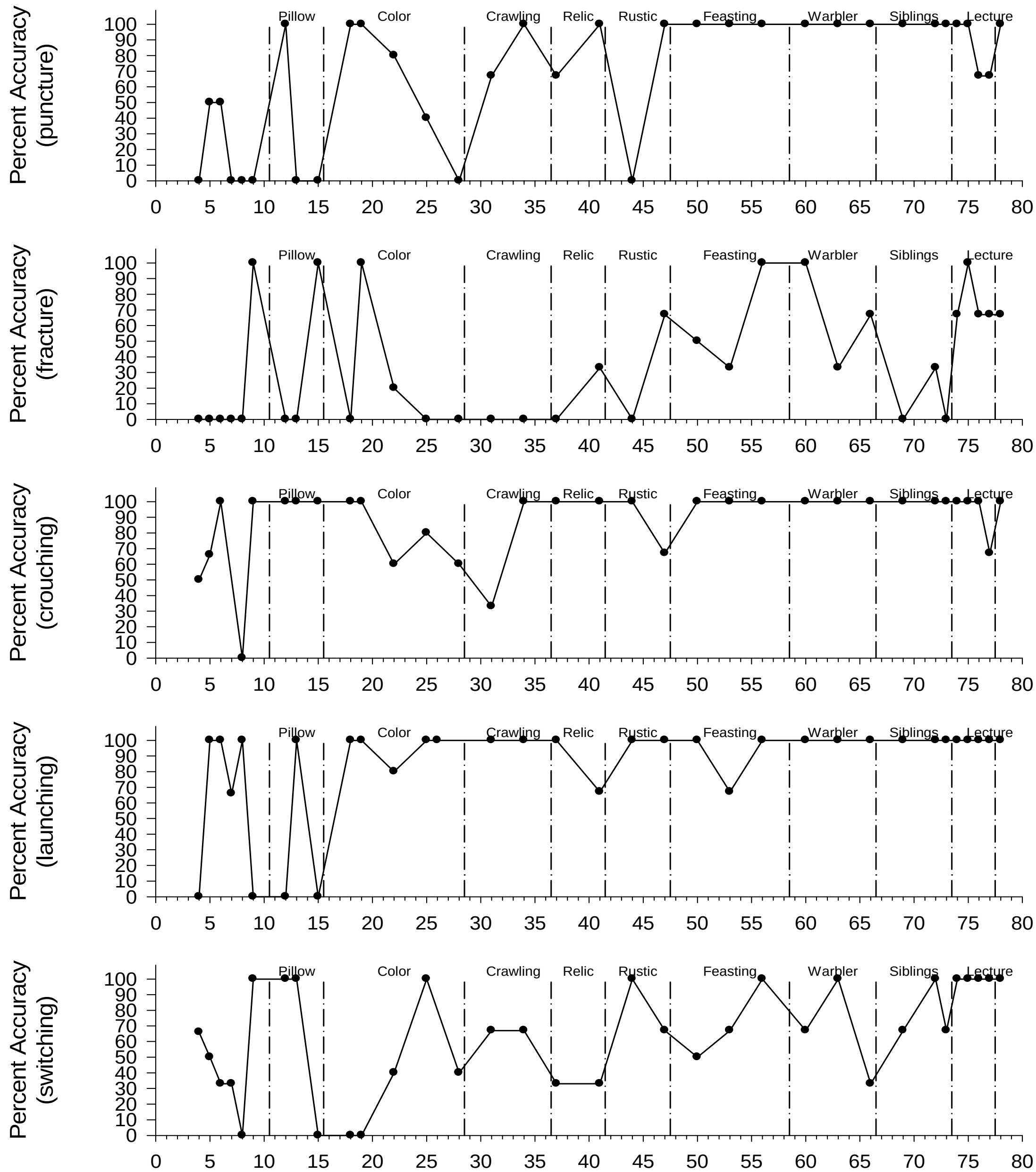

Percent Accuracy
Percent Accuracy
Percent Accuracy
Percent Accuracy
Percent Accuracy (colleague)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

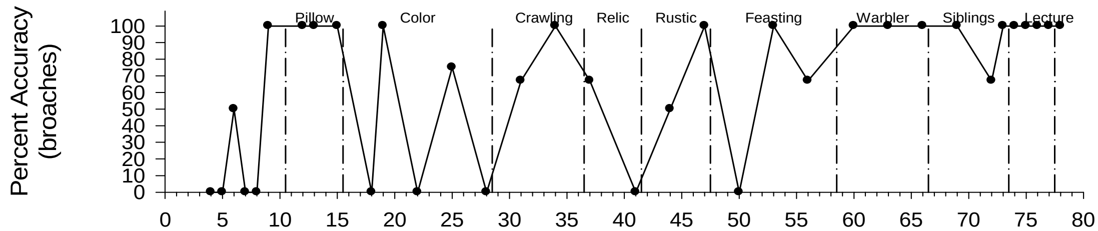

Percent Accuracy (broiler)
Percent Accuracy (gala)
Percent Accuracy (foolish)
Percent Accuracy (feisty)
Percent Accuracy (coastal)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80


Percent Accuracy (mistake)
Percent Accuracy (boosting)
Percent Accuracy (tastiest)
Percent Accuracy (frosting)
Percent Accuracy (masthead)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80


Percent Accuracy (hostile)
Percent Accuracy (oblong)
Percent Accuracy (oblique)
Percent Accuracy (squabbling)
Percent Accuracy (cobbler)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80


Percent Accuracy (glibly)
Percent Accuracy (sublet)
Percent Accuracy (oblate)
Percent Accuracy (future)
Percent Accuracy (nurture)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80


Percent Accuracy (puncture)
Percent Accuracy (fracture)
Percent Accuracy (crouching)
Percent Accuracy (launching)
Percent Accuracy (switching)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80



Percent Accuracy (broaches)
Pillow
Color
Crawling
Relic
Rustic
Feasting
Warbler
Siblings
Lecture
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80