## Introduction

Apraxia of speech (AOS) is a motor speech disorder characterized by slow, effortful speech, distortions, syllable segmentation, and dysprosody (McNeil et al., 1997). Despite general consensus that AOS constitutes a motor programming impairment, the precise nature of this impairment remains underspecified. The present study investigates motor programming in AOS within the context of a recent motor programming model, to further specify the impairment in AOS.

The model assumes that control of serial movements (e.g., speech) involves sequencing of motor units (Klapp, 1995, 2003). Motor programming consists of two subprocesses, INT and SEQ. INT organizes the internal structure of a unit (e.g., timing of muscle contractions) by integrating various movement components into a coherent structure, and loads the unit into a motor buffer until time of initiation. The model assumes that increased unit-complexity results in longer INT-processing, and that INT can be preprogrammed (completed before initiation). SEQ is responsible for organizing the serial order of units, by retrieving units from the buffer in the correct sequence upon initiation. Thus, SEQ cannot be preprogrammed. It is further assumed that SEQ takes longer when more units are in the buffer.

Evidence for the model comes from reaction time studies using finger movements (Klapp, 1995; Wright et al., 2004). For example, using button presses as responses, duration (complexity) of a single press was found to affect INT, not SEQ, whereas number of button presses in a response (1 vs. 4) affected SEQ (and INT). The model has also been extended to speech, where increases in SEQ-processing have been found with additional, identical syllables (dada vs. dadada) but not with different syllables (dada vs. daba), which load on INT rather than SEQ (Deger & Ziegler, 2002; Klapp, 2003). Thus, it appears that repeating syllables, unlike different syllables, are not integrated into a single unit.

Our primary hypothesis is that AOS reflects an impairment of INT, not SEQ, based on hallmarks of AOS such as distortions (difficulty specifying unit-internal structure), segmentation (difficulty integrating syllable sequences), and dysprosody (difficulty specifying relative timing). Absence of serial order errors suggests intact SEQ. This hypothesis is consistent with recent proposals that left inferior frontal cortex is the site of integration of information (unification; Hagoort, 2005) combined with evidence that AOS is associated with lesions in this area (Hillis et al., 2004). In addition, preliminary evidence exists for an INT-deficit in both speech (Deger & Ziegler, 2002) and nonspeech movements (Maas et al., 2005).

## Methods

*Participants*

Data collection is ongoing (including brain-damaged controls); currently, data are available for four individuals with AOS and 10 neurologically intact speakers.

*Procedures*

Four responses involving the syllable /ba/ were used. Responses were either single syllables or sequences of four. To isolate motor programming, phonological content was kept constant; instead, syllable (vowel) duration was varied (S=short, 150ms; L=long, 450ms). Sequences involved two different temporal structures (SLLS, LSSL).

We used the self-select paradigm (Fig.1). Briefly, participants prepared the response based on a visual cue and indicated readiness to respond by pressing the space bar. This interval (Study Time (ST)) captures INT. Then, following a variable delay, a go-signal prompted participants to produce the prepared response as quickly and accurately as possible but within

1000ms. Time between go-signal and speech onset (Reaction Time (RT)) indexes SEQ. After each response, an auditory response model was presented.

Presentation of responses was random and involved 12 blocks. Incorrect responses (premature, late, or phoneme substitutions) were rerun to ensure four correct responses of each type per block. One retention-block (without feedback) was administered 2 days later.

*Predictions*

Relative to controls, the hypothesis of an INT-deficit in AOS predicts
1) longer ST, indicating longer INT-processing
2) equal RT, indicating intact SEQ-processing

**Results**

*Accuracy*

Patients made more errors than controls, especially for sequences (Fig.2). Detailed analyses of timing accuracy will be available at the time of the conference.

*INT: Study Time*

STs greater than 10 seconds were excluded from analysis as invalid data points. Critical to predictions for AOS, ANOVA on log-transformed ST-medians revealed that ST was longer for patients than for controls (Fig.3). Both groups showed a sequence length effect on ST, but no effect of duration. All patients conformed to the group pattern.

*SEQ: Reaction Time*

ANOVAs on log-transformed RT-means revealed no syllable duration effect in either group (Fig.4, top), as expected. Consistent with our hypothesis, there was no group main effect (Fig.4). However, there was a group-by-block interaction: controls but not patients became faster across blocks (though this was not maintained at retention). Finally, no sequence length effect was found (Fig.4, bottom). All patients conformed to the group pattern.

