Introduction

A hallmark of Apraxia of Speech (AOS) is speech segmentation, evident in increased segment and inter-segment durations, reduced coarticulation, dysprosody, and slow speech (1-3). Although AOS has been described as a motor programming disorder, the precise nature of the deficit remains unclear, in part because the nature of motor programming itself is underspecified theoretically (2) and difficult to investigate empirically. Clinically, understanding the nature of the deficit in AOS is important for accurate differential diagnosis and ultimately for optimizing treatment.

The present study examined motor programming in AOS, by applying a modified reaction time (RT) paradigm using a recent two-process model of motor programming that focuses specifically on sequential movements (4,5). Since speech is a sequential motor skill, extension of the model to speech (disorders) has been fruitful (5-7). The current study involved non-speech (finger) movements only, to test a strong version of the hypothesis that AOS involves a central programming deficit. This hypothesis seems plausible given mounting evidence of impaired non-speech motor control in AOS (3), which suggests that more general models of motor control hold promise for understanding and managing this disorder. Moreover, motor programming involves selection of the structures to be used for executing a given movement pattern (8). Thus, it is reasonable to assume that the deficit in AOS extends beyond speech and into other structures.

The two-process model proposed by Klapp assumes that preparation of a sequential movement involves the organization of a series of motor programs. The model distinguishes two separate programming processes (4,5). The first process, INT, organizes the internal structure of each unit contained in the sequential action and it is assumed that this process can be preprogrammed (prepared prior to initiation). Complexity of a unit affects INT processing load and thus the time to complete this process. The second process, SEQ, organizes units into their correct serial order. SEQ cannot be preprogrammed, and is sensitive to the number of units in a given sequence. With practice, a sequence of units becomes integrated to form a single unit (4,9). Although the precise nature of INT and SEQ remains to be specified, evidence for the independence of INT and SEQ has been found using RT paradigms for finger movements and for speech (4,5,9).

For example, Wright et al. (2004) used a self-selection paradigm (Figure 1, Table 2) in which participants prepared the response (button presses), self-terminated this preparation period (called study time, ST), then initiated the response as quickly as possible after a go-signal (called reaction time, RT). ST is assumed to reflect process INT, whereas RT reflects SEQ. It was found that the duration of a single press affected ST and not RT, suggesting that the complexity of a single unit affects INT, not SEQ. Conversely, the number of button presses in a response (1 vs. 4) affected RT, suggesting that number of units affects the SEQ process. With very extensive (random) practice (~1500 trials), this RT difference disappeared, suggesting the formation of a single, integrated unit.

We hypothesize that AOS reflects an impairment of INT, not SEQ, based on hallmarks of AOS such as distortions (difficulty organizing the internal structure of units), segmentation and dysprosody (difficulty integrating units), and the absence of serial order errors (no difficulty with sequencing). To test this hypothesis, we examined INT and SEQ processing using the self-selection RT paradigm for individuals with AOS. To assess whether AOS involved a central degradation in INT we used finger movements rather than speech. Results from subsequent studies focusing on speech should be available at the time of the conference. Thus, the research question addressed here is: Is there evidence for a domain-general INT-deficit in AOS?

Methods

Participants

Three individuals with AOS and 10 young controls have been tested and analyzed (Table 1). Data collection is ongoing, and will include aphasic participants and age-matched controls.

Task and procedures

Using the self-selection paradigm, four different key-press responses were tested (Table 2). The sequence of events on each trial is indicated in Figure 1. The experiment took place over two days (practice, retention). Presentation of the sequences was random and involved 12 blocks each including four correct productions of each sequence; feedback was provided (error messages on screen, auditory model of correct response) after each trial. Retention testing involved 1 block, without feedback.

Analysis and predictions

ST, RT, and error rate will be analyzed with separate 3 (Group: AOS, age-matched controls, young controls) x 2 (Response: L vs. S or 1 vs. 4) x 12 (block) repeated measures ANOVAs. Retention data will be analyzed with separate 3 (Group) x 2 (Response) ANOVAs.

The hypothesis that AOS reflects a deficit in INT but not in SEQ predicts
1) longer ST for the AOS-group compared to other groups due to programming deficit.
2) a larger ST-difference between 1L and 1S responses for the AOS-group than other groups (disproportionate effect of complexity)
3) a larger ST-difference between 1-press and 4-press responses for the AOS group than other groups (disproportionate effect of complexity)
4) no group differences for RT (same overall RT, same RT-difference between 1-press vs. 4-presses), due to intact SEQ.

