Using intonation to disambiguate meaning:

The role of empathy and proficiency in L2 perceptual development

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Abstract

The present study investigates the interplay between proficiency and empathy in the development of second language (L2) prosody by analyzing the perception and processing of intonation in questions and statements in L2 Spanish. A total of 225 adult L2 Spanish learners (L1 English) from the Northeastern United States completed a two-alternative forced choice (2AFC) task in which they listened to four utterance types and categorized them as either questions or statements. We used Bayesian multilevel regression and Drift Diffusion modeling to analyze the 2AFC data as a function of proficiency level and empathy scores for each utterance type. We show that learner response accuracy and sensitivity to intonation is positively correlated with proficiency, and this association is affected by individual empathy levels in both response accuracy and sentence processing. Higher empathic individuals, in comparison with lower empathic individuals, appear to be more sensitive to intonation cues in the process of forming sound-meaning associations, though increased sensitivity does not necessarily imply increased processing speed. The results motivate the inclusion of measures of pragmatic skill, such as empathy, to better account for intonational meaning processing and sentence comprehension in second language acquisition.

Keywords: Second language acquisition, Sentence processing, Speech perception, Intonation, Empathy

Word count: 8,319

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A fundamental difficulty of speech comprehension is that listeners can come to understand different messages when presented with the same linguistic information (Cain, Oakhill, & Lemmon, 2004). This can be especially problematic when one begins the endeavor of learning a new language. In particular, it is common for second language (L2) learners to struggle with intonation—i.e., the melodic contour of an utterance—in the target language (Trofimovich & Baker, 2006). The difficulties associated with intonation can result in comprehension and communication mishaps because the tune is associated not only with linguistic information, e.g., utterance type or syntactic constituency, but also pragmatic information, e.g., polite discourse (Astruc, Vanrell, & Prieto, 2016), bias, or presupposition (Henriksen, Armstrong, & García-Amaya, 2016). The present study investigated how the comprehension of intonation develops in adult L2 learners.

Recent research on monolingual populations suggests that individual differences in pragmatic skills, such as empathy, may play a role in meaning disambiguation (Bishop & Kuo, 2016; Esteve-Gibert, Portes, Schafer, Hemforth, & D'Imperio, 2016; Esteve-Gibert et al., 2020; Orrico & D'Imperio, 2020). Concretely, higher empathy individuals, in comparison with lower empathy individuals, appear to be more sensitive to the intonational cues of speech during the process of forming sound-meaning associations. Furthermore, increased attention has been given to how individual differences in learner backgrounds play a role in the process of L2 acquisition (Hu et al., 2013; Liu, 2017; Rota & Reiterer, 2009). The present study contributes to these lines of research by examining how individual differences in pragmatic skills affect the development and processing of intonation during sentence comprehension. Specifically, we investigated the interplay between language proficiency and an individual pragmatic skill (empathy) when learning an L2. We focused on the role of empathy in the development of L2 prosody by analyzing the perception and processing of intonation in questions and statements in L2 Spanish.

Background and motivation

L2 acquisition of prosody. The difficulties associated with learning an additional language in adulthood are numerous. More often than not the focus falls on individual sounds, or segments, though there is evidence that adults who learn an L2 face suprasegmental challenges as well (Craft, 2015, among others; Thornberry, 2014; Trofimovich & Baker, 2006). Concretely, L2 learners often struggle with intonation, i.e., melodic variation at the utterance level. This is, in part, because in everyday discourse speakers can use intonation to indicate syntactic structure, to signal whether an utterance is a question or a statement, to focus constituents, as well as to convey affective meaning. Notably, the manner in which intonation is mapped to meaning is often language-specific. For these reasons, the development of L2 intonation represents a facet of L2 phonological learning that often results in comprehension and communication difficulties (Trofimovich & Baker, 2006).

Intonation has a semantic function and through adequate cognitive decoding of the signal a listener can interpret the intended meaning of a given utterance. For example, an intonational contour can indicate to a listener whether the utterance of an interlocutor is declarative or interrogative in nature. As touched upon above, a speaker can use prosody to signal numerous additional pragmatic functions as well. Given the rich variation in pragmatic uses, it is unsurprising that interpreting and decoding intonational contours in a new language represents a particularly challenging aspect of speech comprehension for the language learner. Moreover, the use of first language (L1) prosodic features when speaking the target language can result in misunderstandings because the same prosodic features can convey different linguistic and paralinguistic meaning in the target language (Chen, 2005; Cruz-Ferreira, 1987; Mennen, 2007; Pickering, 2001). As noted by Levis (2016), prosody is also "[…] critical for L2 pronunciation because it plays a major role in cementing social bonds as a key marker of social identity" (p. 154).

