Differences in Implicit vs. Explicit Grammar Processing as Revealed by Hierarchical Weibull Modeling of Reaction Times

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Introduction

Artificial language studies using reaction time measures suggest that grammar learning can occur either with or without awareness of underlying grammatical rules (where learning is operationalized as slow-downs to rule-violating trials; Leung & Williams, 2011; Batterink, Reber, & Paller, 2014).

However, traditional linear analyses of reaction times cannot capture qualitative differences in processing between participants with vs. without rule awareness (Rouder, Lu, Speckman, Sun & Jiang, 2005; Rousselet & Wilcox, in press).

Hierarchical Weibull distribution modelling can analyze reaction time data in terms of underlying constructs from cognitive psychology such as peripheral processes, central processing, and cognitive architecture.

We report the results of a conceptual replication of Batterink et al.'s (2014) implicit L2 grammar learning experiment, analyzed via hierarchical Weibull modelling.

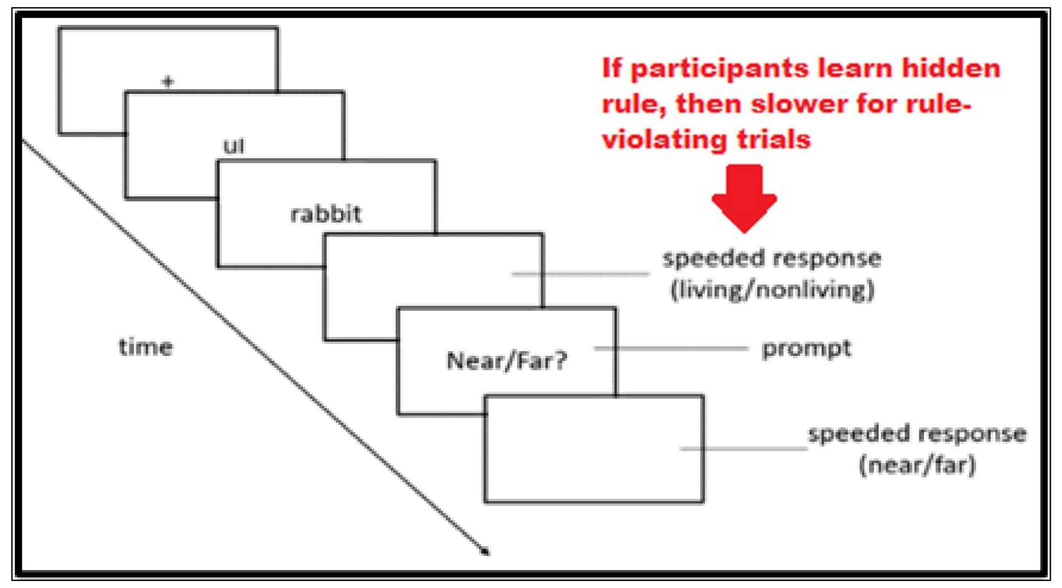
Research Question: Do participants with vs. without rule-awareness differ in the underlying processes involved in grammar processing?

Experiment design ... based on Batterink et al. (2014)

Participants were native English speakers with varying levels of additional language experience, recruited from psychology courses at Uni. of Illinois at Chicago (N = 26, of which 1 excluded for low accuracy, 1 for not completing task in allotted time)

Semi-Artificial Language *"gi horse, ne pencil, ul student, ro computer…"*		**Participants are not told...** Living	Nonliving
Participants are told...	**Near**	**gi**	**ro**
	Far	**ul**	**ne**

Participant Attributes	**Mean (S.D.)**
Gender	18 female, 8 male
Age	19.76 (1.88)
Self-reported English reading proficiency	4.81 (0.39)
Self-reported English writing proficiency	4.73 (0.52)
Self-reported English speaking proficiency	4.96 (0.19)
Percent reporting additional language	88.46%
Additional language reading proficiency	2.77 (1.41)
Additional language writing proficiency	2.59 (1.46)
Additional language speaking proficiency	3.63 (1.07)



1. Language Background Questionnaire
- Short, computer-based survey with questions about basic demographic information and about experience with native/additional languages

