# Inverse reaction time as an awareness measure in artificial grammar learning experiments

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## Abstract

Artificial grammar learning (AGL) experiments are frequently adopted to test implicit (unconscious) learning of linguistic generalizations by adult learners. Since explicit (conscious) learning seems inevitable for adult learners, awareness measures are necessary to assess if learners are conscious of acquired linguistic generalizations. Confidence level, for instance, would be uncorrelated or inversely correlated with learning performance if acquired linguistic knowledge is implicit. In this study, we examined if inverse reaction time (IRT) could be a fine-grained and objective confidence-based awareness measure in adult AGL experiments. With data from three phonological AGL experiments recruiting adult participants, we confirmed that confident responses are faster than unconfident ones and that slower (i.e., less confident) responses reflect the application of successfully acquired implicit knowledge.

Keywords: artificial grammar learning, inverse reaction time, awareness, confidence, phonology

## Introduction

In recent years, linguists have been using artificial grammar learning experiments (AGL; Reber 1967) to test various hypotheses regarding implicit (unconscious) and explicit (conscious) learning of linguistic generalizations. In typical AGL experiments, learners are exposed briefly to language input without being informed of hidden linguistic regularities and an upcoming test of their learning performance. Successful extension of hidden regularities to novel forms in the test by learners without awareness of the acquired generalizations would be viewed as evidence for implicit learning. Awareness measure is thus vital to the analysis of experimental results in AGL studies. In particular, for adult participants, artificial language learning is equivalent to L2 learning and an explicit learning process seems inevitable (e.g., Hulstijn 2005). One widely accepted awareness measure is the confidence level (CL) of learners' responses in test sessions. If learners' high response accuracy is uncorrelated or inversely correlated with their CL, the acquired knowledge is assumed as implicit (i.e., zero-correlation criterion; Dienes 2007). However, *subjective* CL does not always reflect adult learners' awareness of target knowledge as the learners, albeit with explicitly acquired target knowledge, could be too humble to report their certainty (e.g., Maie & DeKeyser 2020).

In this study, we thus propose to use inverse reaction time (IRT; -1000/RT in milliseconds) as a confidence-based awareness measure. IRT is more normally distributed than other response latency measures such as log-RT (Brysbaert & Stevens 2018) and comes with two primary advantages over subjective CL. First, IRT directly reflects learners' hesitation the arises from their CL, which is thus more *objective* than learners' own post-response CL ratings. Second, IRT is a gradient scale that can capture subtle changes in the effects of CL. In the rest of this squib, we will triangulate the relationship between IRT, CL, and implicit/explicit learning in adult AGL experiments with data from the author's three phonological AGL studies.

## Three phonological AGL studies

The three phonological AGL studies share a similar core experimental design, namely exposing *adult* learners to auditory training input and later testing them with novel items in an auditory acceptability judgment task. Comparisons were always made between two groups exposed either to training input supporting the learning of presumably implicit phonological knowledge or to input that did not. Learning performance was assessed in a two-alternative forced-choice acceptability judgment task in the three experiments. Core hypotheses in each study are detailed below.

In Chen (2020), the author tested if human learners have an inductive bias against a non-domain-final rising tone (R), a constraint that is phonetically natural and assumed to be implicit phonological knowledge. 53 participants were either exposed to disyllabic input without any non-final R (target group) or to disyllabic input without any non-final high tone (non-target group) – the latter tonal gap is phonologically arbitrary and perhaps unlearnable. Accordingly, only the target group was expected to demonstrate the implicit learning of the target constraint. In Chen (submitted), the learnability of the Obligatory Contour Principle (OCP) prohibiting adjacent level tones (OCP-Level; e.g., *H<u>L</u>-<u>L</u>H, *<u>H</u>-<u>H</u>L) was compared to that of OCP banning same adjacent tonal *unit* (OCP-Unit; e.g., *<u>HL</u>-<u>HL</u>, *<u>LH</u>-<u>LH</u>), and only widely attested OCP-Level was assumed to be learnable implicit phonological knowledge. 60 participants were exposed either to disyllabic input without adjacent tonal levels (target group) or to input without adjacent identical tonal units (non-target group), and only OCP-Level was expected to be acquired as an implicit generalization. Finally, in Chen (in prep.), the main research question is whether a skewed distribution of learning input in favour of shorter words could foster the implicit learning of local vowel harmony (VH) patterns. 60 adult learners were exposed to learning input with VH, but one group perceived more disyllabic items than trisyllabic ones (target group) and the other group listened to an equal number of disyllabic and trisyllabic items (non-target group). Only the target group was expected to converge on an implicit local VH grammar and extend the grammar to novel trisyllabic word forms.