For learners interested in obtaining native-like pronunciation, intonation is particularly relevant, as prosodic features have been found to be important cues in the perception of non-target-like accents, above and beyond other features of language (Jilka, 2000; Munro, 1995; Pettorino, De Meo, & Vitale, 2014). Nonetheless, intonation is not traditionally taught in the L2 classroom, perhaps because it is not common knowledge that proper control of prosody allows the learner not only to produce speech that is more intelligible, but also to comprehend speech in varied communicative settings (de-la-Mota, 2019). The primary focus is generally placed on syntax and morphology, with target language phonology receiving much less, if any, attention (Rao, 2019). When target language pronunciation is addressed, it often focuses on segmental elements (de-la-Mota, 2019), despite the fact that merely being intelligible at the segmental level does not necessarily imply one will be pragmatically understood. As a result, some research has found that intonation is one of the last aspects of L2 phonology that learners acquire (e.g., Kvavik & Olsen, 1974).

Research on L2 intonation has been concerned primarily with speech production. Learner difficulties tend to be ascribed to L1 transfer, and models of L2 phonology, by and large, focus on the speech segment, as in the Speech Learning Model revised (Flege & Bohn, 2021), or contrasts between segments, i.e., PAM-L2, L2LP (Best & Tyler, 2007; Van Leussen & Escudero, 2015, respectively). Theoretical work that specifically considers prosody in the acquisition of L2 phonology is virtually non-existent, though some researchers have considered how the aforementioned models might account for suprasegmental phenomena (See Trofimovich & Baker, 2006). Nevertheless, a dearth of knowledge remains regarding how perception of intonation develops in L2 learning, and even less is known about how individual pragmatic differences account for learner outcomes. The purpose of the present project is to address this gap in the literature by examining the perception and processing of intonation during adult L2 phonological acquisition.

Acquisition of Spanish prosody. As with all phonetic phenomena, a lack of invariance in the acoustic content of prosodic realizations also increases the difficulty of the learner's task. Beyond the level of the individual, however, dialectal differences can account for additional difficulties. Spanish is extensively spoken across the world, with relatively small geolectal differences between varieties when compared with other languages, such that speakers from distinct regions can still generally understand each other. That being said, phonetic variation is abundant. For instance, the pitch accent of the same utterance type—e.g., a declarative broad focus statement—may be realized differently with regard to pitch movement and/or syllable duration depending on the variety. Intonational strategies can be different altogether. Consider absolute interrogatives in Caribbean and Argentine Spanish, which are produced with a nuclear hat pattern in the former and a final falling F0 contour in the latter, both of which differ from the more common final rise found in many other varieties (See Hualde & Prieto, 2015).

Previous research on the acquisition of Spanish prosody has primarily focused on the production of statements and questions, particularly in the study abroad context, using pre-, post-test designs (See Craft, 2015; Henriksen, Geeslin, & Willis, 2010; Thornberry, 2014; Trimble, 2013a, among others). Though the degree of improvement is variable based on a myriad of factors—such as context formality (Trimble, 2013a), use of Spanish (Henriksen et al., 2010; Trimble, 2013a), social integration (Trimble, 2013a), or the development of meaningful social relationships with native speakers (Thornberry, 2014)—this line of research suggests that learners gradually acquire target-like intonation as they gain experience in the L2. There is a paucity of research on the perception of Spanish intonation, but limited studies corroborate the general finding in speech production that mastery is indeed possible for adult learners (Brandl, González, & Bustin, 2020; Nibert, 2005, 2006; Trimble, 2013b). For instance, Trimble (2013b) examined the perception of intonational cues in statements and absolute interrogatives in L1 English L2 Spanish adult learners that had studied abroad in Venezuela, Spain, or not at all. Using a gating task, Trimble (2013b) found that intonational cues that were absent from participants' L1 were difficult to perceive, though learners were more accurate with statements than questions, and that familiarity with the target variety improved accuracy. The investigation lends support to the general notion that the L2 intonation system develops in tandem with proficiency in Spanish, which was positively correlated with time spent studying abroad.

