An EEG investigation into early syntactic processing: A rapid parallel visual presentation study of agreement and WH-dependencies in English

Introduction. Theories of language comprehension focus on how sentences are understood, word-by-word. However, simultaneous presentation of short sentences shows increased recall accuracy [1,2] and divergent EEG/MEG recordings [3–6] ~300ms, which has been interpreted as some grammatical analysis above the word level. Our research question is: how much grammatical analysis does the mind/brain execute for rapidly presented sentences, and how quickly? We conducted two English EEG studies examining subject-verb agreement and WH-questions, adapting the paradigm from [4–6]. We find that behavioral and neural responses to short sentences presented in parallel distinguish between grammatical vs scrambled sentences, and between different kinds of WH-constructions; however, they do not distinguish grammatical vs ungrammatical agreement. This suggests a limit on the detail of grammatical structure that can be extracted visually and processed in a single, quick fixation in English.

Methods. For both experiments, participants (N = 34) observed short sentences (4–5 words) displayed for ~250ms, followed by ~550ms of blank screen (**Fig 1A**). Participants received a match/no match memory probe and presentation times were dynamically adjusted based on accuracy. Brain activity was recorded using a 64-channel Ag/Cl EEG system.

Materials. [Agreement Experiment] 48 sets of English sentences were prepared based on declarative sentences [*Grammatical*]. Versions were created with an agreement error [*Ungrammatical*], scrambled word order [*Scrambled*], and a length-matched consonant string [*CString*]. [WH Experiment] 64 sets of English sentences were prepared based on matrix questions, manipulating whether the subject [±*Wh-Subj*] and/or object [±*Wh-Obj*] was a WH-construction.

Results. [Agreement Experiment – Behavioral]. Probe accuracy for both experiments was analyzed via mixed-effects logistic regression. Accuracy was lower for *Scrambled* ($p < 0.01$) and *CString* ($p < 0.01$) with respect to *Grammatical*, but no difference was found for *Ungrammatical* ($p = 0.19$) (**Fig 1B**). [EEG] Artifacts were removed using ICA. Raw EEG data for both experiments were epoched -100-800ms from onset, with 100ms baseline correction. Data were average referenced. Spatio-temporal cluster-based permutation tests [7] were conducted over sensor data from 100–800ms, with pairwise comparisons between *Grammatical* and violation conditions. *Grammatical* stimuli were more positive compared to *Scrambled* stimuli between 100-800ms in right lateral channels ($p = 0.0081$; **Fig 1E**), and *CString*, 169–800ms ($p < 0.01$; **Fig 1D**). No significant clusters were found distinguishing *Grammatical* from *Ungrammatical* stimuli.

[WH Experiment – Behavioral]. A significant facilitatory effect was found for ±*Wh-Subj* ($p < 0.01$), and a significant inhibitory effect was found for the interaction between ±*Wh-Subj* and ±*Wh-Obj* ($p < 0.01$) resulting in reduced accuracy for +Wh-Subj, +Wh-Object trials (**Fig 1C**). [EEG]. Data processing was the same as the previous experiment, but with 2×2 ANOVAs for spatio-temporal cluster-based permutation tests. A significant cluster of ±*Wh-Obj* was identified between 478-556ms over right posterior sensors ($p = 0.0256$; **Fig 1F**). A significant effect of ±*Wh-Subj* was identified between 253-332ms in left lateral sensors ($p = 0.0267$; **Fig 1G**). No significant clusters were found for the ±*Wh-Subj* × ±*Wh-Obj* interactions. Taken together, this suggests a difference in the processing of WH-object, WH-subject, and multiple-WH configurations.

Conclusion. In two experiments, we found that, when stimuli are presented rapidly and in parallel, behavioral and EEG results distinguish simple transitive sentences from scrambled or non-linguistic controls (Agreement Experiment) and distinguish different kinds of well-formed structures (WH Experiment), but do not detect ungrammatical agreement dependencies.