## Data analysis

A total of 1,956 responses from the test sessions in Chen (submitted) and Chen (in prep.) were provided with binary CL ratings, which allowed us to establish the link between CL and IRTs. We regressed raw IRTs against Group (target vs. non-target), CL (yes vs. no), and their interaction in linear mixed-effects modelling, which indicated a significant main effect of CL ($\beta$ = 0.173, *se* = 0.023, $t$ = 7.67, $p$ < .001). That is, IRTs were more negative (i.e., *faster*) for confident responses than for unconfident ones (Figure 1, left panel).

We then incorporated another 2,958 responses without CL ratings from the test sessions in Chen (2020) and coded binary response accuracy for all 4,914 responses for target and non-target groups depending on whether participants did correctly reject novel items violating learnable/unlearnable tonal constraints or extend local VH successfully to novel items. Our main prediction, according to the zero-correlation criterion, is that response accuracy does not correlate or is inversely correlated with IRTs only for the target groups that were expected to acquire implicit linguistic knowledge. To test the prediction, we regressed response accuracy against IRT ($z$-scored within participants), Group, and their interaction in logistic mixed-effects modelling, which indicates a significant IRT × Group interaction ($\beta$ = -0.106, *se* = 0.044, $z$ = -2.401, $p$ = .016; Figure 1, right panel). Crucially, for the target groups, a higher IRT predict a higher (and above-chance) response accuracy, whereas the chance-level accuracy regardless of IRT suggests no sign of learning for the non-target groups. The above findings are in line with our main prediction.

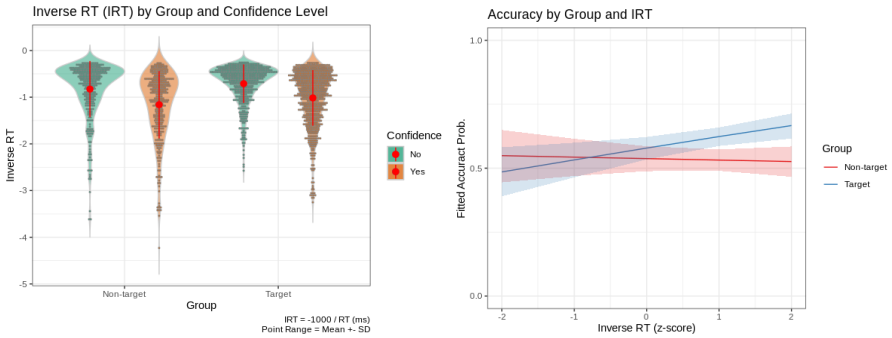


Figure 1. Descriptive raw IRT distributions by Group and Confidence Level (left), and response accuracy by Group and $z$-scored IRT (right).

## Discussion

With data from three adult phonological AGL experiments that were analyzed with IRT, we showed that (i) response latency is significantly shorter for *subjectively* confident responses, and (ii) slower responses were found to be more accurate only for the target groups expected to learn implicit phonological

knowledge. IRT should thus be viewed as a reliable and objective index of CL, which could in turn reflect the application of implicit/explicit knowledge in adult AGL studies. We speculate that the responses of adult learners in an acceptability judgment task in AGL studies are guided first by explicitly learned knowledge, which may or may not coincide with patterns hidden in the training input. The chance-level accuracy of more confident responses from the target groups (Figure 1, right panel), for instance, could be a case of applying an incorrect explicit generalization to their acceptability judgment. When an explicit generalization is not helpful for learners to make a definite decision, they hesitate and allow their intuition based on implicitly acquired target knowledge to lead the way. However, learners exposed to an unlearnable pattern or assigned to a condition that does not facilitate learning (e.g., the *non-target* groups) may simply fail to demonstrate both types of knowledge.

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