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Oral Motor Tracking in Normal and Apraxic Speakers

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INTRODUCTION

Apraxia of speech has been a topic of much controversy. Arguments have focused on whether the underlying pathogenesis of the disordered behaviors described as apraxic is linguistic or motoric. Although debate continues, the extant, though limited, data suggest that apraxia of speech is a disorder of speech motor control (e.g., McNeil, Weismer, Adams, & Mulligan, 1990). A second controversy surrounding apraxia of speech that has been the focus of recent literature (e.g., Luschei, 1991; Weismer & Liss, 1991) concerns whether apraxia of speech also affects nonspeech movement control. Robin (1992) has argued that apraxia of speech is a disorder of motor control that manifests itself in both speech and nonspeech movements of the articulators.

Although it was once thought that apraxic speakers had abnormal control of peak velocity during speech (e.g., Kent & Rosenbek, 1983), it is abundantly clear that no relation exists between apraxic speakers and the control of peak velocity (McNeil et al., 1990; Robin, Bean, & Folkins, 1989). Robin et al. (1989) hypothesized that apraxia of speech might best be understood as a problem of coordination within and between articulators. Along these lines, McNeil and colleagues (1990) reported that apraxic speakers had greater instability (poorer control) of the articulators during nonspeech fine force and position control tasks than did normal or aphasic speakers.

McClean, Beukelman, and Yorkston (1978) used a visuomotor tracking task to measure the coordination of movement for individual articulators. Tracking tasks have a number of important advantages over fine force or position control tasks, the most important of which is that they are dynamic rather than static. Thus, the control and coordination of articulator movement can be assessed. Also, subjects may be required to track predictable and nonpredictable signals. Finally, one can require subjects to track predictable signals at different speeds or frequencies.

Normal subjects tracking predictable targets use a different strategy than do those tracking nonpredictable targets. Tracking a predictable target successfully requires a model of the target motion. That is, subjects track the target based on an internal representation of target motion and attend to the external target only intermittently to ensure that the model is accurate. Support for this mode of tracking comes from the fact that in both speech and nonspeech systems (Flowers, 1978; Moon, Zebrowski, Robin, & Folkins, 1992), subjects typically phase-lead a predictable target, whereas if they were *following* the external signal, they would phase-lag the target. The use of an internal model or predictive mode allows for smooth movement transitions. By contrast, tracking a nonpredictable signal requires subjects to attend to the target constantly and *not* to rely on an internal model. Thus, subjects must adjust their movement patterns online. As a result, subjects show significant phase lag during nonpredictable tracking tasks, and their movements are more jerky as they continually adjust to error. The result is that overall tracking of nonpredictable targets is poorer than that found for predictable tracking as measured by cross-correlation. (It is also the case that tracking performance decreases as the frequency of the predictable signal increases, but this may be because more rapid predictable targets require more frequent checks, and thus performance decreases [Noble, Fitts, & Warren, 1955]).

In the course of a large study aimed at understanding speech motor control and its impairments, we extended the visuomotor tracking paradigm of McClean et al. (1978) to include predictable targets of different frequencies and a nonpredictable target condition. The present study reports data from apraxic and non-brain-damaged (NBD) speakers on phase relationship and cross-correlation of tracking. It was expected that apraxic speakers would have lower correlations than would normal speakers in all conditions. It also was hypothesized that apraxic speakers would phase-lag predictable targets, whereas NBD speakers would evidence phase synchrony or lead. Finally, it was anticipated that all subjects would show phase lag during nonpredictable tracking.

If apraxic subjects performed poorly on both predictable and nonpredictable tracking, then one could argue that motor control, regardless of tracking mode (internal or external), was impaired. If apraxic speakers performed better on predictable tracking than they did on nonpredictable tracking, it could be hypothesized that they were able to develop an internal model or plan but had difficulty executing the movements in a coordinated manner. If, however, apraxic speakers performed better on nonpredictive tracking than predictable tracking, then one could hypothesize that these subjects did not generate an internal plan to predict movement outcomes but were able to follow an external target that required no such predictive strategy. Thus, the motor control problem would be at the planning or predictive stage of movement execution, and the movements for predictable targets would be jerky rather than smooth.