In a similar vein, Brandl et al. (2020) also investigated the perceptual development of intonation in questions and statements in L2 Spanish. Specifically, Brandl et al. (2020) examined the effect of L2 proficiency on the perception of broad-focus and narrow-focus declaratives and polar and absolute interrogatives in adult L1 English L2 Spanish learners. The learners completed a forced-choice task in which they were presented audio and visual stimuli in matched and mismatched conditions. The participants' task was to determine whether the sentence presented aurally was the same as the sentence presented visually. Brandl et al. (2020) found that perception and processing of L2 intonation improved in conjunction with proficiency in Spanish, though it was conditional on the utterance type, with polar ('yes/no') interrogatives being more difficult to process and acquire when compared with simple statements. The authors concluded that perception of L2 intonation develops gradually in conjunction with L2 proficiency.

To summarize, the extant literature suggests that mastery of L2 perception of intonation seems feasible for adult learners, as processing speed and accuracy both improve as L2 proficiency increases. That being said, some utterance types present more difficulties than others. Furthermore, familiarity with the L2 variety can positively impact learner outcomes, which is particularly relevant given the rich phonetic and phonological variability attested in Spanish prosody. Much less is known regarding how perceptual development is modulated by individual differences, such as those related to pragmatic skill.

Empathy and pragmatic skill. The construct empathy refers to one's ability to infer the intentions of others. It is associated with understanding the feelings and emotions of those with whom one interacts (Baron-Cohen & Wheelwright, 2004). Research on empathy has associated the construct with Theory of Mind and perspective-taking (Baron-Cohen, 2011; Carruthers, 2009; Frith & Frith, 2003). Importantly, in recent years empathy has served as a proxy for investigating individual pragmatic skill.

Studies on monolingual populations suggest that individual pragmatic skills correlate with variability in semantic/pragmatic interpretation of ambiguous linguistic items (e.g., Degen & Tanenhaus, 2016; Nieuwland, Ditman, & Kuperberg, 2010). That is, in this line of research, individuals described as having higher pragmatic skill tended to prefer pragmatically enriched interpretations and individuals described as having less pragmatic skill tended to prefer more literal/semantic interpretations. In addition, more pragmatically skilled individuals have also been found to rely on different phonetic cues to parse syntactically ambiguous sentences when compared with less pragmatically skilled individuals (Bishop & Kuo, 2016). Thus, one possibility is that variability in intonation processing is also linked to individual differences in pragmatic skills. A series of studies has investigated how empathy influences language processing in monolingual populations (Esteve-Gibert et al., 2016, 2020; Orrico & D'Imperio, 2020). This work operationalizes the construct empathy as a pragmatic skill and has focused on it as a source of individual differences.

For instance, Esteve-Gibert et al. (2020) examined how listeners with different levels of empathy interpreted intonation and meaning in contexts in which a temporary lexical ambiguity could only be resolved through intonation. Empathy was measured using the Empathy Quotient (EQ, Baron-Cohen & Wheelwright, 2004), a self-report questionnaire, and participants were partitioned into groups corresponding with low or high empathy. Esteve-Gibert et al. (2020) tested French monolinguals in a visual-world paradigm eye-tracking task that resembled a card guessing game. Target objects were homophones in French (e.g., *cane*, Eng. "female duck"; *canne*, Eng. "walking stick"). Esteve-Gibert et al. (2020) found that processing of the lexical ambiguity (the homophones *cane*/*canne*) was modulated by empathy level when intonation was the only cue available. Specifically, highly empathic individuals varied their looking behavior as a function of intonational cues while less empathic individuals did not. That is, higher empathy individuals, in comparison with lower empathy individuals, were found to be more sensitive to intonation cues in the process of forming sound-meaning associations. In short, individuals with more pragmatic skill (higher empathy) appear to be able to use intonation to resolve temporary lexical ambiguities that can lead to confirmatory vs. contrasting interpretations. This research underscores the importance of considering individual pragmatic differences when examining intonational meaning processing and sentence comprehension.

Related research in the SLA context is scant, though early studies included affective variables—such as attitude, motivation, empathy, and, more recently, grit, among others—as they pertain to individual differences. Empirical studies on empathy are limited, though the construct received attention from scholars as early as the 60's and 70's (Brown, 1973; Guiora & Acton, 1979; Guiora, Beit-Hallahmi, Brannon, Dull, & Scovel, 1972; Guiora, Brannon, & Dull, 1972; See Guiora, Taylor, & Brandwin, 1968). The particular body of work linking empathy with SLA has focused on speech production, or, more specifically, on what early scholars considered 'authentic pronunciation' and, more recently, 'pronunciation aptitude' (See Rota & Reiterer, 2009), though no strong associations have been found. To the best of our knowledge, no studies have explored the construct empathy as it pertains to L2 perceptual development. Thus, we extend this research to the SLA context to determine if individual differences in this pragmatic skill affect the development of intonation in L2 processing and sentence comprehension.