Results

Due to limited number of participants, no statistical tests were performed, and thus the results are preliminary. Error rate was higher for AOS than controls (Figure 2). Consistent with prediction 1, overall ST appeared longer for the AOS-group than for controls (Figure 3). Note that there appeared to be no group-differences for RT (Figure 4), suggesting a localized slowing rather than overall reduced processing speed. Regarding predictions 2 and 3, we used normalized values (ratios, 1S/1L and 4/1) to assess the relative cost of INT processing. For single presses there did not appear to be any differences in INT processing cost (Figure 5); however, for the relative cost of single-press vs. multiple-press sequences, the AOS-group appeared to show lower values (Figure 6), suggesting that the INT-cost was more similar for these patients than for the controls. Moreover, whereas the controls tend to show a reduction in this INT-cost difference across blocks, no such change is apparent for the AOS-group (Figure 6A). Finally, with respect to prediction 4, there was no group difference in overall RT (Figure 4), nor was there any change in cost for either group.

Discussion

This study addressed the hypothesis that AOS involves a deficit in the INT process of motor programming, including the assignment of temporal structure. A strong version of this hypothesis predicts that INT is also impaired for non-speech movements. Preliminary results from 3 individuals with mild AOS provide support for this hypothesis, evident in greater overall ST, indicating increased processing load on INT, as well as in greater ST-differences between 1-press and 4-press responses, though not for single responses of different duration. Since the sequences place higher demands on absolute and relative timing, these findings may indicate difficulty in assigning temporal structure during preprogramming. Although recent findings using the same paradigm suggest that aging affects SEQ rather than INT (10), we will present data at the conference from age-matched controls to rule out age-related effects. Finally, there were no group differences in RT or in relative cost of 1 vs. 4 responses, which is consistent with the hypothesis that SEQ processing is unimpaired in AOS.

References

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Figure 1. Sequence of events for a trial in the self-selection paradigm (9). The word "READY" is presented for 500 ms in the center of the screen, immediately followed by a symbol indicating the required response (1S, 1L, 4S, or 4L). Participants prepare the required response and press the space bar when ready to respond. After a variable delay, the go-signal is presented for 300 ms. Participants execute the response by pressing the F-key on the computer keyboard with their left index finger as soon as possible after the go-signal, but within 1000 ms (longer RTs elicit an error message). Depression of the F-key produces a tone to indicate the duration of the key press.

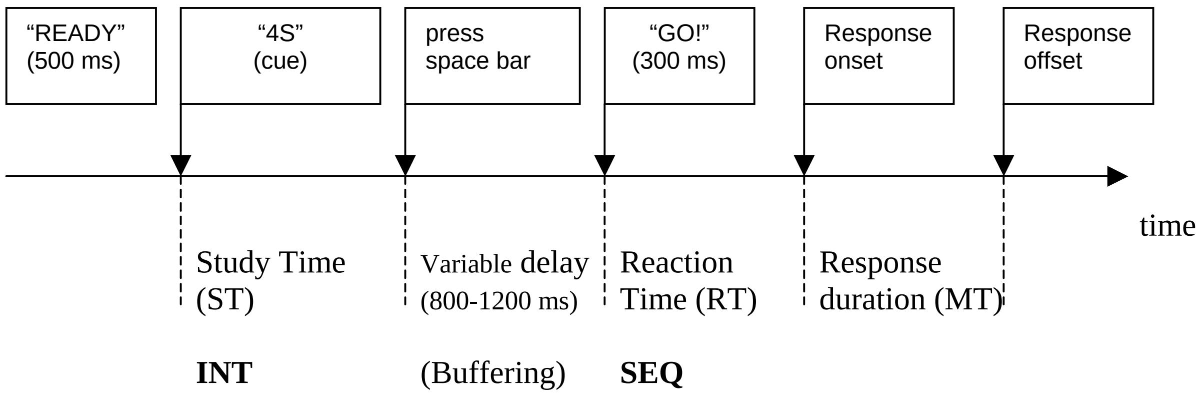


Figure 2. Percentage correct, collapsed across blocks. Error bars indicate standard errors.