METHOD

Subjects

Five apraxic and 23 NBD speakers participated. All NBD speakers reported normal speech, language, and hearing and had no known evidence of neurologic or uncorrected vision disorders. The apraxic subjects ranged in age from 20.9 to 79.5 years with a mean of 52.5 years. The NBD subjects ranged in age from 17.2 years to 44.3 years with a mean of 28.2 years. Four of the apraxic subjects have been described in detail by Robin et al. (1991). The remaining subjects fit the same selection criteria as that study (Kent & Rosenbek, 1983). Of these apraxic subjects, four were relatively "pure" in that they had no concomitant language problems, save one who had anomia.

Procedures

The specific procedures used in this investigation have been described in detail by Moon, Zebrowski, Robin, and Folkins (1992). A summary follows.

Visual Feedback and Instructions. A horizontal bar (1.5 in. wide) was displayed on an oscilloscope screen as a target for tracking. The bar moved vertically up to 5 cm. Transduced articulator signals from either the lower lip, jaw, or fundamental frequency (F_o) of sustained phonation were displayed as a dot centered horizontally on the bar. Subjects were instructed to keep the dot on the target bar throughout the extent of the bar's vertical movement.

Lower lip and jaw movements were transduced using a standard strain-gauge cantilever system (Barlow, Cole, & Abbs, 1983; Muller & Abbs, 1979). Subjects were seated in a dental chair and their heads were immobilized using a wall-mounted cephalostat. The strain-gauge cantilevers were fixed to the lower lip and the underside of the jaw at the midline with pieces of double-sided tape. A bite block was used to stabilize the jaw during lower lip tracking.

Control of the laryngeal system was assessed by having subjects modulate the fundamental frequency (F_o) of sustained phonation. Each subject

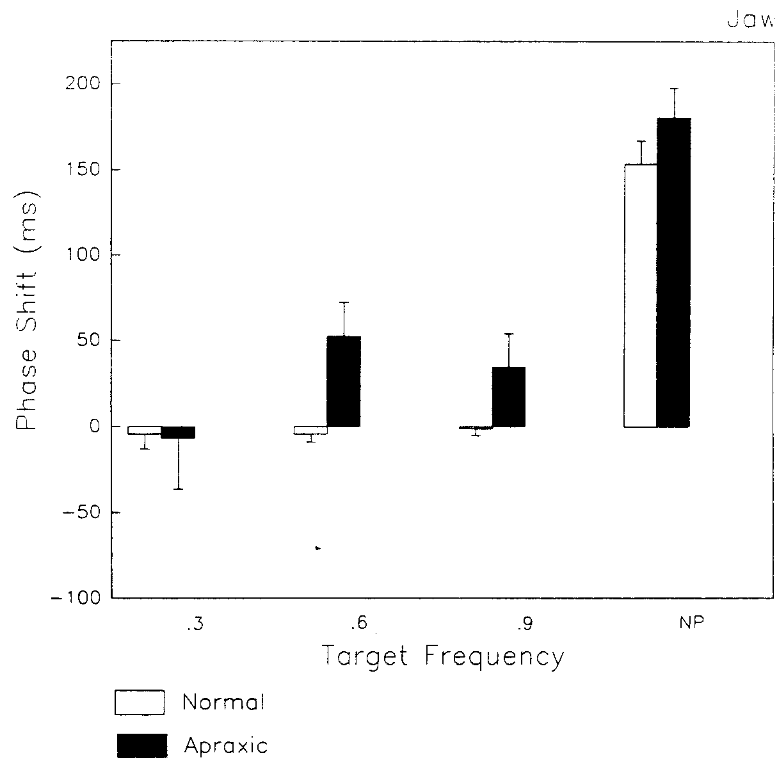

Figure 1. Phase shift in milliseconds for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the jaw.

voiced a prolonged /a/, and the voice signal was transduced with a microphone, amplified, and input to a custom-built online F_0 extraction module. This module produced an output voltage varying as a function of the F_0 that was fed back to the subject.

Tasks. The range of target excursion for the lower lip and jaw was 10 mm. The strain-gauge offsets were adjusted for each subject so that the 10-mm target excursion occurred in the middle of the individual's maximum movement range. The range of target excursion for F_0 tracking was 40 Hz. The output of the fundamental frequency extractor was offset so that the lower limit of the 40 Hz excursion was at a comfortable pitch set by the subject.

Four tracking conditions were employed for each articulator. These included sinusoids of 0.3, 0.6, and 0.9 Hz, which made up the predictable target, and a nonpredictable signal composed of ten equal amplitude frequencies ranging from 0.1 to 1.0 Hz in 0.1 Hz steps. Presentation order was counterbalanced.