The present study

We investigate how proficiency and empathy are related to the development of L2 prosody by analyzing the perception of intonation in questions and statements in L2 Spanish. This study was pre-registered on the Open Science Framework[1] and designed to address the following research questions:

1. Is perceptional development in L2 Spanish modulated by proficiency and intonation type (i.e., Brandl et al., 2020)?
2. Do pragmatic skills—specifically, empathy—modulate the rate of development in L2 prosody?
3. Does speaker variety affect perception accuracy and processing speed?

[1] See https://osf.io/dh4zp/?view_only=162d6d13e5814417bcb9de349f18cb62

Regarding RQ1, we hypothesize that accuracy will increase and processing time will decrease as a function of proficiency and intonation type. As shown in previous studies, absolute interrogatives (i.e., yes-no questions) will present the most difficulty for L2 learners of Spanish, followed by partial interrogatives (i.e., wh-questions) and declarative broad focus and narrow focus statements. Based on the findings of Esteve-Gibert et al. (2020), we posit that prosodic development will occur sooner and at a faster rate in higher empathy individuals (RQ2). In this operationalization, 'sooner' refers to lower proficiency levels in a cross-sectional design, that is, at an earlier developmental stage when compared with lower empathy individuals. Finally, with regard to RQ3, based on tentative findings from native speaker pilot data, we hypothesize that, overall, L2 learners will have the most difficulty (lower accuracy, slower response time) with the Cuban variety.

This project presents a conceptual replication of Brandl et al. (2020) in that we employ a similar experimental paradigm using similar stimuli in order to analyze the relationship between proficiency and L2 perception of intonation. We extend this research by taking into account pragmatic skill, specifically empathy, in L2 sentence processing. Importantly, this research builds on recent studies looking at the role of individual pragmatic skills in language processing and extends them to the field of SLA.

Method

Participants

Two hundred twenty-five individuals completed a two-alternative forced choice (2AFC) task in which auditory stimuli were identified as being questions or statements. Participants were recruited using the Prolific.ac online experimental platform and were compensated at a rate of

$9.52 per hour for their time. We estimated the task would take approximately 15 minutes to complete, thus each participant was paid $2.70 for completing all three tasks. The mean time to completion was approximately 13 minutes. The pool of participants was filtered using criteria set in Prolific.ac to ensure participants self-reported as being L1 English speakers born, raised, and currently living in the Northeastern US with no knowledge of any languages other than English or Spanish. They reported no hearing difficulties and were required to use headphones on a personal computer. Upon beginning the experiment, all participants responded to the following screening questions: 1) What part of the US are you from? 2) At what age did you begin learning Spanish? 3) Are you proficient in any languages other than English/Spanish? Additionally, participants responded to the prompt "I am most familiar with Spanish from…" and using a pull-down window they selected a variety of Spanish or "I am not familiar with any variety of Spanish". We excluded data from any participant that responded that they were not from the US Northeast, that they began learning Spanish before the age of 13, or that they were proficient in a language other than English/Spanish. Participants responding categorically across all trials were also excluded. In sum, participants were adult native speakers of American English with varying levels of proficiency in Spanish, ranging from functionally monolingual to highly proficient. All participants with knowledge of Spanish were adult L2 learners, operationally defined as having begun the endeavor of learning Spanish after the age of 13.

Tasks

The study consisted of three tasks: a 2AFC task, a lexical decision vocabulary assessment, and a Likert-type questionnaire to assess empathy. The tasks were programmed in Python using Pyschopy3 (Peirce et al., 2019) and presented online via Pavlovia. All code and materials used to generate the tasks are freely available on the Open Science Framework (https://osf.io/dh4zp/?view_only=162d6d13e5814417bcb9de349f18cb62).

2AFC. In the 2AFC, task participants were presented with an audio file containing a statement (declarative: broad focus or narrow focus) or a question (yes-no or wh-). Their task was to determine, as quickly and as accurately as possible, if the utterance they heard was a question or a statement. Specifically, they responded to an on-screen prompt asking “Is this a question?” using the keyboard. To respond participants typed ‘1’ for ‘yes’ (i.e., “yes, this is a question”) and ‘0’ for ‘no’ (i.e., “no, this is not a question”).

