Quantifying P600 latency differences between L1 and L2 speakers using GAMMs

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The P600 is often taken as an indicator of syntactic processing success [1]. For non-native (L2) speakers, previous research has suggested that the P600 is temporally delayed relative to native (L1) speakers [e.g., 2,3]. However, few studies have directly quantified this delay. One possible reason might be the lack of user-friendly methods to quantify the latency properties of ERP components. We bridge this gap by taking an onset detection method from eye-tracking research with its own R package [4], and extending it to quantify latency differences in the P600. We demonstrate the usefulness of the method in two open datasets comparing P600 latencies for grammatical violations between L1 and L2 speakers [2,3].

Building on [4], our method involves modelling ERP amplitude changes over time using generalised additive mixed models (GAMMs). The GAMMs' parameter estimates were then used to simulate 10,000 difference curves for the ungrammatical–grammatical P600 effect within L1 and L2 speakers. For each simulated curve, two measures of P600 effect latency were quantified: (i) peak latency, i.e., the timepoint of maximum amplitude in a given window; (ii) onset latency, i.e., the timepoint at which the (baseline-corrected) difference curve first differed statistically from zero. Comparing the different groups' P600 effect latencies was achieved by subtracting the distribution of latencies across simulations and computing a confidence interval for the mean of the difference. If the interval did not contain zero, the difference was interpreted as statistically significant.

Datasets. We tested whether the GAMM-based method would license the same conclusions as [2] and [3]. In [2], data were analysed from 29 German L1 speakers and 66 German L2 learners reading sentences with gender agreement violations (**Table 1a**), with the conclusion that P600 peak latency was delayed in L2 versus L1 speakers. In [3], 22 Dutch L1 speakers, and 42 intermediate and advanced Dutch L2 learners read sentences with word-order violations that were either grammatical or ungrammatical in their L1 (German; **Table 1b**). [3] concluded that P600 latency was only delayed in L2 versus L1 speakers for violations where grammaticality conflicted with the L1.

Results. Unlike [2], we found that P600 peak latency was not significantly delayed in L2 speakers, M = 41 ms, 95% CI = [–56, 118] ms (**Fig. 2A**). However, while not tested in [2], onset latency was significantly delayed, M = 288 ms, 95% CI = [67, 573] ms. Our method thus yielded similar conclusions to [2]; deviations likely due to our analysing more subjects. In the data from [3], there was no clear P600 peak (**Fig. 1B**), but onset latencies yielded similar conclusions, e.g., $M_{conflict}$ = 171 ms, 95% CI = [16, 376] ms; $M_{no\text{-}conflict}$ = 20 ms, 95% CI = [–88, 124] ms (L1 vs. advanced L2 speakers; **Fig. 2B**). The GAMM-based method thus supports previous studies with quantitative evidence of delayed L2 grammatical processing, even in advanced learners.

Figure 1. Grand average ERPs in **A.** [2] and **B.** [3]. Points and error bars indicate mean P600 peak and/or onset latency and its 95% CI.