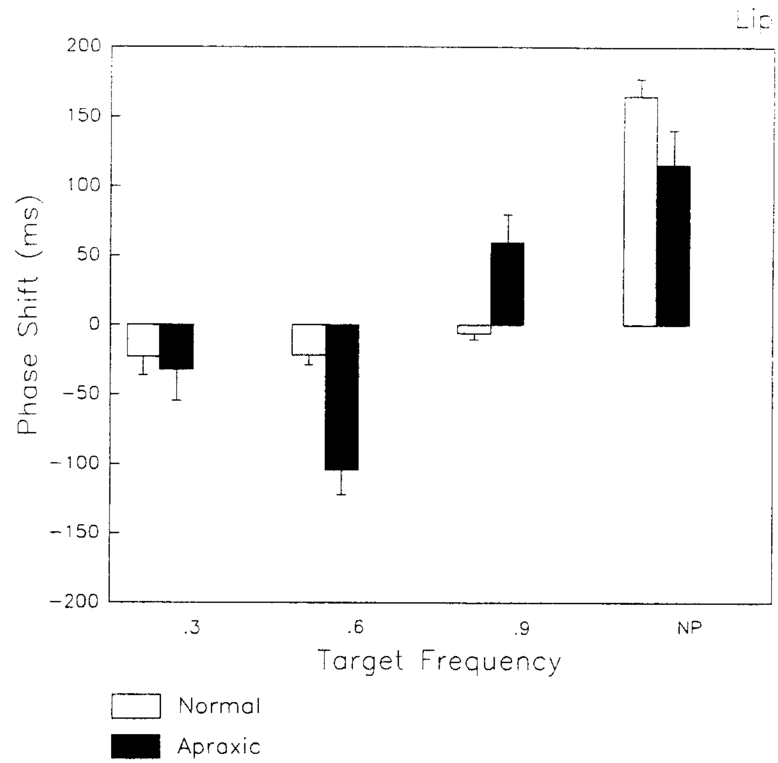

Figure 2. Phase shift in milliseconds for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the lip.

Data analysis. Target and tracking signals were recorded using a Sony (PC-108) digital recorder and were subsequently digitized at 50 Hz for analysis. Within each condition, six 10-sec tracking blocks were extracted from the digitized signals for analysis. For the purposes of this preliminary report, only the best cross-correlation and phase shift were examined.

RESULTS

The first question addressed phase relationships between the target and tracking behavior. Figures 1, 2, and 3 show phase relationships for the apraxic and NBD groups for each tracking condition. Results are shown for each tracking frequency (0.3, 0.6, 0.9) and the nonpredictable condition. Negative phase values indicate phase lead and positive values indicate phase lag.

For the jaw (Figure 1), NBD speakers showed essentially no phase difference for the predictable targets (sinusoids). The apraxic trackers showed phase lag at 0.6 and 0.9 Hz. That means that for the faster sinu-

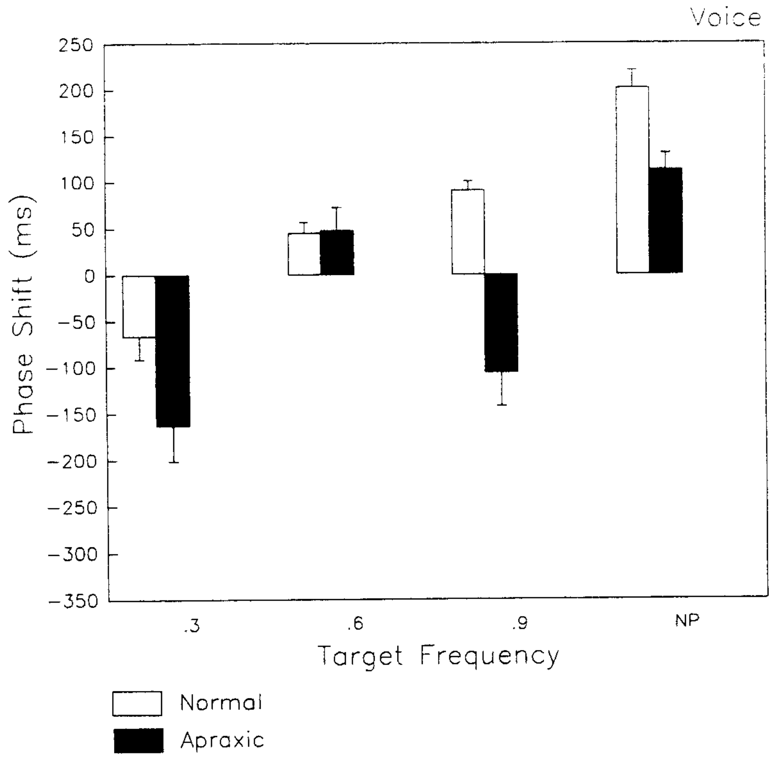

Figure 3. Phase shift in milliseconds for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the voice.

soids, apraxic trackers were not anticipating the target motion. For the unpredictable signal, significant phase lag characterized both groups.