The auditory stimuli consisted of 64 critical items, 16 of each utterance type. To generate the stimuli, we recorded native Spanish speakers of eight different varieties (Cuban, Peninsular-Madrileño, Peninsular-Andalusian, Puerto Rican, Chilean, Argentine, Mexican, and Peruvian). The eight native speakers all produced the same 64 critical items. All utterances were segmented using Praat (Boersma & Weenink, 2018) and normalized for peak intensity. The 2AFC task included 64 trials in which the stimuli presented were randomized across speaker variety. Each variety had the same probability of being selected on a given trial, such that, on average, a given participant heard each variety approximately eight times (See online supplementary materials for more information). Prior to pre-registering our research questions and hypotheses, we piloted the 2AFC experiment on 100 monolingual Spanish speakers to assure the quality of the items and assess the difficulty of the task. We did not come across any issues.

LexTALE. To assess Spanish proficiency we administered the Lexical Test for Advanced Learners of Spanish (LexTALE-ESP, henceforth LexTALE) (Izura, Cuetos, & Brysbaert, 2014; Lemhöfer & Broersma, 2012). The LexTALE is a lexical decision experiment used to provide a standardized assessment of proficiency/vocabulary size in Spanish. In this task participants see a series of words on the computer screen and must decide if they are real or fake using the keyboard (‘1’ for real, ‘0’ for fake). LexTALE scores can range from −20 to 60. Monolingual Spanish speakers generally score above 50. Scores from individuals with little or no knowledge of Spanish tend to be negative. Adult learners with low to medium proficiency can range from 0 to 25, and advanced learners generally score above 25. We conceive of proficiency as a continuous variable and therefore consider a monolingual English speaker to have little to no proficiency in Spanish (i.e., a negative value on the LexTALE). In our data set, participant scores ranged from −16 to 55, suggesting all proficiency levels were likely represented in the sample. The mean score was 12.95 (95% CrI: [11.18, 14.72]) with a standard deviation of 13.60 (95% CrI: [12.38, 14.9].

Empathy Questionnaire. The construct empathy was assessed using the Empathy Quotient (EQ, Baron-Cohen & Wheelwright, 2004). The EQ is a 60-item questionnaire that presents four point Likert-type items ranging from ‘strongly agree’ to ‘strongly disagree’. Forty of the questions assess empathy and 20 are filler items. In order to avoid response bias, choices indicating empathic responses are coded to elicit “agree” responses in half the target items and “disagree” responses in the other half. The target items are scored with 2 or 1 points based on if the participant responds “strongly” or “slightly”. Finally, the EQ is scored by summing the total points to produce a single value indicating an individual’s level of empathy. Thus, the minimum possible value is 0 (low empathy) and the maximum is 80 (high empathy). In our data set the average empathy quotient was 37.88 (Range: [9, 69], 95% CrI: [36.13, 39.68], SD: 13.39, 95% CrI of SD: [12.28, 14.67]). The empathy quotient in its entirety is available in the supplementary materials.

Procedure

Participants recruited via Prolific.ac completed all three tasks in a single session. The 2AFC task was first, followed by the LexTALE task, and, finally, the empathy quotient questionnaire. We planned to collect data from approximately 300 individuals: 100 monolingual Spanish speakers not reported here and 200 L2 learners). Following Brandl et al. (2020), we assumed the effect size for perceptual learning was moderate in terms of the criteria set forth for L2 research by Plonsky and Oswald (2014) (Cohen's D = 0.600, Pearson's r = 0.287). Based on this assumption, we estimated that we would need 94 participants to have an 80% chance of capturing the proficiency effect with a type II error rate of 5%. Our hypothesis related to empathy as a possible mediator of perceptual learning is exploratory in nature; therefore, we did not base our sample size estimate on any parameter estimates related to this effect. That said, we believed the aforementioned exploratory effect was likely to be small, and, considering the resources necessary and available to us, planned to recruit 100 additional participants.

We excluded data from participants in the following circumstances: error during data collection, clear lack of understanding or engagement during the task (i.e., all '1' responses, failed three attention checks, etc.), participants reporting having learned Spanish before the age of 13, or participants with knowledge of languages other than English and Spanish. Data from a total of 78 participants were discarded because the experimental session timed out and/or data was incomplete. An additional 8 participants were discarded due to low accuracy (n = 5), incomplete data (n = 2), and failed attention checks (n = 1). A total of 225 participants met the criteria for inclusion.