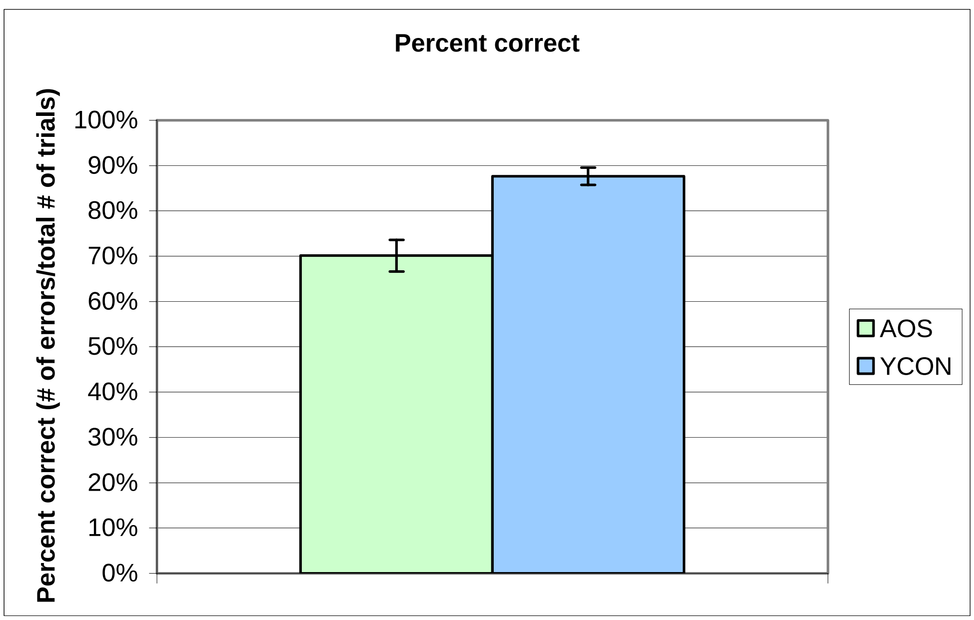
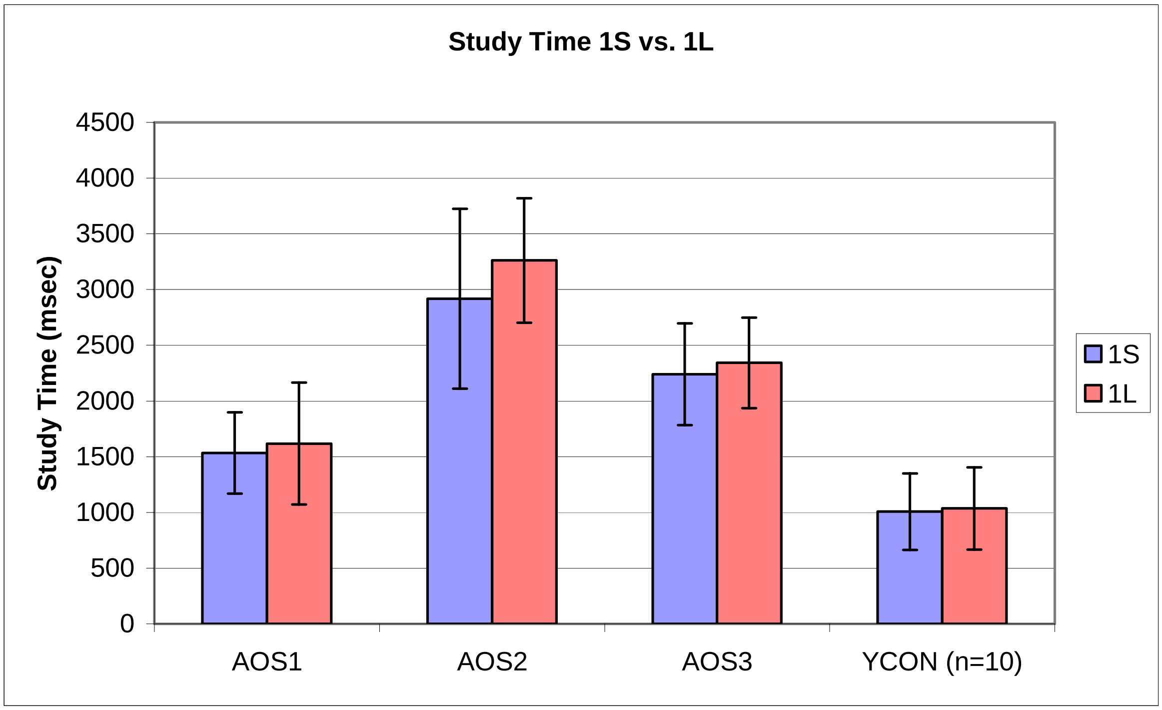


Figure 3. Study Time for 1S and 1L responses (A) and for 1-press vs. 4-press responses (B). Error bars represent 1 standard deviation.