**Discussion**

These results are consistent with the hypothesis of an INT-deficit in AOS, based on longer STs for the patients and equal overall RT (SEQ). As such, these speech data are consistent with those reported for these same patients on a fingertap task (Maas et al., 2005). However, no syllable duration effect was observed on ST in either group, which may mean that specification of absolute timing in speech is not particularly demanding for INT. While the absence of a syllable duration effect complicates interpretation of the ST group difference, the fact that these same patients also showed longer ST for finger movements does suggest a central INT-programming problem and therefore overlapping neuromotor systems for programming of various tasks.

As noted above, no RT-differences were found between groups demonstrating intact SEQ processing for these patients. As well, this finding suggests that longer STs are not due to general slowing, but rather specific to preprogramming (INT) while sparing buffer retrieval operations (SEQ). However, the Group-Block interaction on RT does suggest that SEQ may not be entirely intact either: controls but not patients sped up SEQ-performance during practice.

No sequence length effect was found on RT for controls, contrary to previous studies that found sequence length effects for repeated syllables (Deger & Ziegler, 2002; Klapp, 2003). However, prosodic structure was not specified in those studies. The present study used repeating

syllables with a specified prosodic structure, which apparently facilitated unification of speech sequences (though not for finger movements; Klapp, 1995; Maas et al., 2005; Wright et al., 2004). While one might have expected patients to show a sequence length effect on RT if they failed to integrate the sequence into a single unit, the absence of such an effect may suggest that, like controls, these (relatively mildly impaired) patients did manage to successfully integrate the sequence into a single unit (despite requiring longer INT-processing to accomplish this). Alternatively, the absence of a sequence length effect is also consistent with a buffer capacity limitation to one syllable (Rogers & Storkel, 1999). Failure to integrate the sequence should be evident as a higher pause-to-syllable duration ratio; acoustic analyses addressing these alternatives will be available at the conference.

In conclusion, the preprogramming stage of processing (INT) appears to be particularly impaired in AOS, relative to buffer retrieval and sequencing operations (SEQ). Acoustic analyses will address whether these patients integrated repeating-syllable sequences, or rather produced these sequences syllable-by-syllable. Clinically, this study has potential relevance for diagnostics, in that the present paradigm appears sensitive to different processing stages, and for treatment, in that practice aimed at facilitating unit integration may be expected to be beneficial.

**References**


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**Table 1.** Participant information.

| | Sex | Age | Native Language | Hand | Profession | Etiology | Time post onset | Aphasia | AOS | Oral/Limb apraxia | Dysarthria |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOS1 | M | 69 | English-Spanish | L | College professor | Single LH CVA mca region | 41 months | Mild nonfluent aphasia | Mild-moderate | None/None | Mild unilateral weakness |
| AOS2 | F | 68 | English | R | Manager data processing | Single LH CVA | 43 months | Very mild anomia | Mild-moderate | None/None | None |
| AOS3 | M | 59 | English | R | College professor | Single LH CVA | 35 months | Very mild anomia | Mild | None/None | Mild unilateral weakness |
| AOS4 | M | 27 | English | R | College student | Single LH CVA | 80 months | Mild-moderate nonfluent aphasia | Very mild | None/None | None |
| | | | | | | | | | | | |
| CON (n=10) | 9F 1M | $\bar{X}$ = 24 (range 20-35) | 10 English | 8R 1L 1ambi | College students | | | | | | |