Statistical analyses

We report two primary statistical analyses that were pre-registered prior to collecting the learner data: response accuracy and drift diffusion models. All additional analyses are exploratory in nature and explicitly described as such. First, we analyzed response accuracy using Bayesian multilevel logistic regression. The model considered response accuracy for the population effects *utterance type* (declarative broad focus, declarative narrow focus, interrogative yes/no, interrogative -wh), *LexTALE score* (i.e., proficiency), *empathy quotient*, and the higher order interactions. The likelihood of the model was Bernoulli distributed with a logit link function. The criterion, *response*, was coded as '1' for correct responses and '0' for incorrect responses. Thus, the first analysis modeled the probability of responding correctly to the prompt "Is this a question?". We specified group-level effects for participants, speaker variety, and items. The slope for *utterance type* varied for the participant effect, as did the *LexTALE* by *empathy quotient* interaction for the speaker variety effect. All continuous variables were standardized and 'interrogative yes/no' was set as the baseline for *utterance type*, thus the model intercept represented the probability of a learner with average proficiency and average empathy responding correctly to a yes/no question.

The same model was fit to the response time data with the exception of the model likelihood, which was assumed to be distributed as lognormal. Response time was measured from the offset of the auditory stimuli. We arbitrarily excluded response times longer than ten seconds, which represented 37 tokens of 14,400 (0.26%). Participants were able to respond at any time after the onset of the auditory stimuli. There was a total of 443 (3.08%) tokens with negative response times. Of this subset, learners responded with 80.36% accuracy, therefore, we added the minimum value of the data set as a constant to all response times. As a result, the response time distribution comprised only positive values, a requirement of drift diffusion models (see below). We also fit an additional exploratory model with the same population- and grouping-effects structure using d’ (d prime) as the outcome variable.

The second primary analysis utilized Bayesian drift diffusion modeling (DDM, Ratcliff & McKoon, 2008). This approach to analyzing behavioral data models decision-making as a random-walk decision process. DDMs can simultaneously take into account responses and response times in two-choice tasks in a single model, thus they are particularly beneficial when analyzing tasks in which speed-accuracy tradeoffs may be present. We estimate the parameters of the DDM using Bayesian methods and subsequently fit measurement error models on the posterior estimates of the resulting parameters.

A DDM estimates four parameters: boundary separation, bias, drift rate and non-decision time. Boundary separation, α, quantifies the amount of information necessary to make a decision. The boundaries represent the thresholds for the two alternatives in the task, which, in our case, implies correct and incorrect responses. Bias, β, gives an indication of a preference for one of the choices at the beginning of the decision-making process. A positive bias value indicates a preference for the upper boundary, whereas a negative bias is an indicator of a preference for the lower boundary. The drift rate, δ, provides an assessment of the rate at which information is accumulated. A higher δ implies a random walk that arrives at one of the thresholds faster and is interpreted as an indication that the participant finds the task to be easier. Conversely, a lower drift rate is interpreted as indicating a more difficult task. The sign of the value is also relevant. Positive drift rate refers to evidence accumulation for the upper boundary and negative drift rate for the lower boundary. Finally, non-decision time, τ, models the part of the time course that is not associated with decision-making (e.g., the time necessary to perceive a stimulus prior to evidence accumulation). Figure 1 provides an example of a hypothetical DDM for the 2AFC task in the present project.

