Bias-corrected reaction time analyses corroborate findings of implicit grammar learning in an artificial language experiment

David Abugaber,[1] Laura Batterink,[2] & Kara Morgan-Short [1,3]

[1] Department of Hispanic and Italian Studies, University of Illinois at Chicago [2] Department of Psychology, Western University [3] Department of Psychology, University of Illinois at Chicago

Introduction

Whether adult learners of second languages (L2) are able to acquire L2 grammar without conscious awareness is a matter of significant debate (Leung & Williams, 2011; Hama & Leow, 2013).

Using a semi-artificial language in which novel pseudoword articles predicted animacy (i.e., living/nonliving status) via a hidden, untaught rule, Batterink, Oudiette, Reber, and Paller (2014) found that participants who reported no awareness of the underlying rule nonetheless showed slower median reaction times for rule-violating trials, suggesting L2 grammar acquisition without awareness.

However, the use of sample medians across unequal sample sizes may lead to overestimation of population medians when distributions are positively skewed (Miller, 1988). This is the case in Batterink et al. (2014), in which rule-following trials outnumber rule-violating trials by design.

We report the results of a conceptual replication of Batterink et al.'s (2014) implicit L2 grammar learning experiment, using the bootstrap-based bias-correction technique proposed by Rousselet and Wilcox (in press).

Bias-correction technique

Sample medians tend to overestimate the true median when the distribution is positively skewed (see figure), and this effect is bigger in smaller samples (Miller, 1988). In Batterink et al. (2014), rule-following trials outnumber rule-violating trials by design. Thus, the reported slow-down effect to rule violations may be an artifact of the analysis's comparison of medians across samples of different sizes.

This can be overcome using a bootstrap-based bias-correction technique (Rousselet & Wilcox, in press):

1. Generate a bootstrapped distribution of median estimates by continually re-sampling the raw data.
2. Calculate the bias as the difference between the median of the raw data and the mean of the bootstrapped median estimates.
3. Subtract this estimated bias from the median of the raw data to produce a bias-corrected median estimate.