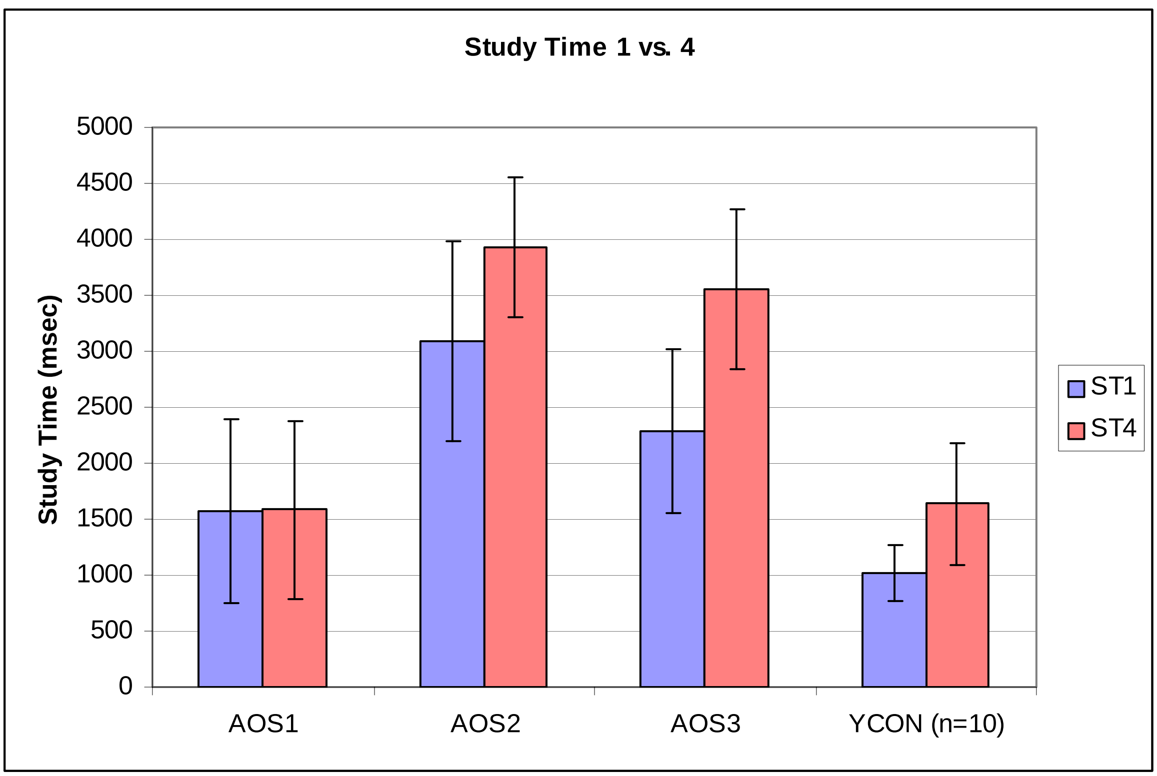


Figure 4. Reaction Time for 1S and 1L responses (A) and for 1-press and 4-press responses (B). Error bars represent 1 standard deviation.