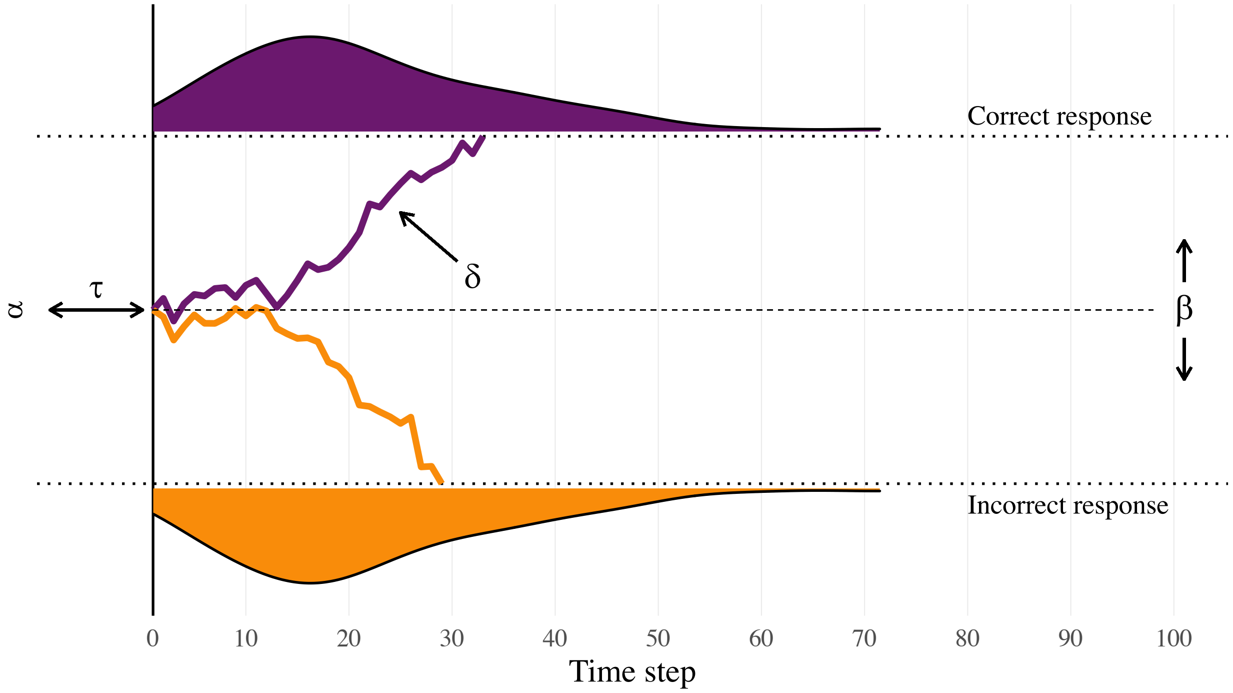

Figure 1. A drift diffusion model of the present study. The upper and lower bounds represent correct and incorrect responses, respectively. The boundary separation (α) is the distance between the two thresholds and indicates the evidence required to make a decision. Non-decision time (τ) represents the time course before evidence accumulation begins, i.e., time used for any process except decision-making. Bias (β) is the starting point for the evidence accumulation in the vertical plane (i.e., closer or further away from a given threshold), and drift rate (δ) quantifies the rate of evidence accumulation. The purple and orange lines represent examples of a decision resulting in a correct (purple) and incorrect (orange) decision. The corresponding density curves represent the distribution of response times at either threshold.

We estimated the aforementioned parameters by fitting a DDM to the response and response time data of each participant independently. We opted for this approach, as opposed to fitting a single model including all participants, for computational reasons. Put simply, the model likely would have taken weeks to fit, whereas the no-pooling (i.e., by-participant) method took approximately 26 hours. Thus, after fitting the DDMs, we obtained a posterior distribution of plausible values for boundary separation, drift rate, bias, and non-decision time for each participant. Next, we used measurement-error models to analyze boundary separation (α) and drift rate (δ) independently. These models followed the same functional form as the response accuracy model described above. That is, in two separate models, we analyzed the boundary separation and drift rate data as a function of *utterance type* (interrogative yes/no, interrogative -wh), *LexTALE score* (i.e., proficiency), *empathy quotient*, and the higher order interactions. The primary difference between the measurement-error models and the traditional regression analyses described for the response data is that the former can incorporate a measure of uncertainty around a point estimate. To give a concrete example, the analysis of the boundary separation data included the posterior median and the standard error for each participant as the outcome variable, as opposed to using just a single point estimate.

For all models, we included regularizing, weakly informative priors (Gelman, Simpson, & Betancourt, 2017). Generally, we sample from the posterior distribution of a given model for statistical inferences. To assess our pre-registered hypotheses we established a region of practical equivalence (ROPE) around a point null value of 0 (see Kruschke, 2018) using the following formula:

$$ROPE = \frac{\mu_1 - \mu_2}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}}$$

For all models, median posterior point estimates are reported for each parameter of interest, along with the 95% highest density interval (HDI), the percent of the region of the HDI contained within the ROPE, and the maximum probability of effect (MPE). For statistical inferences, we focus on estimation rather than decision-making rules, though, generally, a posterior distribution for a parameter β in which 95% of the HDI falls outside the ROPE and a high MPE (i.e., values close to 1) are taken as compelling evidence for a given effect. All exploratory analyses, explicitly described as such, include posterior point estimates, the 95% HDI, and the MPE. We conducted all analyses using R and fit all models using the probabilistic programming language `stan` via the R package `brms` (Bürkner, 2017, 2018). Finally, we provide more information for all analyses in the supplementary materials.