2. Vocabulary Pre-training
- Participants introduced to artificial language articles: *gi, ro, ul, ne*
- Only instructed on near/far meaning, not on living/nonliving meaning
- Practice through forward and backward translation tasks

3. Reaction Time Task
- 2 blocks of 284 rule-following trials, 44 rule-violating trials
- Rule learning measured as slowdowns to rule-violating trials
- Trial structure:

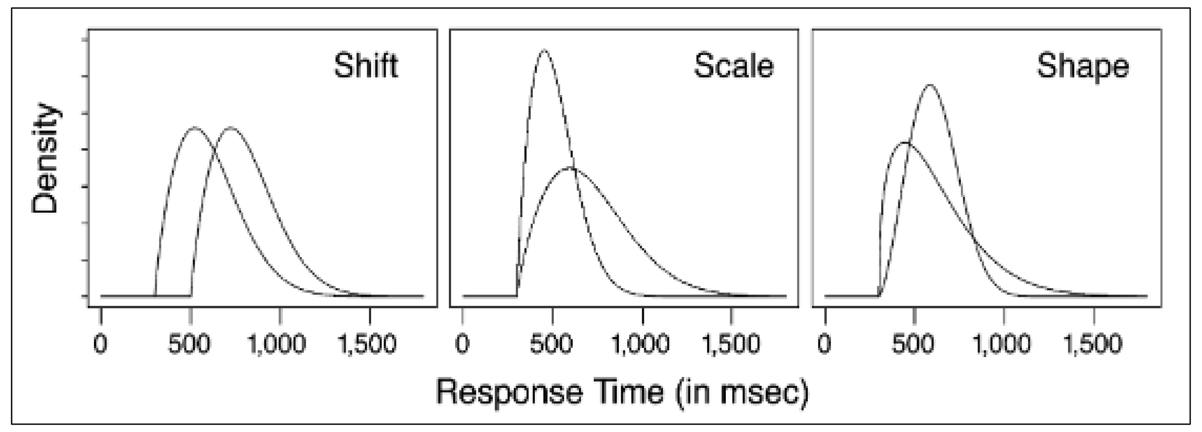
-fixation cross (1000ms) →
-artificial language article (350ms) →
-English noun for living/nonliving response (for 500ms, then replaced by blank screen until response) →
-near/far response (until response)

4. Debriefing Questionnaire
- Assessed participant's awareness of hidden rule through structured questionnaire
- Participants coded as either "rule-aware" or "rule-unaware" based on responses, as per criteria in Batterink et al. (2014)

Hierarchical Weibull Modeling

Certain analysis methods examine the entire shape of a reaction time distribution rather than simple measurements of central tendency (Whelan, 2008; Lindeløv, 2019). Among such methods, the Weibull model features several advantages (Rouder et al., 2005):

- Shown to fit data relatively well
- Reasonably robust to misspecification in the model
- Can improve model inferences by adjusting output parameter estimates through Bayesian inferencing based on data pooled across participants



Weibull modelling outputs three parameters (illustrated in above figure, reproduced from Rouder et al., 2005). These can be generally described in terms of cognitive constructs (see Balota & Spieler, 1999) as follows:

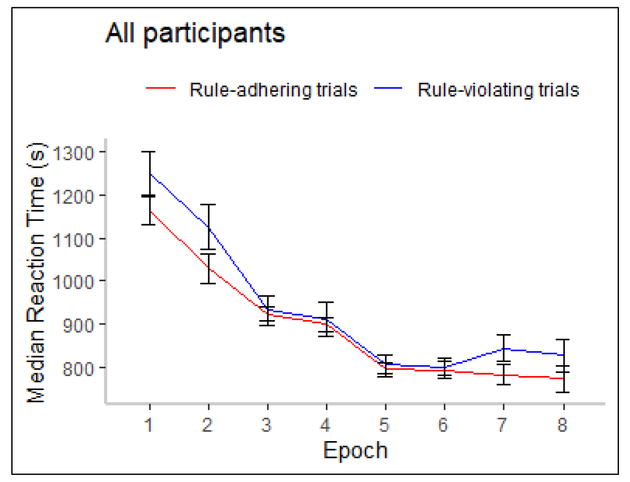
Shift: speed of peripheral processes, i.e., quick sensory/motor processes that occur automatically