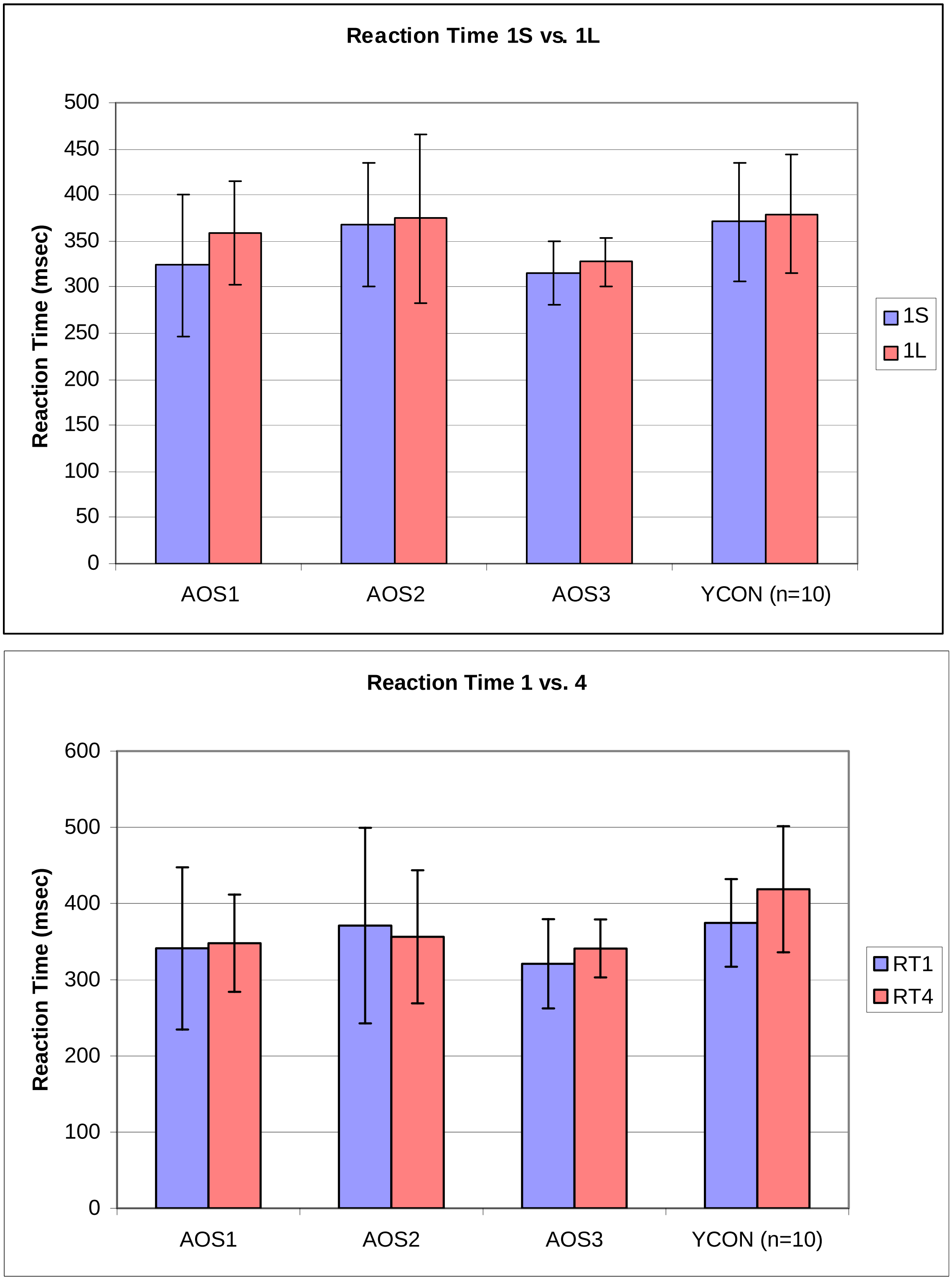


Figure 5. Relative cost of INT processing (ratio of ST-1S over ST-1L) across blocks (A) and collapsed across blocks for each patient separately (B). Error bars represent 1 standard deviation. Red line indicates equal processing time; higher values indicate longer processing for 1S than for 1L, lower values indicate longer processing for 1L than for 1S.

