Modeling individual differences in processing deficits in aphasia

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INTRODUCTION

Patients with aphasia frequently experience difficulties in comprehending reversible non-canonical sentences such as 'The son was washed by the father', where the positions of the agent ('the father') and the theme ('the son') are interchanged. This difficulty is reflected in other reversible non-canonical structures as well. However, they do not face much difficulty in comprehending canonical counterparts or even irreversible non-canonical sentences such as 'The dog was washed by the man'. Irreversible non-canonical sentences are easy to comprehend mainly because world knowledge (that a dog cannot possibly wash a man) helps in inferring the meaning of the sentence and canonical sentences are easy to comprehend because they follow the regular 'agent-goal-theme' word order. But in reversible non-canonical structures world knowledge is insufficient to infer the meaning, hence these structures require the use of grammatical knowledge.

Theories that explain the impairment in aphasia fall into two main classes: (1) representational accounts, which claim that patients suffer impairment in grammatical knowledge; and (2) processing accounts, which claim that patients' grammatical knowledge is intact but they suffer impairment in the processing ability, i.e. the ability to correctly use the grammatical knowledge. One of the most prominent representational account, the **Trace Deletion Hypothesis** (TDH) (Grodzinsky, 2000), claims that patients with aphasia lose their ability to build traces of syntactic movements. The processing accounts differ in their precise claims about the processing impairment. Caplan et al. (2007) propose that the sentence processing deficit in agrammatic aphasia is a consequence of **intermittent deficiency** in the capacity to carry out syntactic, semantic, and task-related computations. Another processing account, **slowed processing** (Haarmann & Kolk, 1991), ascribes the processing deficit in aphasia to a pathological slowdown.

Compared to unimpaired individuals, aphasic patients are highly variable in their behavioral responses. Hence, a theory of sentence processing deficit in aphasia should also be able to explain individual level behavior. Here, we evaluate the two classes of accounts using a sentence processing framework (Lewis & Vasishth, 2005) implemented in the cognitive architecture, ACT-R. We also estimate parameters for individual patients to account for the individual differences between patients.

METHODS

We model the sentence-picture matching task in the visual world paradigm study reported in Hanne et al. (2011). In this study, patients (n=7) and aged-matched controls (n=7) listened to German canonical (*Der Sohn fängt den Vater* 'The son is catching the father') and analogous reversible non-canonical (*Den Sohn fängt der Vater* 'The father is catching the son') sentences while they were shown two pictures (a target and a distractor) on the screen. After participants heard the sentence, they had to select the picture that matched the sentence. The data consists of eye movements during the sentence presentation, picture selection responses, and response times.

We first model controls' offline responses (accuracy and response time) and then induced impairments in the model depending on the hypotheses: intermittent deficiency as increased utility noise in the system (utility noise defines the degree of nondeterminism in selecting processing rules), slowed processing as slowed procedural memory, and the trace deletion hypothesis as an absence of trace information in the parse tree.

We test five models of aphasic sentence processing: (1) **TDH-1** implements the trace deletion hypothesis with the syntactic assumption that the subject originates in VP, then moves to IP and is assigned the agent theta role in IP by the trace of VP; (2) **TDH-2** implements the trace deletion hypothesis with the syntactic assumption that the subject originates in VP, then moves to IP and is assigned agent theta role through its trace inside VP; (3) **M1** implements slowed processing; (4) **M2** implements intermittent deficiency; and (5) **M3** is an additive model that implements both, slowed processing and intermittent deficiency.
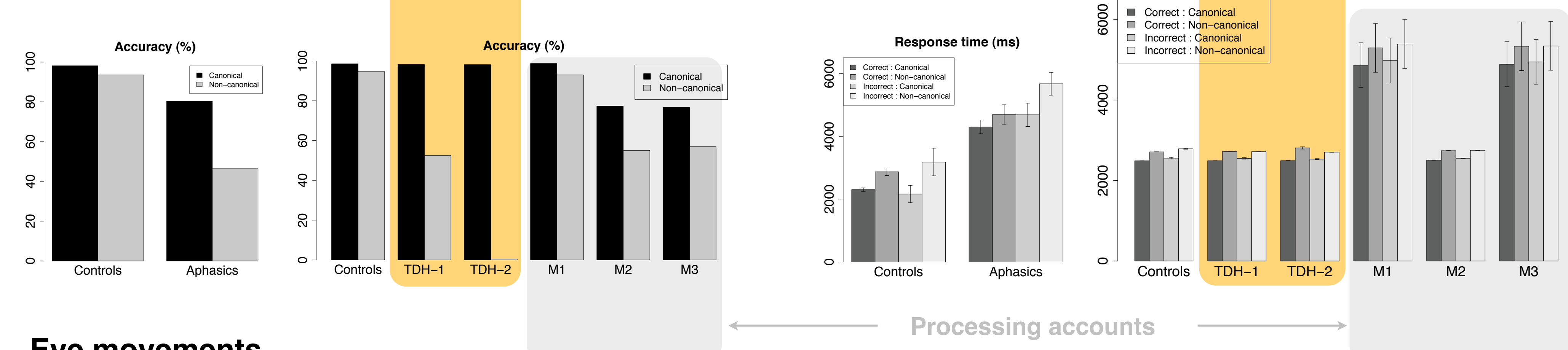
To characterize the variability between patients with aphasia, we estimate different values for the two parameters—utility noise and slowed procedural memory—for each patient. The best parameter values are selected using the normalized root-mean-square deviation measure.