For the lip (Figure 2), the NBD trackers again demonstrated essentially no phase difference in all conditions. The apraxic trackers showed significant phase lead at 0.6 Hz and no difference at 0.3 Hz and 0.9 Hz. Both groups showed large phase lag for the unpredictable signal.

For voice tracking (Figure 3), significant phase advance at .3 Hz was present for both groups with no phase difference at 0.6 Hz and 0.9 Hz. Both groups showed phase lag for the nonpredictable signal, but apraxic trackers showed the most. Apraxic trackers found the voice-tracking task extremely difficult. No apraxic tracker completed all voice-tracking trials, whereas all normal speakers completed them.

In general, apraxic trackers did not always present the longest lag times. However, apraxic trackers were more often behind the target (phase lag) than were the NBD speakers. It is important to note that when only those phase relationships characterized by reasonable cross-correlations were examined, the apraxic trackers did not differ from the NBD trackers.

Tracking performance accuracy is displayed as cross-correlations between the target and the tracker's performance. When cross-correlations are

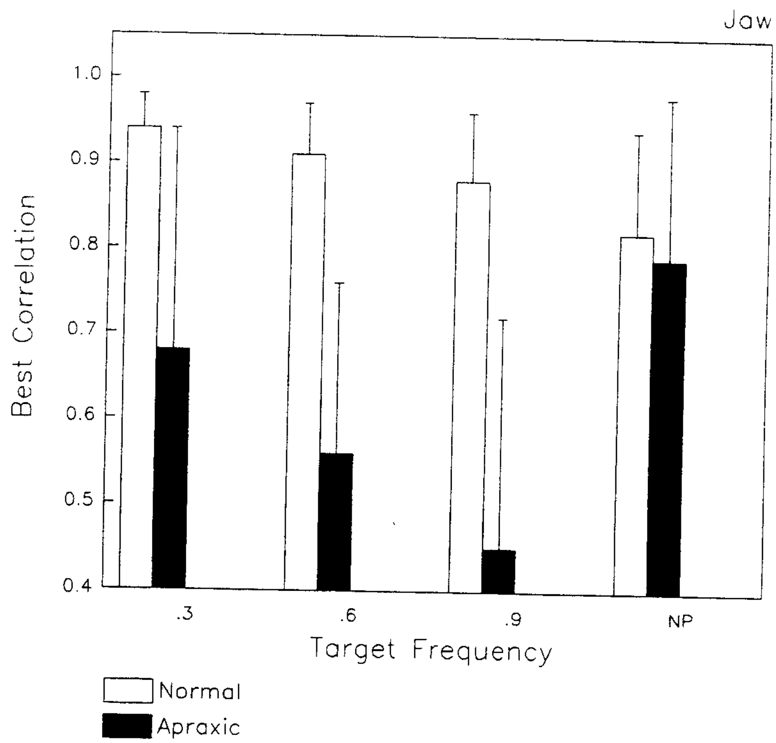

Figure 4. Best cross-correlation for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the jaw.

low, however, phase relationships are difficult to interpret. Figure 4 shows best cross-correlation for both groups for jaw tracking. For both groups, jaw-tracking accuracy decreased across the predictable target signals, with the poorest performance at the fastest target speed, 0.9 Hz. Apraxic trackers' performances were poorer, and much more variable than NBD trackers'. However, apraxic trackers' performed best on the nonpredictable task whereas NBD trackers performed poorest on that task.

Lip tracking is shown in Figure 5. Again, tracking performance decreased across predictable target signals, with the poorest performance for both groups on the fastest signal. Apraxic trackers performed more poorly than NBD trackers. Again, apraxic trackers showed their best performance with the unpredictable signal, whereas NBD trackers showed their poorest performance on that trial.

For voice tracking, shown in Figure 6, a similar pattern of performance was obtained. Predictable tracking by both groups was poorest at the highest target speeds, with the apraxic trackers performing more poorly than NBD trackers for all speeds. However, for the nonpredictable signal the apraxic trackers showed their best performance and NBD trackers their poorest.