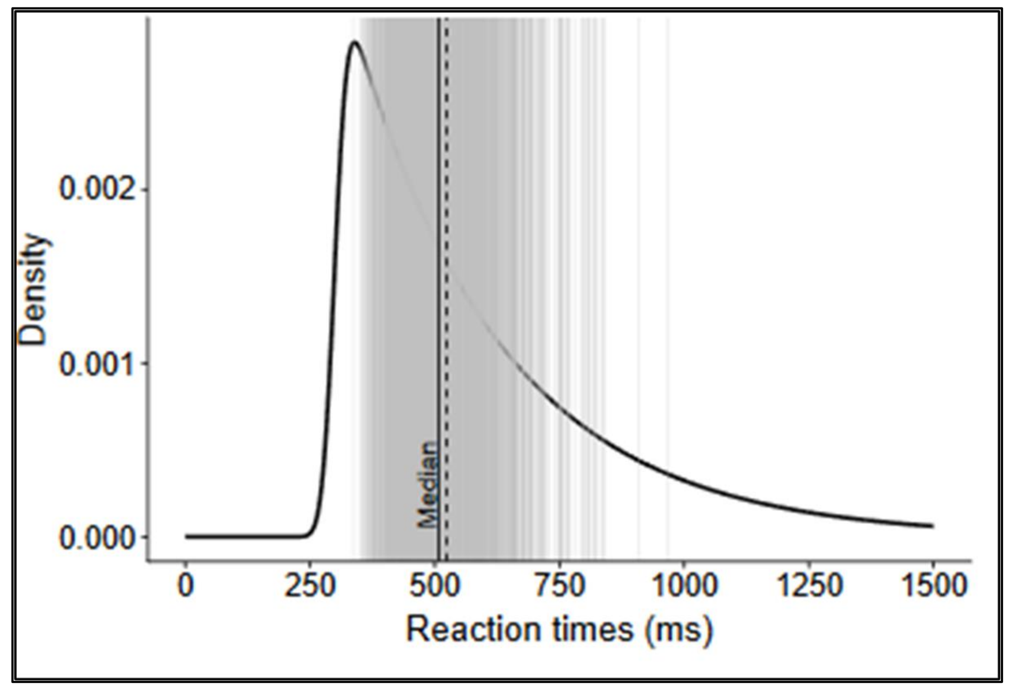


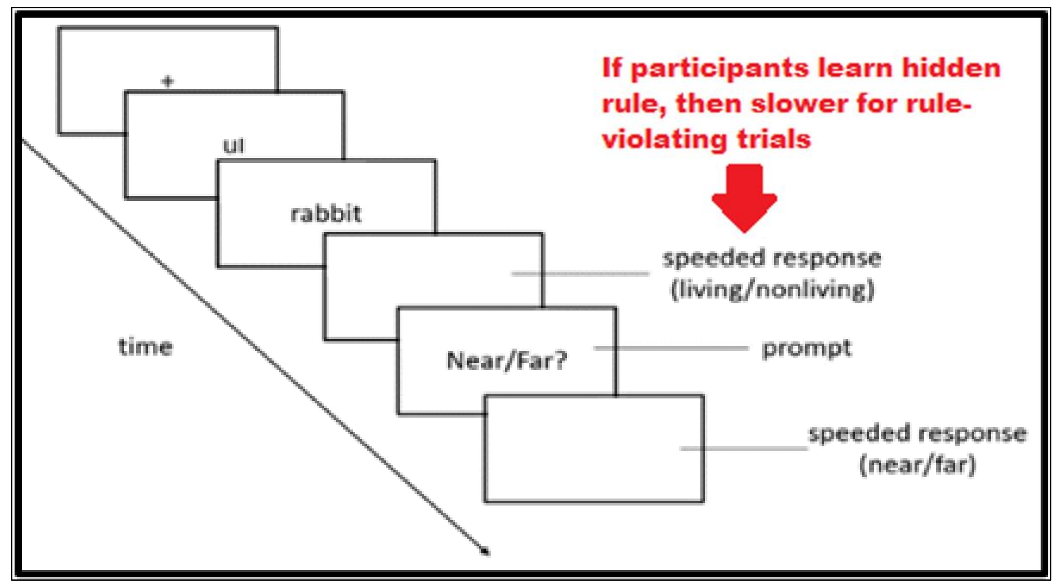
Illustration of bias in sample medians (figure reproduced from Rousselet & Wilcox, in press). Ex-Gaussian distribution with parameters μ=300,σ=20 and τ=300. The vertical grey lines indicate 1,000 medians from 1,000 random samples of 10 observations. The vertical black line marks the true population median. The vertical dashed line marks the mean of the 1,000 bootstrap-generated sample medians (vertical gray lines). Bias is shown by the small but noticeable disparity between the solid and dotted lines.

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

Participants were native English speakers with varying levels of additional language experience, recruited from introductory psychology courses at the University of Illinois at Chicago (*N* = 40, 5 removed for low task accuracy, 2 for missing data)

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	30 female, 10 male
Age	18.60 (0.80)
Self-reported English reading proficiency	4.89 / 5.00 (0.31)
Self-reported English writing proficiency	4.87 / 5.00 (0.41)
Self-reported English speaking proficiency	4.89 / 5.00 (0.38)
Percent reporting additional language	90%
Additional language reading proficiency	3.36 / 5.00 (1.36)
Additional language writing proficiency	3.03 / 5.00 (1.44)
Additional language speaking proficiency	3.72 / 5.00 (1.15)



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

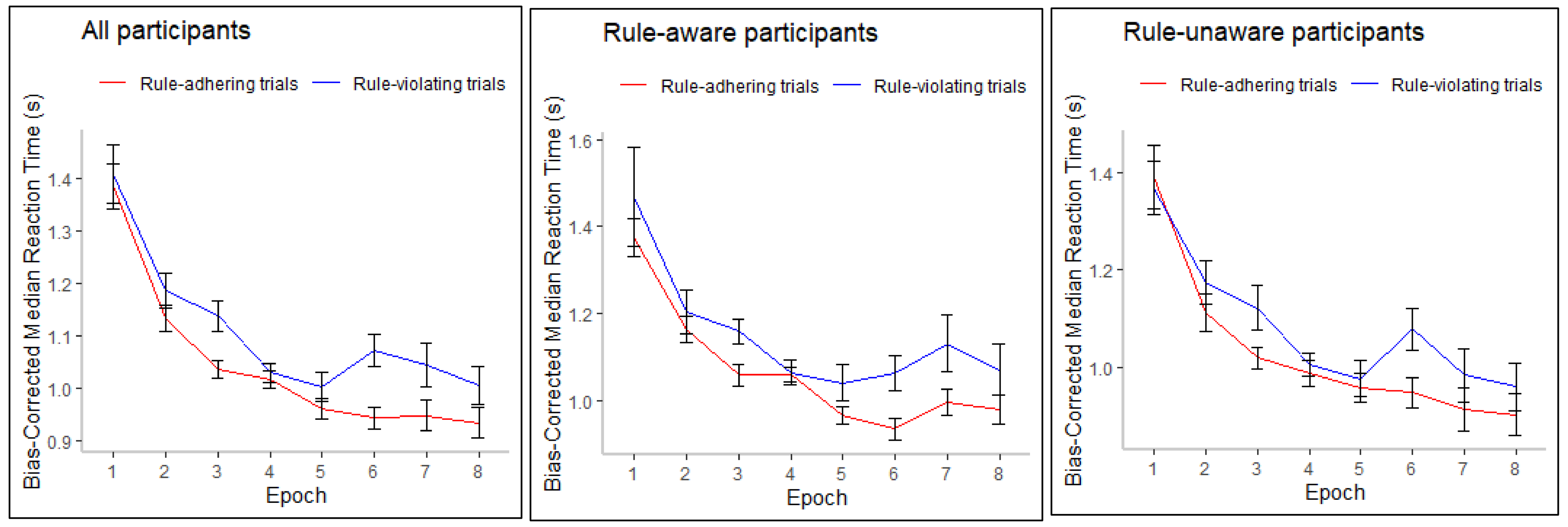
3. Reaction Time Task
- 2 blocks of 284 rule-following trials, 44 pseudorandomly-interspersed rule-violating trials
- Trial structure:

-fixation cross (1000ms) →
-artificial language article (350ms) →
-English noun for living/ nonliving response (for 500ms, then 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)

Analyses & Results

As in Batterink et al. (2014), analyses of variance were performed on median reaction times for each of eight equally-spaced epochs, with participants' Rule Awareness status (rule-aware vs. rule-unaware participant) as a between-participant factor and Experiment Condition (rule-conforming vs. rule-nonconforming trial) and Epoch (for epochs 1-8) as within-participant factors.