CONCLUSIONS

Four major conclusions can be drawn from the present work: (1) aphasic patients' impaired sentence processing, reflected in their offline and online behavior during the sentence-picture matching task, is best captured by a model assuming two processing deficits—intermittent deficiency and slowed processing; (2) the model suggests that individual patients may have the two deficits in differing degrees which necessitates moving beyond the conventional practice of evaluating average behavior among patients; (3) we show that the two models of aphasia based on the Trace Deletion Hypothesis fail to capture the effects of reduced accuracy, delays in offline responses and normal online performance in correctly answered trials; and (4) we show that a well-developed model of unimpaired sentence comprehension grounded in ACT-R, can be extended to model impaired sentence processing and behavioral responses in the visual world paradigm.

RESULTS

Representational accounts / Processing accounts

Accuracy (%) — Controls, Aphasics — Canonical, Non-canonical

Accuracy (%) — Controls, TDH-1, TDH-2, M1, M2, M3

Response time (ms) — Controls, Aphasics — Correct : Canonical, Correct : Non-canonical, Incorrect : Canonical, Incorrect : Non-canonical

Response time (ms) — Controls, TDH-1, TDH-2, M1, M2, M3

Eye movements

Canonical sentences

Controls (correct resp.); Aphasics (correct resp.); Aphasics (incorrect resp.); Aphasics (correct resp.); Aphasics (incorrect resp.)

Non-canonical sentences

Controls (correct resp.); Aphasics (correct resp.); Aphasics (incorrect resp.); Aphasics (correct resp.); Aphasics (incorrect resp.)

Individual differences between patients

Patient: JK, Patient: JR, Patient: MP, Patient: PR, Patient: RK, Patient: WE, Patient: WR

Canonical, Non-canonical / Data, M3

Individual parameter values

Controls, Aphasics

Slowed processing (y-axis: 0.02 – 0.08) vs Intermittent deficiency (x-axis: 0.05 – 0.2)
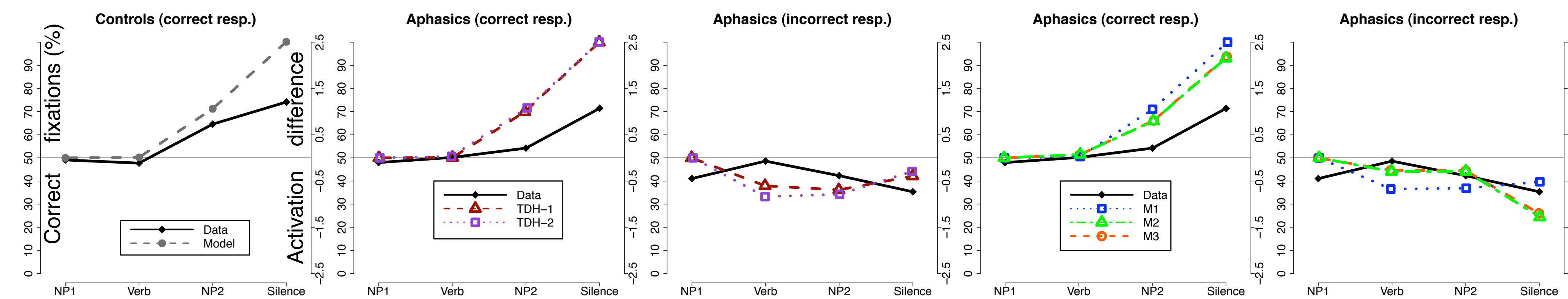
WR, PR, WE, JK, MP, JR, RK