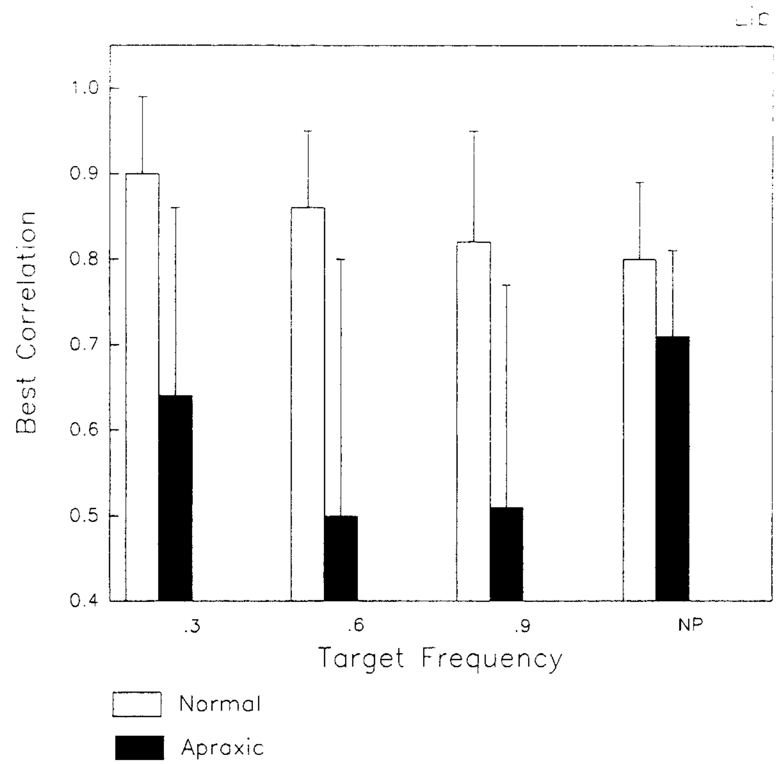

Figure 5. Best cross-correlation for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the lip.

DISCUSSION

For the predictable tracking tasks, the apraxic trackers always performed more poorly than the NBD subjects. For the nonpredictable task, however, apraxic trackers demonstrated their best performance, which was nearly as good as the normal trackers'. In other words, the unpredictable tracking task brought out the best in the apraxic trackers. In addition to these quantitative differences, there also were qualitative differences between subject groups. Figure 7 contrasts the smooth versus jerky tracking performances of two subjects. The apraxic tracker's performance is shown in the lower graph, and a brain-damaged nonapraxic tracker's performance is shown in the upper one. The target is the smooth sine wave; the subject's performance is the waveform with noise components. The apraxic tracker's path was jerky, showing constant adjustment to error, whereas the nonapraxic tracker's path was smoother, showing an infrequent need to adjust the tracking path.

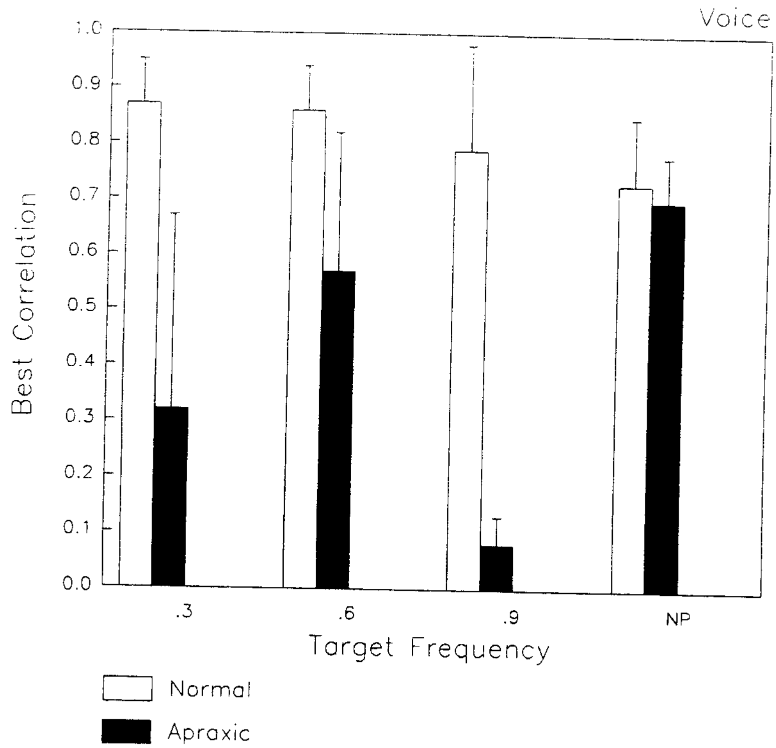

Figure 6. Best cross-correlation for 0.3, 0.6, 0.9 Hz, and the nonpredictable signal for the voice.

