Effects of Surprisal and Contextual Entropy on L2 and Heritage Language Processing

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Computational theories of language processing like Surprisal Theory [1], provide testable predictions for broad-coverage evaluations using reading time (RT) corpora [2-3]. However, most prior research has focused on adult monolingual speakers (though see [4]), limiting the generalizability of findings across diverse lpinguistic populations. This study evaluates how surprisal [1] and contextual entropy [5-6] impact RTs in L2 and heritage speakers, to shed light on integrative and anticipatory processing mechanisms in non-dominant languages.

Predictions. Surprisal Theory [1] suggests that processing difficulty correlates with a word's surprisal—its contextual probability given prior context (Eq. 1). Others have proposed that contextual entropy, which measures the degree of uncertainty about how it will continue (Eq. 2), may also influence RTs, if a speaker estimates processing time for a word before encountering it [5-6]. Unlike surprisal, which might reflect integration difficulty, entropy effects provide evidence for anticipatory processing [6-7]. If L2 and HL speakers use incremental contextual cues for prediction, both surprisal and entropy should affect L2 RTs. However, prior research shows L2 speakers are less effective at using linguistic context for prediction than L1 speakers [8-9]. For HL speakers, despite target-like performance in non-reading tasks [10], limited written input [11] may reduce sensitivity to surprisal and entropy during reading.

Analysis 1: Using the MECO-L2 corpus [12], we analyzed eye movements of L1 and L2 English speakers from diverse L1 backgrounds reading English texts. Linear mixed-effects models were fitted on three log-transformed eye-tracking measures—first fixation (FF), gaze duration (GD), and total reading time (TT), representing early, medium, and late processing stages, respectively. Predictors included surprisal and entropy (estimated from GPT-2 small [13]), word-level controls (e.g., length, frequency), and spillover effects (formula in Eq. 3). **Results:** Coefficients for surprisal and entropy (with 95% confidence intervals) were plotted for each group in Fig 1. Surprisal significantly predicted FF in 8 groups and GD/TT across all groups. Entropy was significant for 2 groups in FF and 9 groups in GD/TT. Interestingly, entropy effects were not significant for L1 English in FF/GD and only marginally significant in TT. A combined model including speaker group (L1 vs. L2) as a predictor and its interactions revealed that surprisal effects were weaker and frequency effects stronger in L2 speakers.

Analysis 2: Using a Russian eye movement corpus [14], we analyzed L2 and low-proficiency HL speakers of Russian whose dominant language is English. The analysis is identical to Analysis 1, with surprisal and entropy estimated from mGPT [15]. **Results (Fig. 2):** For HL speakers, higher surprisal and entropy generally slowed processing, with surprisal marginally significant in TT and entropy significant in GD and TT. However, neither surprisal nor entropy had an effect in the L2 group. Models with speaker group as a predictor showed that L2 speakers relied less on surprisal and more on frequency compared to HL speakers.

Discussion Overall, we found strong evidence of surprisal and entropy effects on L2 English processing across diverse L1 backgrounds, demonstrating their generalizability. However, L2 speakers rely more on word-level than contextual cues compared to L1 speakers. Notably, we are the first to show surprisal and entropy effects in HL processing. Despite limited written input, HL readers are influenced by these factors and utilize contextual cues more effectively than L2 Russian speakers. Lastly, we note that the absence of surprisal and entropy effects in L2 Russian may stem from the script difference between Russian and their L1 English.

Eq. 1: surprisal(w) = −log P(*w*|*c*)

Eq. 2: entropy(w_t) = E [surprisal(w)]

Eq. 3: log(FF/GD/TT) ~ surprisal + entropy + logfreq + prev.surprisal + prev.logfreq + prev.len.scaled + prev.entropy + (1|Subject) + (1|Word)