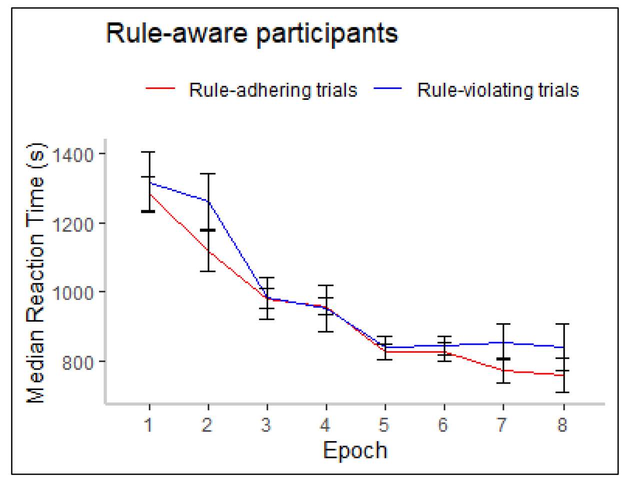
Scale: central processing speed

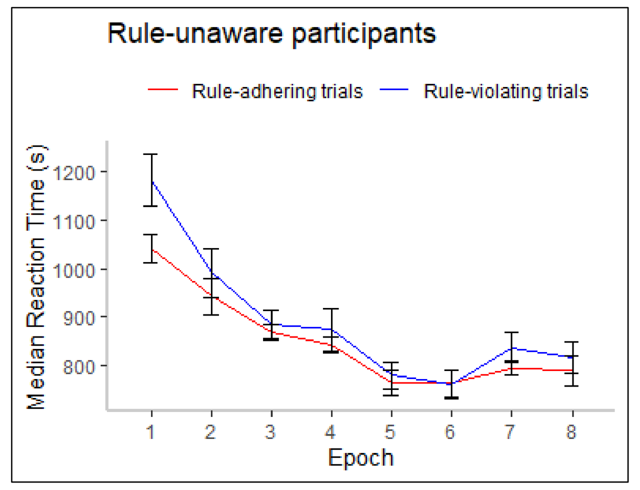
Shape: processing architecture, i.e., stages or strategies used in carrying out cognitive tasks