It is apparent from these data that there are no easy answers to help us understand the mechanisms underlying apraxia of speech. However, several points need to be made. First, these data support the notion that movement control for nonspeech tasks is impaired in apraxia of speech. Further, these impairments are discernible when only one articulatory system is being controlled (e.g., the lip). Second, as hypothesized by Robin et al. (1989), intraarticulator coordination was impaired, particularly for predictable signals. Third, we had hypothesized several possible outcomes of tracking performance, one of them being that a performance by apraxic trackers on the nonpredictable target superior to their performance on the predictable ones, would suggest that the apraxic speakers did not develop an accurate internal model of target motion. We also hypothesized that tracking performance for the predictable target would be jerky rather than smooth. Apraxic trackers performed exactly in these ways.

Because the apraxic trackers were poor predictors of the target movement, we propose that the apraxic speakers may have problems developing an internal model or plan of intended movement patterns. Several hypotheses concerning the nature of this planning problem are possible. First, apraxic trackers may be unable to develop a plan. However, this

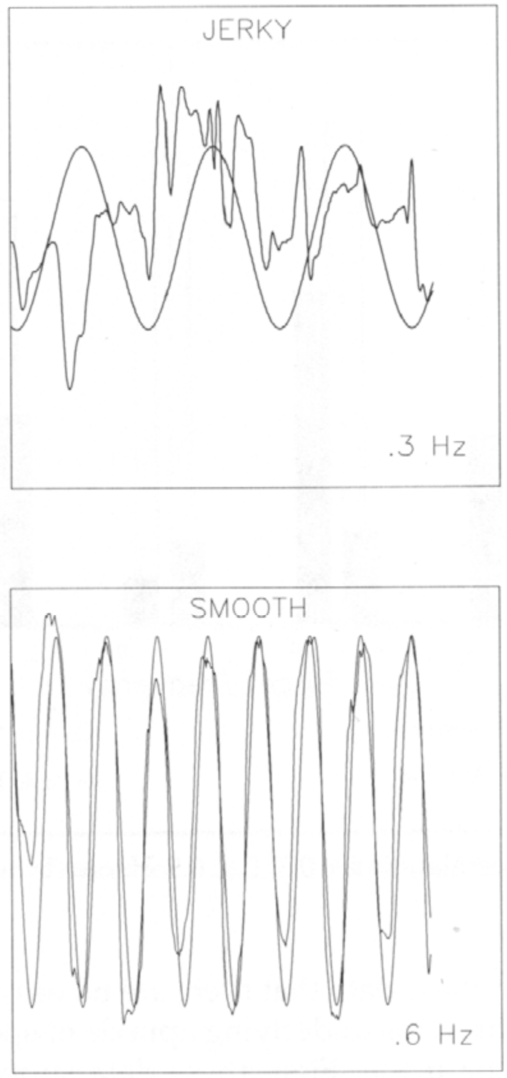

Figure 7. Tracking performance of two subjects (one apraxic speaker, AS, top, and one brain-damaged nonapraxic speaker, NAS, bottom) illustrating smooth and jerky tracking performance.

explanation may be obviated by the finding that their phase relationship to the target was not consistently behind the target. Again, we note the difficulty in interpreting phase relationships when the cross-correlation values are low. A second hypothesis would be that apraxic speakers develop a model of movement, but the model is inaccurate or poorly defined. Another potential explanation is that the apraxic speakers develop a plan, but the model occurs online and does not allow for prediction of the upcoming movements. Finally, it could be hypothesized that the movement model is in place, but the apraxic tracker has difficulty accessing the plan during online tasks. The results of this study do not allow us to address any of these possibilities, adequately. However, because the apraxic speakers performed as well as the normal speakers when tracking unpredictable targets, we suggest that apraxia of speech results from a breakdown at some level of the planning stage of movement rather than a breakdown in motor execution. Further studies will address each of these hypotheses to advance our understanding of oral motor tracking in apraxic and normal speakers.

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