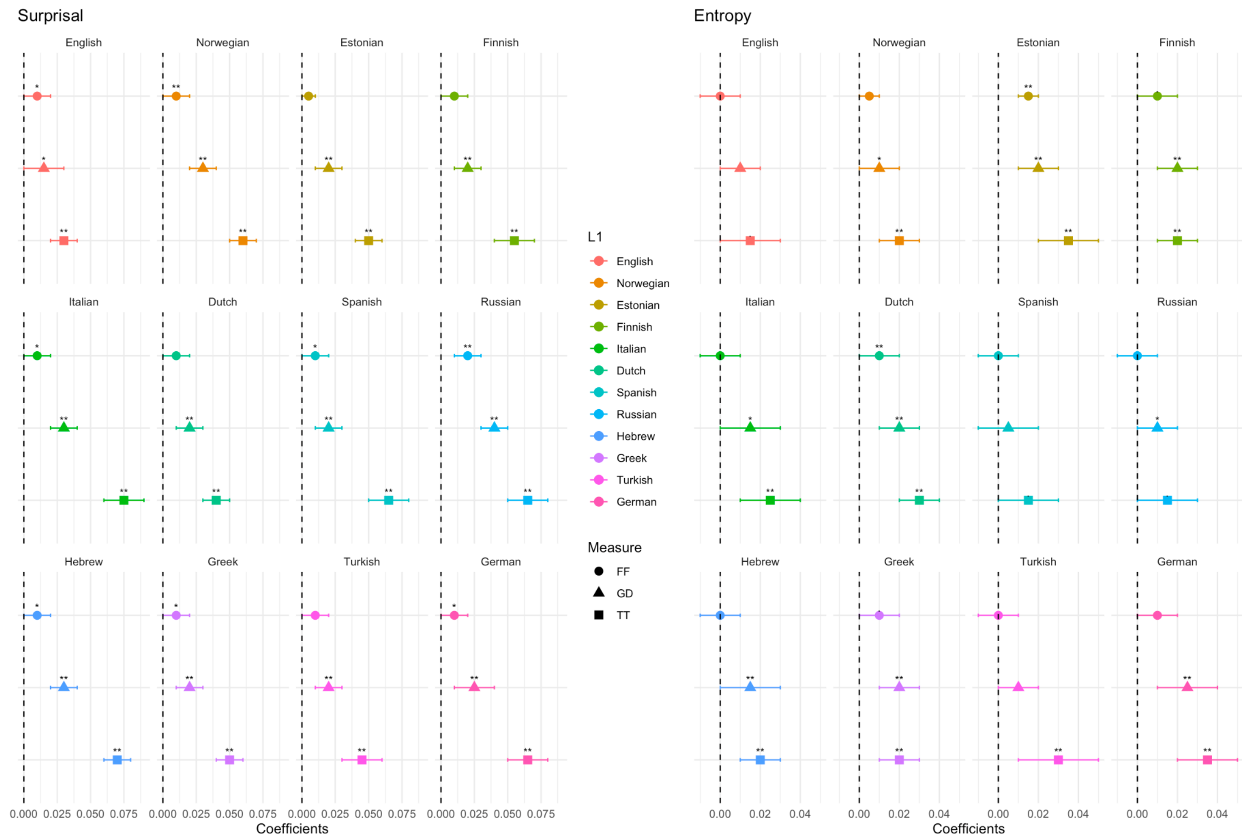

Fig. 1. Effects of surprisal and entropy across speaker groups in MECO-L2

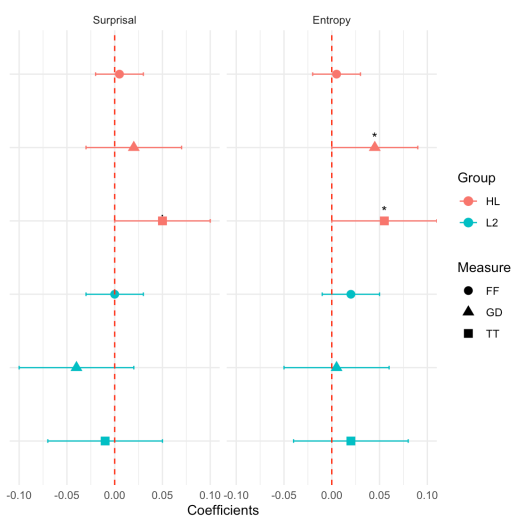

Fig. 2. Effects of surprisal and entropy in L2 and HL Russian

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