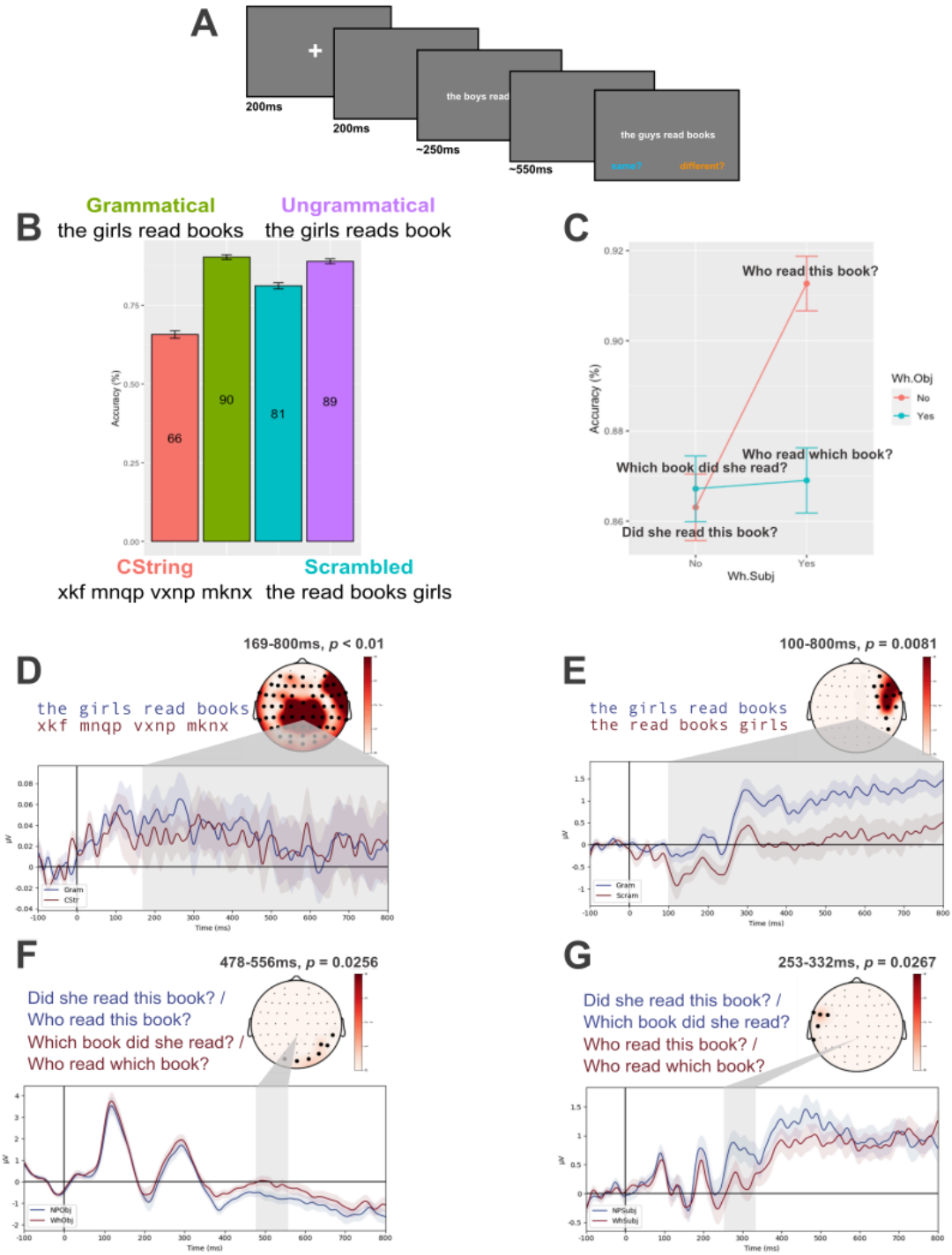

Figure 1. (A) Trial structure; (B) Agreement Experiment behavioral results; (C) WH Experiment behavioral results; (D) *Grammatical* vs *CString* EEG results; (E) *Grammatical* vs *Scrambled* EEG results; (F) ±*Wh-Obj* EEG results; (G) ±*Wh-Subj* EEG results

References

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