**Figure 1.** Sequence of trial events in the self-selection paradigm.

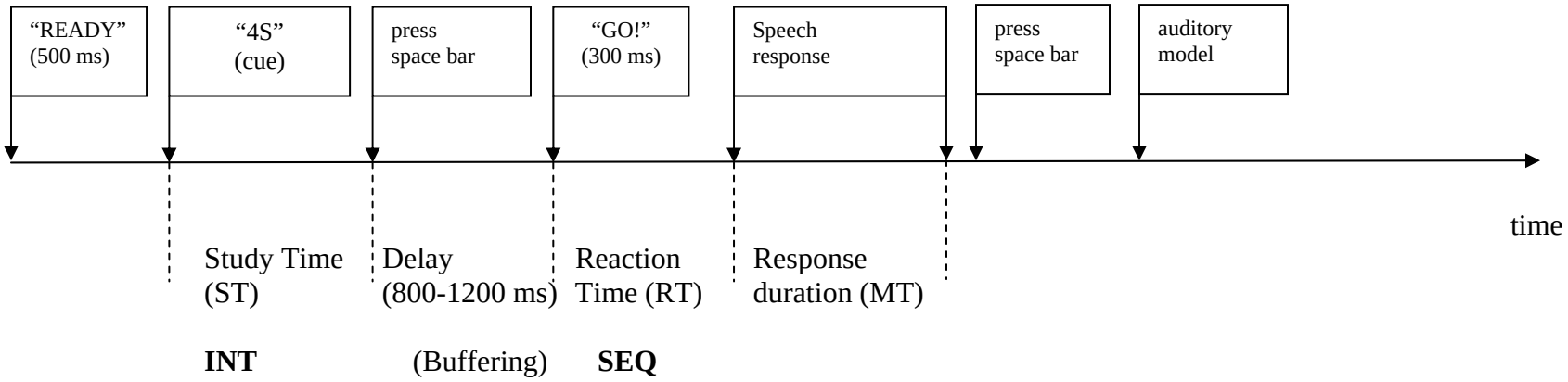

**Figure 2.** Percent correct by response for AOS (n=4) and CON (n=10). Error bars represent standard error.

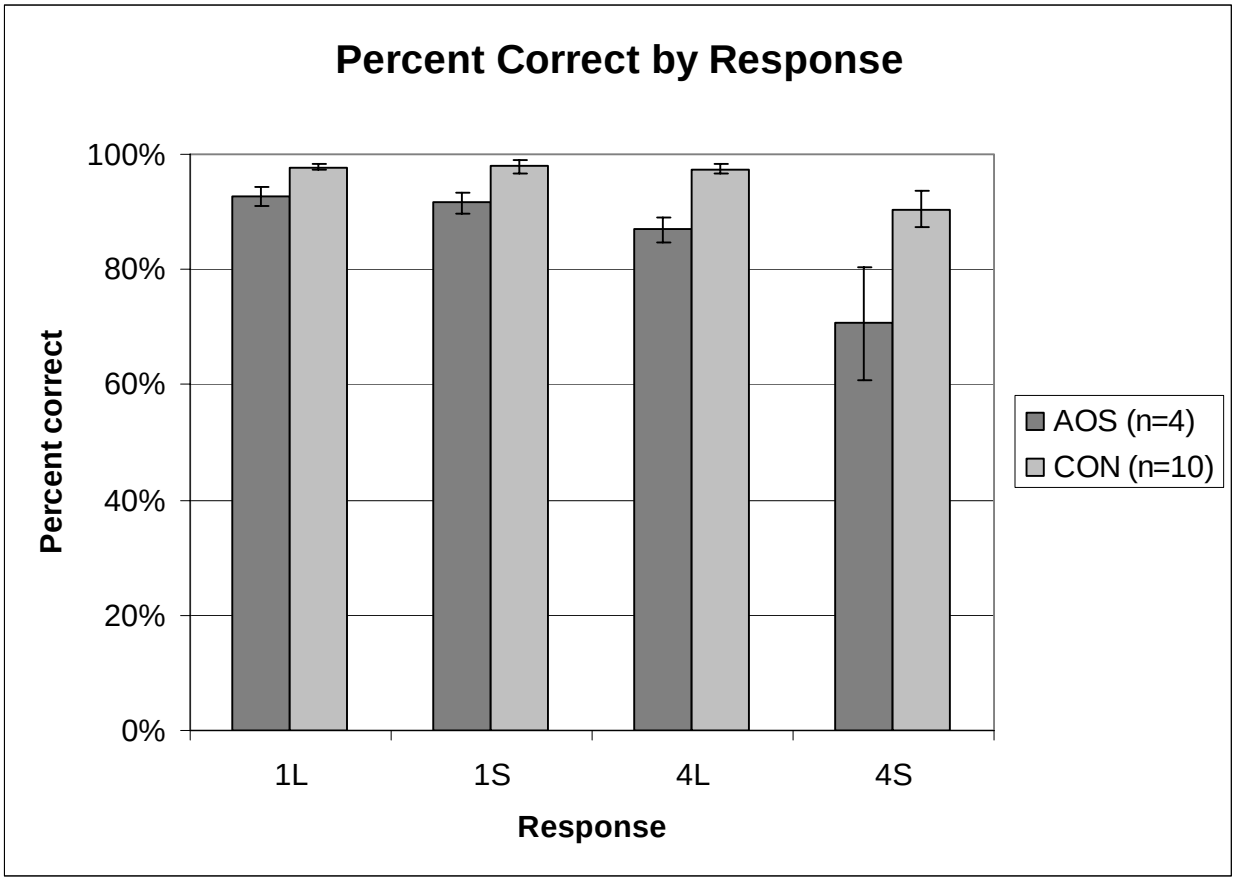

**Figure 3.** Study Time (ST) for single short versus single long responses (top) and for single vs. sequences (bottom) for AOS (n=4) and CON (n=10). Error bars represent standard error.