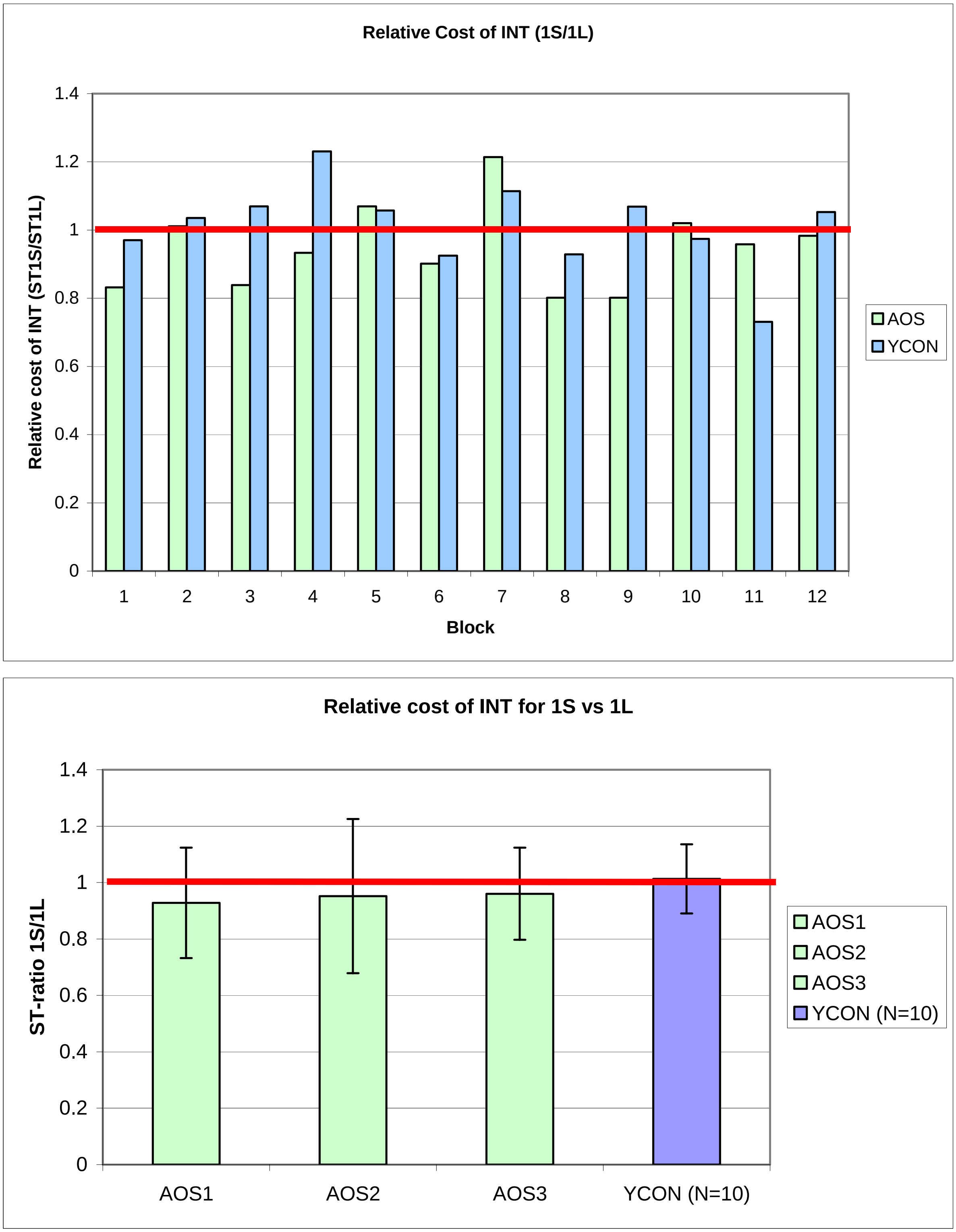
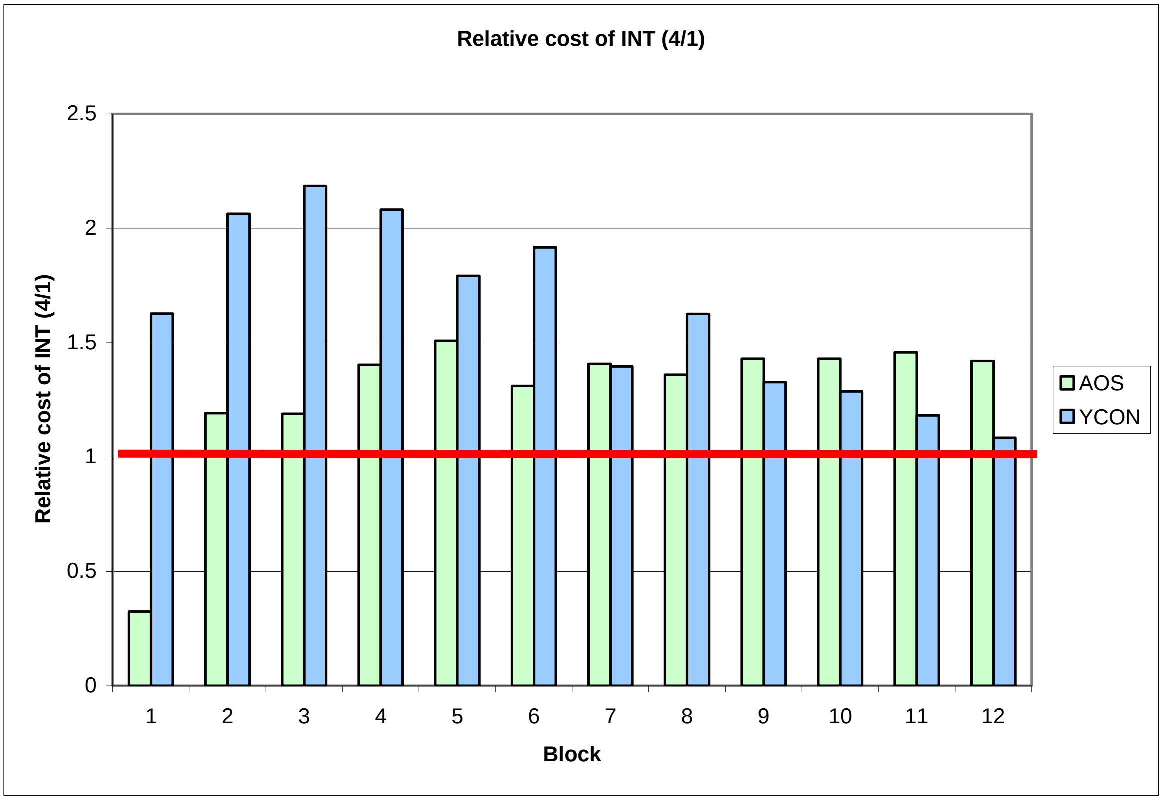


Figure 6. Relative cost of INT processing (ratio of ST-4 over ST-1) across blocks (A) and collapsed across blocks for each patient separately (B). Error bars represent 1 standard deviation. Red line indicates equal processing time; higher values indicate longer processing for 4 than for 1, lower values indicate longer processing for 1 than 4.