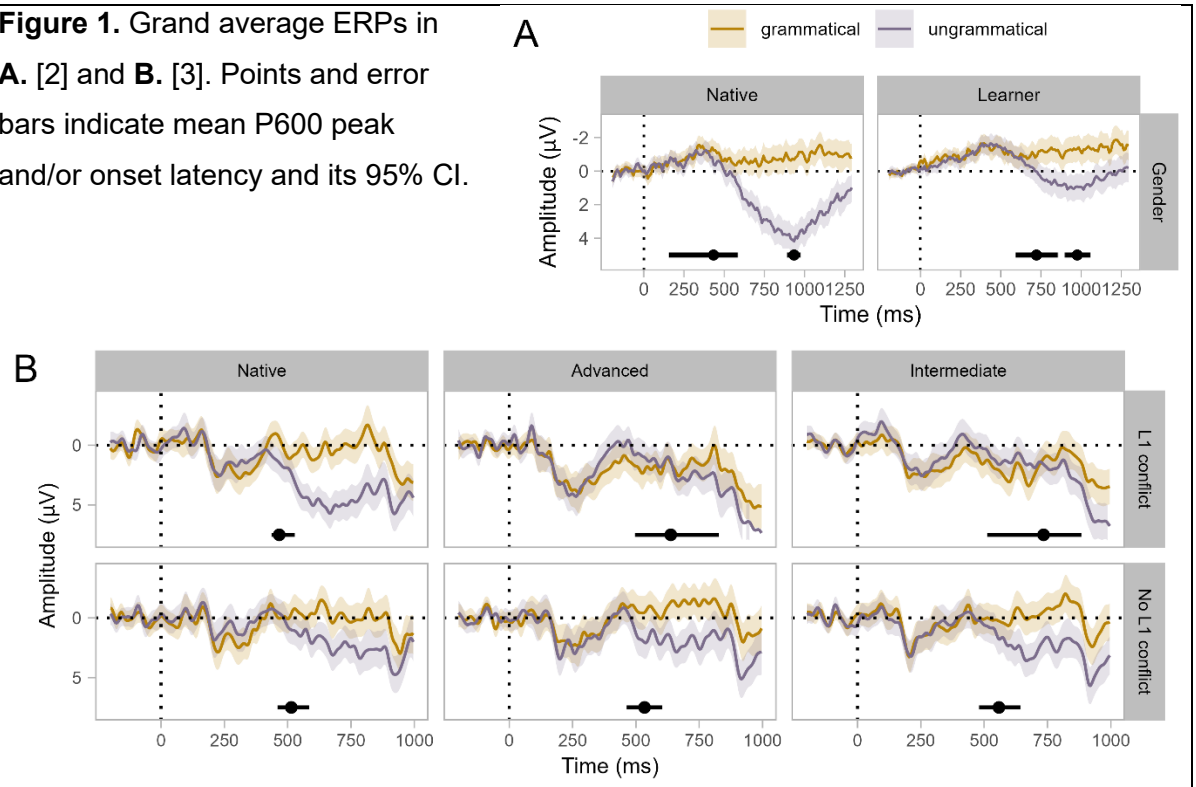
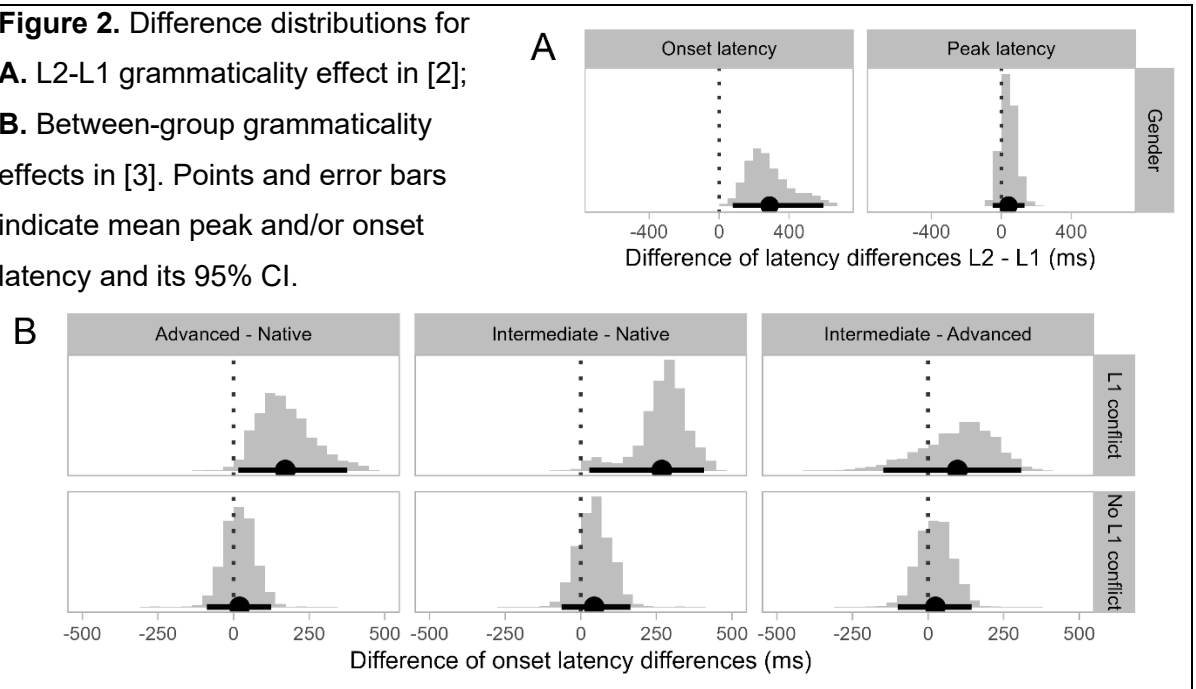


Figure 2. Difference distributions for **A.** L2-L1 grammaticality effect in [2]; **B.** Between-group grammaticality effects in [3]. Points and error bars indicate mean peak and/or onset latency and its 95% CI.



References.

[1] Kaan et al. The P600 as an index of syntactic integration difficulty, *LCP*, 2000.

[2] Meulman et al. GAM-based individual difference measures for L2 ERP studies, *Res Meth App Ling*, 2023

[3] Mickan & Lemhöfer. Tracking Syntactic Conflict between Languages over the Course of L2 Acquisition: A Cross-sectional Event-related Potential Study, *JoCN*, 2020

[4] *Redacted*.

Table 1. Example stimuli showing the different **violation types** across analysed experiments. The target word is indicated in bold.

(a) Meulman et al. (2023)	
Gender agreement	German: Nach der Schlägerei ist das/*der **Auge** des Angestellten…
	*English translation: After the fight, the.$_{neut}$/*the.$_{masc}$ **eye** of the worker is…*
(b) Mickan & Lemhöfer (2020)	
Word order	Dutch: Ik heb het huiswerk voor maandag niet **kunnen** doen**/*doen** kunnen.
(L1 conflict)	*German (L1): Ich habe die Hausaufgaben für Montag nicht *__können__ machen/ __machen__ können.*
	English translation: I have not been __able to do__ the homework for Monday.
Verb position (No L1 conflict)	Dutch: Wij komen uit Berlijn maar/*hoewel wij **wonen** daar niet meer.
	*German (L1): Wir kommen aus Berlin aber/*obwohl wir __wohnen__ da nicht mehr.*
	English translation: We're from Berlin but/although we no longer __live__ there.