Analyses & Results

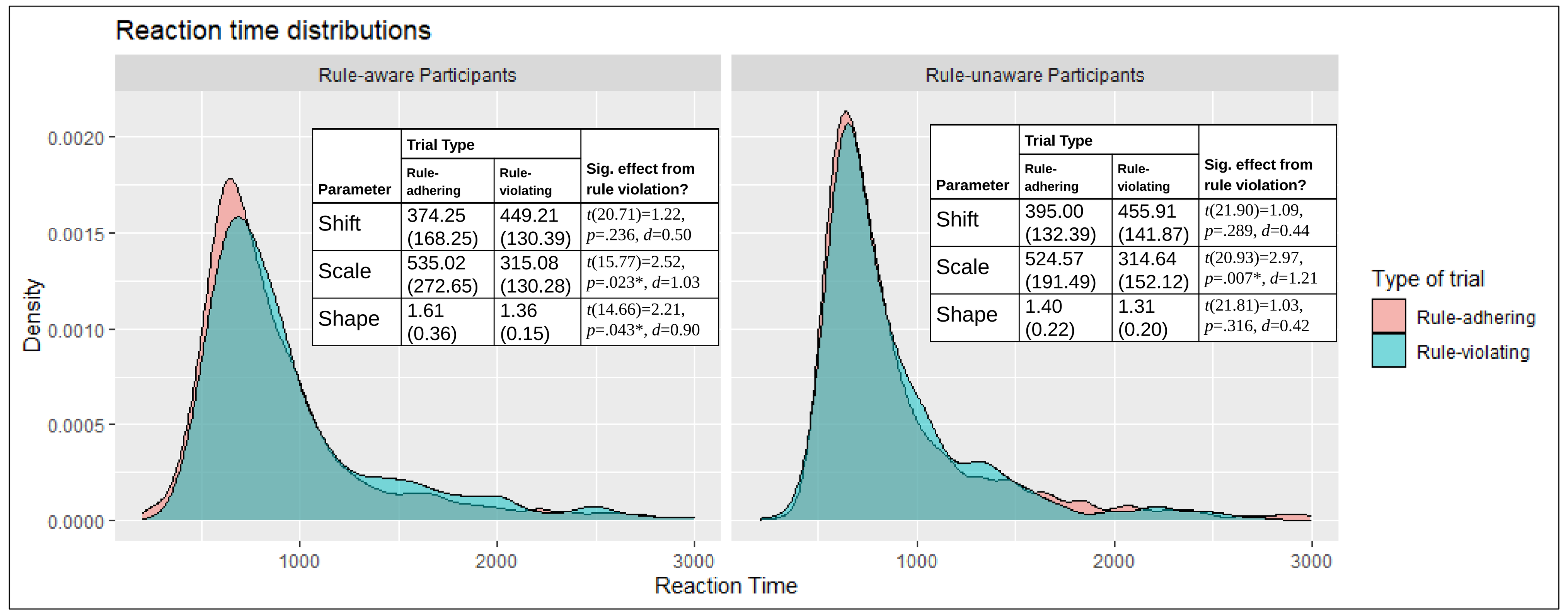
Linear analysis: replicated Batterink et al.'s (2014) findings of learning in both rule-aware (n = 12) and rule-unaware (n = 12) participants. Mixed effects ANOVA shows sig. effect of trial-type (rule-adhering vs. rule-violating) on median epoch reaction times, $F(1,22)=12.55$, $p = .002$, $\eta 2_G = .04$, with no sig. effects or interactions from Awareness (all $p > .05$). Error bars in figures below show standard errors.







Hierarchical Weibull analysis: models fit separately for each of rule-aware (n = 12) and rule-unaware (n = 12) participants and for each of rule-adhering and rule-violating trials using R scripts from Rouder et al. (2005)



Rule-aware Participants

Parameter	Trial Type: Rule-adhering	Trial Type: Rule-violating	Sig. effect from rule violation?
Shift	374.25 (168.25)	449.21 (130.39)	$t(20.71)=1.22$, $p=.236$, $d=0.50$
Scale	535.02 (272.65)	315.08 (130.28)	$t(15.77)=2.52$, $p=.023$*, $d=1.03$
Shape	1.61 (0.36)	1.36 (0.15)	$t(14.66)=2.21$, $p=.043$*, $d=0.90$

Rule-unaware Participants

Parameter	Trial Type: Rule-adhering	Trial Type: Rule-violating	Sig. effect from rule violation?
Shift	395.00 (132.39)	455.91 (141.87)	$t(21.90)=1.09$, $p=.289$, $d=0.44$
Scale	524.57 (191.49)	314.64 (152.12)	$t(20.93)=2.97$, $p=.007$*, $d=1.21$
Shape	1.40 (0.22)	1.31 (0.20)	$t(21.81)=1.03$, $p=.316$, $d=0.42$

Rule-aware participants: violations induce changes in processing speed (scale) and processing architecture (shape)

Rule-unaware participants: violations only induce a change in processing speed (scale)

Discussion

Hierarchical Weibull modelling suggests that rule-aware and rule-unaware participants differ in how they implement grammar processing.

For both kinds of participants, rule violations induce changes in processing speed. However, for rule-aware participants only, violations change the cognitive architecture involved.

Thus, although rule awareness is not tied to differences in reaction times *overall* (replicating Batterink et al., 2014), it does change the underlying cognition involved.

Possible takeaway for language teaching: although explicit metalinguistic awareness may not be strictly necessary for learners to acquire L2 grammar, it *does* make a difference in how it is processed (at least in early stages).

Limitations

Computer-based laboratory study; not necessarily representative of L2 learning in the real world.

Differing levels of prior language background across experiment participants.

Possible issues with using participant self-reports to assess awareness of the hidden grammatical rule (e.g., Leow & Hama, 2013).

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Acknowledgments

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