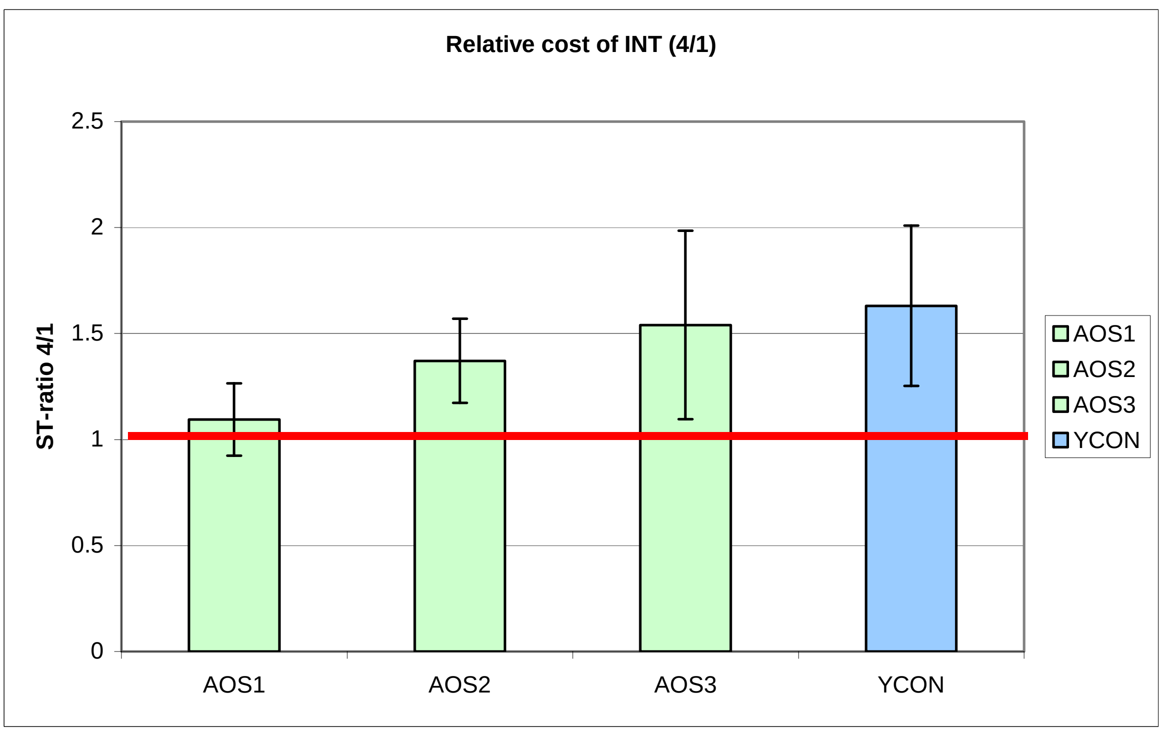
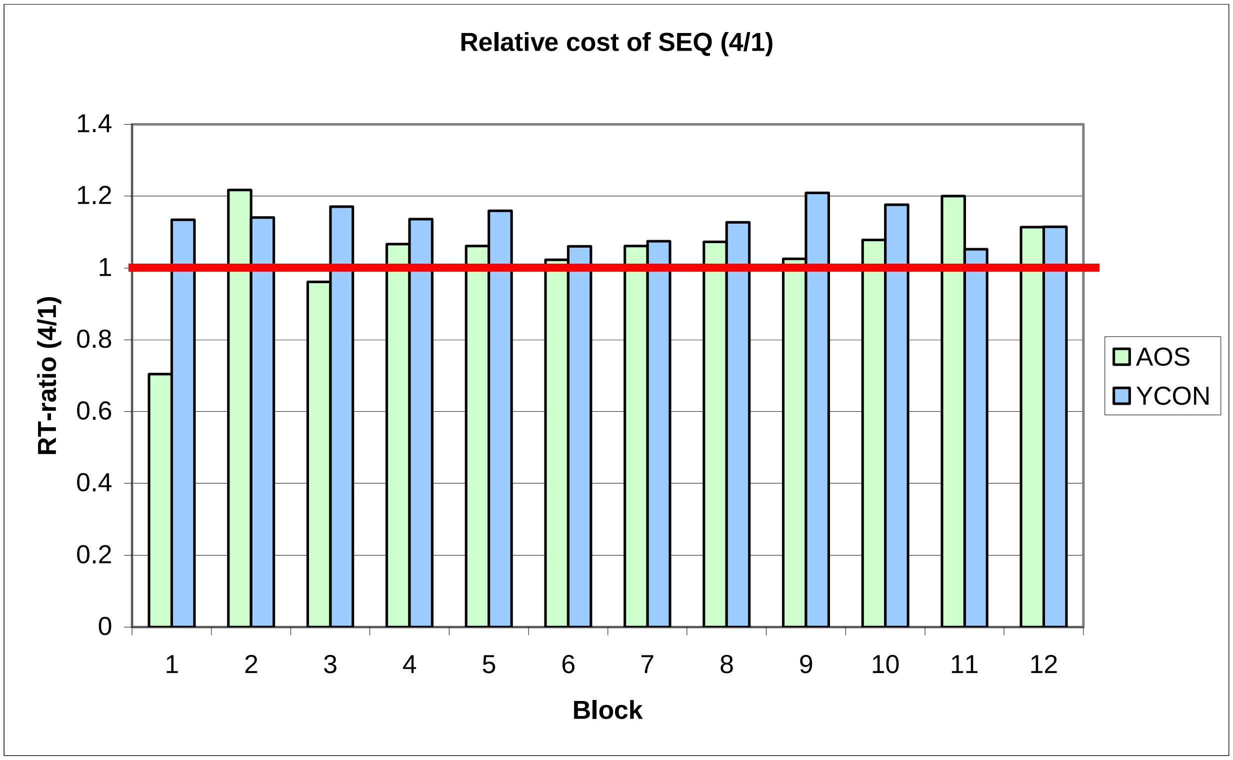


Figure 7. Relative cost of SEQ processing (ratio of RT-4 over RT-1) across blocks (A) and collapsed across blocks for each patient separately (B). Error bars represent 1 standard deviation. Red line indicates equal processing time for 4 vs. 1; higher values indicate longer processing time for 4 than for 1, lower values indicate longer processing time for 1 than 4.