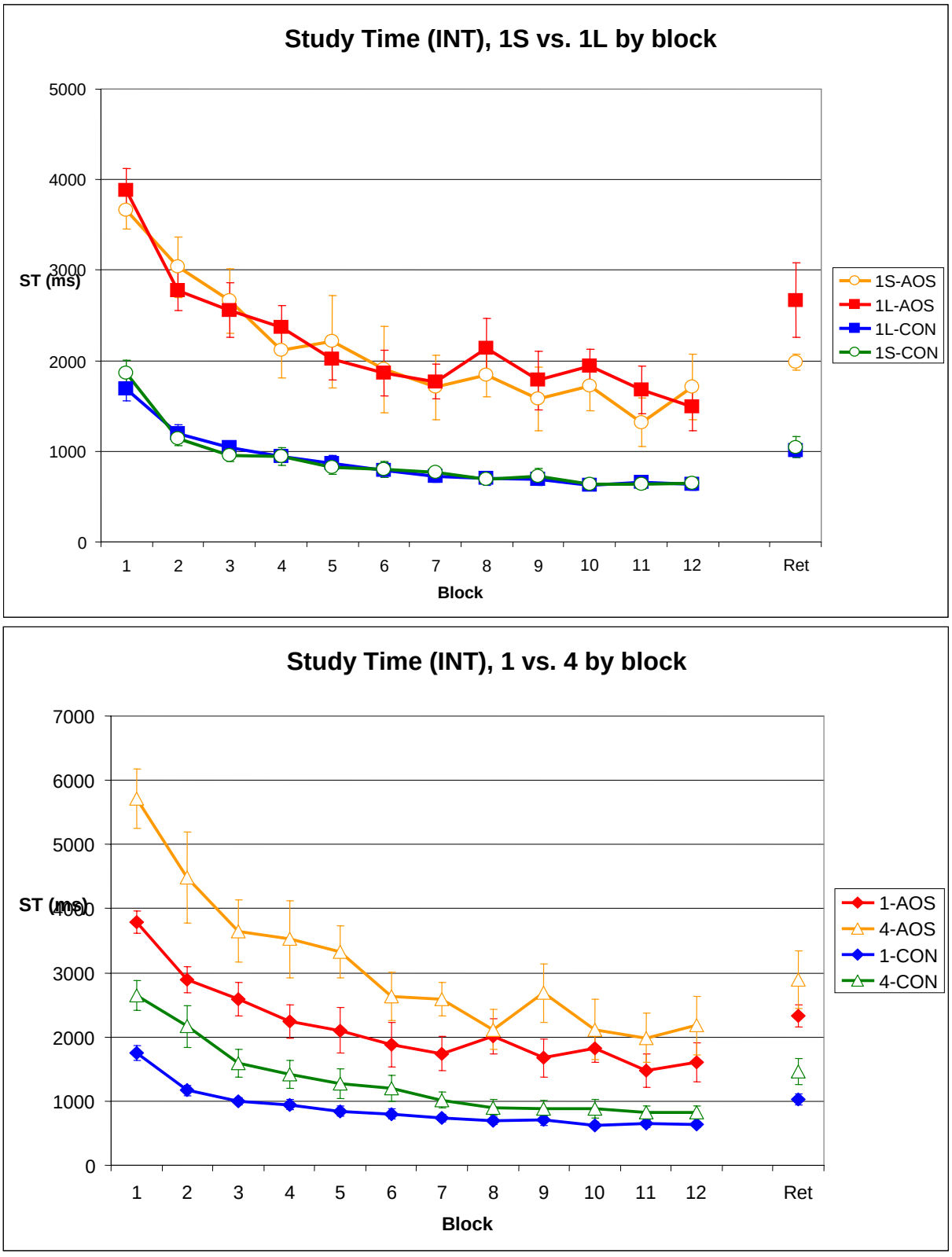

**Figure 4.** Reaction Time (RT) for single long vs. single short syllables (top) and for single vs. sequences (bottom) for AOS (n=4) and CON (n=10). Error bars represent standard error.