Non-bias-corrected analysis: Significant main effect of Condition *F*(1, 31) = 16.54, $p < .001$, $\eta_g^2 = .00$, such that response times to rule-nonconforming trials were significantly slower than to rule-conforming trials. No main effects or interactions from Awareness (*ps* < .05), suggesting that the learning effect was not significantly dissimilar across rule-aware (*n* = 13) and rule-unaware (*n* = 20) participants.

Bias-corrected analysis: The same ANOVAs were performed after performing Rousselet and Wilcox's (in press) bootstrap bias correction technique, iterating 1,000 times using the groupwiseMedian() function from the *Rcompanion* package in R (Mangiafico, 2020). As before, we found a significant main effect of Condition, Condition *F*(1, 31) = 39.10, $p < .001$, $\eta_g^2 = .01$, but no main effects or interactions from Awareness (*ps* > .05).

Predictor	df_{Num}	df_{Den}	*Epsilon*	*F*	*p*	η^2_g
Awareness	1.00	31.00		0.26	.616	.01
Condition	1.00	31.00		16.54	.000	.00
Awareness x Condition	1.00	31.00		1.55	.222	.00
Epoch	2.85	88.35	0.41	20.11	.000	.14
Awareness x Epoch	2.85	88.35	0.41	0.52	.660	.00
Epoch x Condition	4.78	148.14	0.68	1.22	.302	.00
Awareness x Epoch x Condition	4.78	148.14	0.68	1.01	.412	.00

non-bias-corrected analysis

Predictor	df_{Num}	df_{Den}	*Epsilon*	*F*	*p*	η^2_g
Awareness	1.00	31.00		0.20	.661	.00
Condition	1.00	31.00		39.10	.000	.01
Awareness x Condition	1.00	31.00		1.14	.294	.00
Epoch	2.87	88.98	0.41	22.83	.000	.14
Awareness x Epoch	2.87	88.98	0.41	0.52	.662	.00
Epoch x Condition	5.04	156.37	0.72	1.72	.133	.00
Awareness x Epoch x Condition	5.04	156.37	0.72	0.70	.627	.00

bias-corrected analysis

Discussion

Batterink et al.'s (2014) findings of implicit grammar learning were supported even after applying the sample median bias-correcting technique proposed by Rousselet and Wilcox (in press), suggesting that their results were not likely an artifact of sample median bias (Miller, 1988).

More generally, our findings contribute to theoretical debates on implicit L2 learning by providing additional evidence for the possibility of learning of grammatical regularities without any accompanying awareness, in the context of a semi-artificial language learning experiment.

Our findings are relevant for language teaching praxis in suggesting that overt instruction may not be strictly necessary for learners to acquire L2 grammar regularities.

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).

References

Batterink, L. J., Oudiette, D., Reber, J., & Paller, K. A. (2014). Sleep facilitates learning a new linguistic rule. *Neuropsychologia, 65*, 169-179.

Leow, R. P., & Hama, M. (2013). Implicit learning in SLA and the issue of internal validity: A response to Leung and Williams's (2011) "The implicit learning of mappings between forms and contextually derived meanings". *Studies in Second Language Acquisition*, *35*(3), 545-557.

Leung, J. H., & Williams, J. N. (2011). The implicit learning of mappings between forms and contextually derived meanings. *Studies in Second Language Acquisition*, *33*(1), 33-55.

Mangiafico, S. (2020). rcompanion: Functions to Support Extension Education Program Evaluation. R package version 2.3.21. https://CRAN.R-project.org/package=rcompanion.

Miller, J. (1988). A warning about median reaction time. *Journal of Experimental Psychology: Human Perception and Performance*, *14*(3), 539.

Rousselet, G. A., & Wilcox, R. R. (in press). Reaction times and other skewed distributions: problems with the mean and the median. *Meta-Psychology*. Accessed online at https://eprints.gla.ac.uk/189893/1/189893.pdf.

Acknowledgements

Thank you to Dr. Philip Hamrick, Will Camacho, Krishna Bhatia, Victoria Ogunniyi, Hannah Chaddha, Sarah Hassan, Gayatri Chavan, and Amber Lewis for their assistance with this project, which was funded by a National Science Foundation Doctoral Dissertation Improvement Grant (Award #1941189). For any feedback/questions, please email David Abugaber at davidabugaber@gmail.com or visit www.davidabugaber.com.