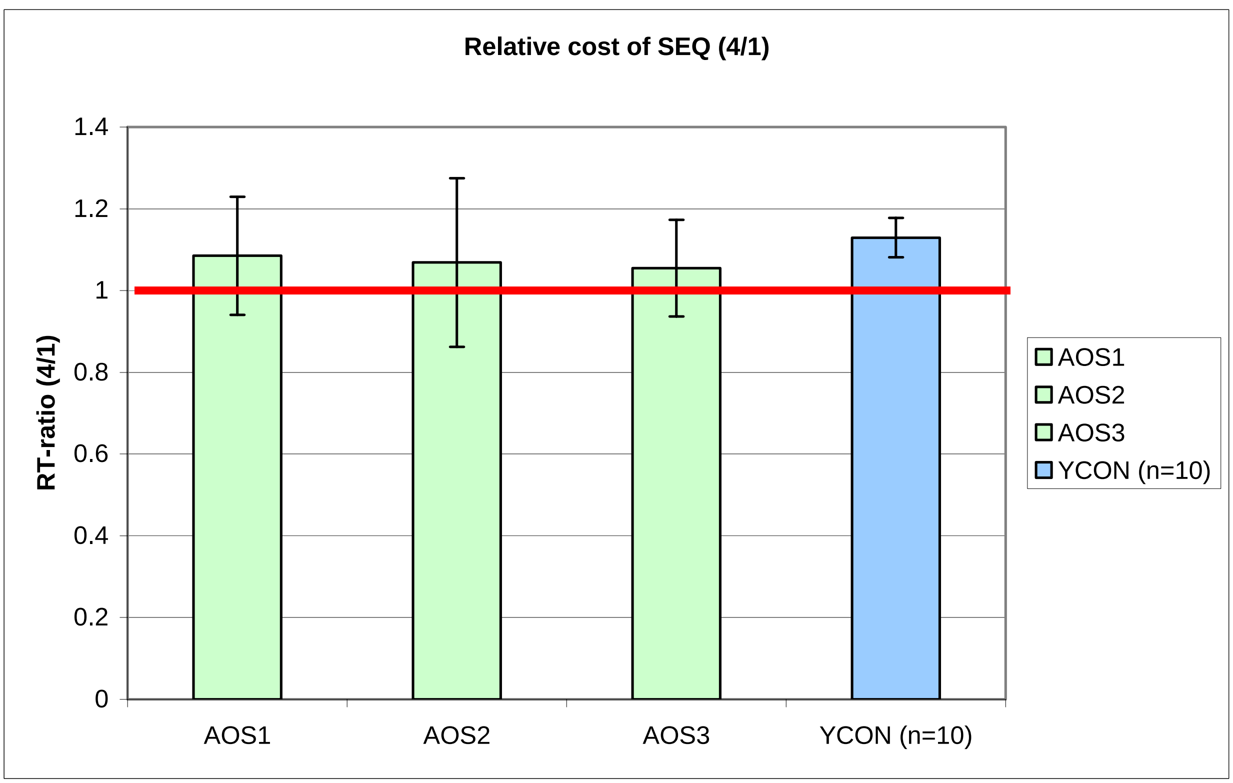


Table 1. Participant information.

	Sex	Age	Native Language	Hand	Profession	Etiology	Time post onset	Aphasia	AOS	Oral/Limb apraxia	Dysarthria
AOS1	M	68	English-Spanish	L	College professor	Single LH CVA mca region	29 months	Mild nonfluent aphasia	Mild-moderate	None/None	None
AOS3	F	67	English	R	Manager data processing	Single LH CVA	31 months	Very mild fluent aphasia	Mild-moderate	None/None	None
AOS4	M	58	English	R	College professor	Single LH CVA	23 months	None	Mild	None/None	Mild right-sided droop
YCON (n=10)	9F, 1M	$\bar{X}$ = 22.5 (range 19-41)	8 English, 1 Spanish-English, 1 Tagalog	10R							

Table 2. Target responses: cues, timing patterns, and total durations.

1S	Short (S)	150 ms	150 ms
1L	Long (L)	450 ms	450 ms
4S	Short-Long-Long-Short (SLLS)	150-450-450-150 (with 100 ms pauses)	1500 ms
4L	Long-Short-Short-Long (LSSL)	450-150-150-450 (with 100 ms pauses)	1500 ms