References: [1] Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences*, 23 (1), 1–71. [2] Caplan, D., Waters, G., Dede, G., Michaud, J., & Reddy, A. (2007). A study of syntactic processing in aphasia I: Behavioral (psycholinguistic) aspects. *Brain and Language*, 101 (2), 103–150. [3] Haarmann, H. J., & Kolk, H. H. (1991). A computer model of the temporal course of agrammatic sentence understanding: The effects of variation in severity and sentence complexity. *Cognitive Science*, 15 (1), 49–87. [4] Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive Science*, 29 (3), 375–419. [5] Hanne, S., Sekerina, I. A., Vasishth, S., Burchert, F., & De Bleser, R. (2011). Chance in agrammatic sentence comprehension: What does it really mean? Evidence from eye movements of german agrammatic aphasi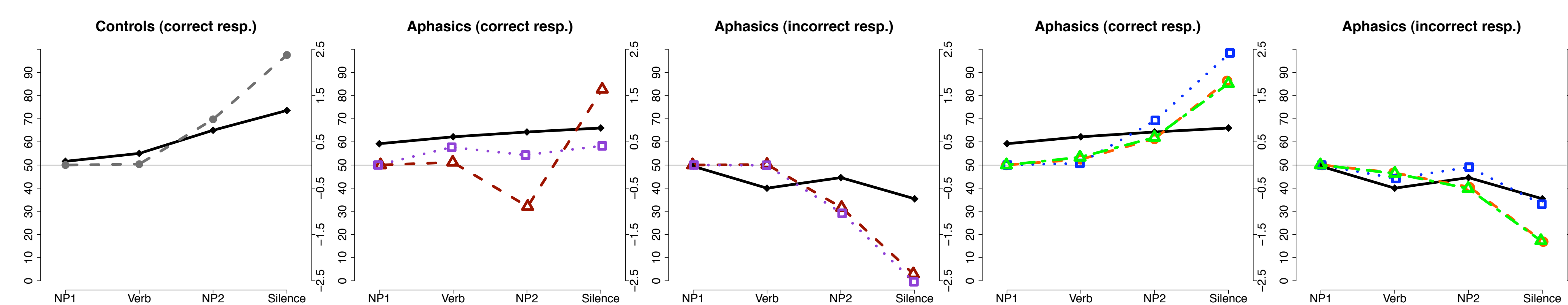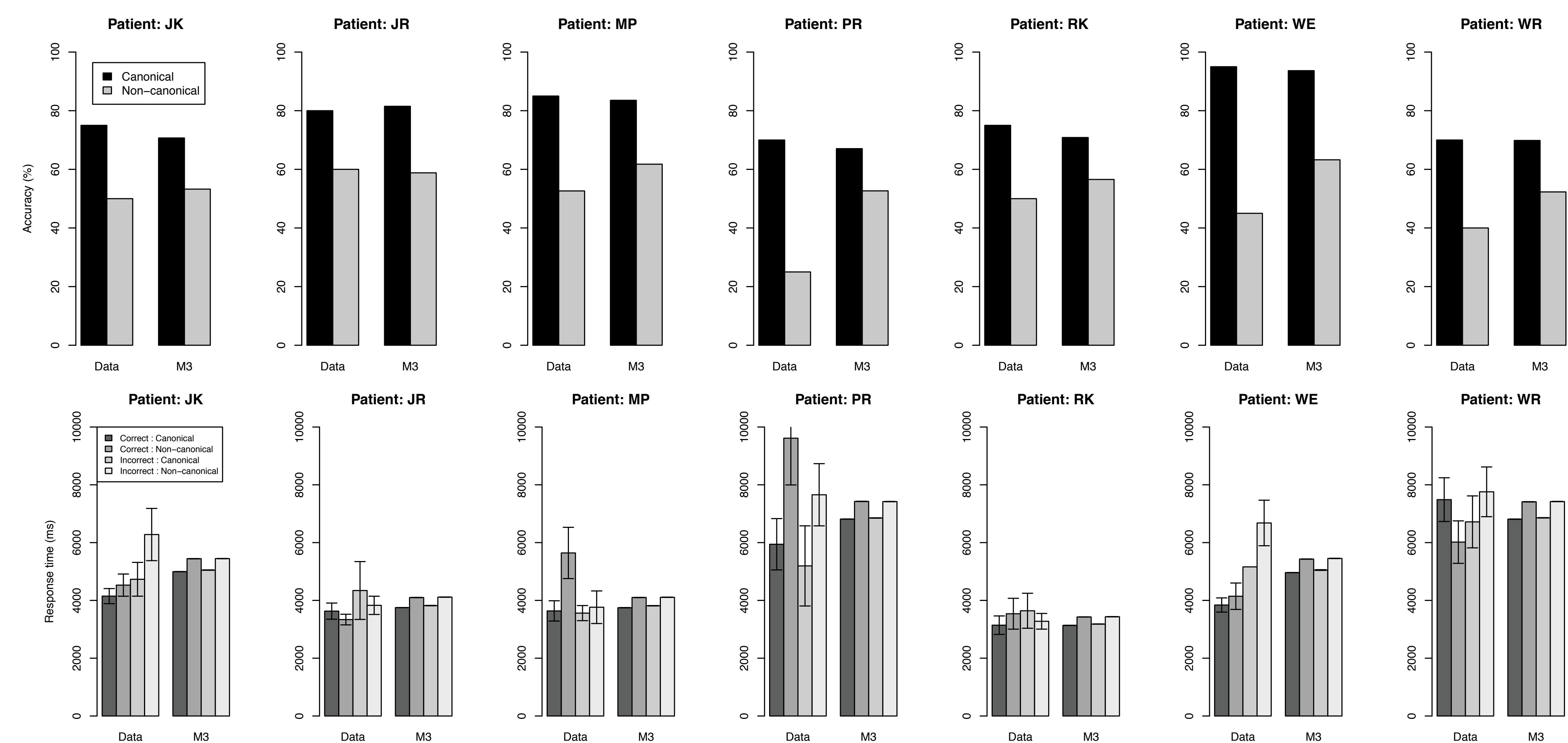c patients. *Aphasiology*, 25 (2), 221–244.