Results

Response accuracy

Figure 2 (left panel) summarizes the posterior distribution of the omnibus response accuracy model, illustrating point estimates ±66% and 95% HDIs in graphical form. An equivalent summary of the posterior distribution in table format is provided in the supplementary materials (See Table 1). The log-odds of a correct response to an absolute interrogative utterance at the average proficiency and EQ levels was 0.53, or approximately 62.95% (β = 0.53, HDI = [0.23, 0.83], ROPE = 0, MPE = 1). In comparison, all other utterance types were associated with an increase in the log odds of responding correctly. The right panel of Figure 2 plots response accuracy of each utterance type in the probability space. As illustrated in the plot, participants were slightly more accurate when responding to wh- questions (β = 0.43, HDI = [0.17, 0.65], ROPE = 0, MPE = 1) with approximately 72.31% correct, and much more accurate when responding to declarative utterances (narrow focus: β = 2.13, HDI = [1.86, 2.40], ROPE = 0, MPE = 1, Accuracy = 93.46%; broad focus: β = 2.34, HDI = [2.06, 2.60], ROPE = 0, MPE = 1, Accuracy = 94.63%).[2]

[2] An exploratory (i.e., not pre-registered) analysis of sensitivity to utterance type was also conducted using d’ in lieu of response accuracy. The results mirrored those found in the response accuracy model. That is, participants showed

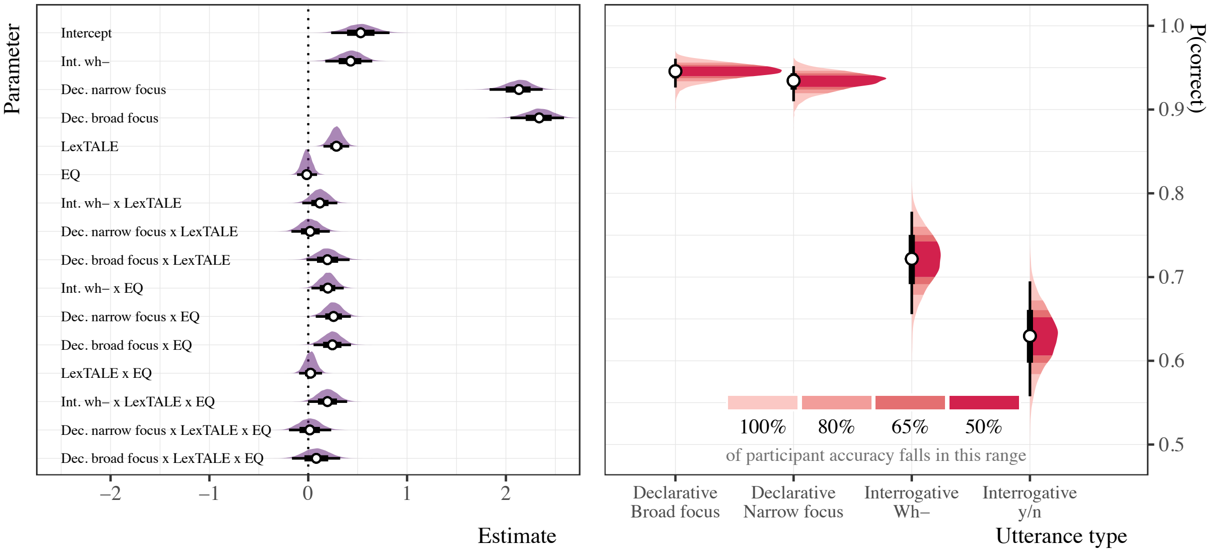

Figure 2. Forest plot summary of the response accuracy model (left panel) and posterior probability of a correct response for each utterance type (right panel). For both plots, white points represent posterior medians ±66% and 95% highest density credible intervals.

Figure 3 plots response accuracy as a function of utterance type and proficiency (left panel) and empathy quotient (right panel). For all utterance types, response accuracy increased as proficiency increased. Though the proficiency effect was most visually obvious for yes/no questions (β = 0.28, HDI = [0.15, 0.41], ROPE = 0, MPE = 1) and wh- questions (β = 0.40, HDI = [0.24, 0.57], ROPE = 0.00, MPE = 1.00), this was also the case for broad focus (β = 0.48, HDI = [0.26, 0.71], ROPE = 0.00, MPE = 1.00) and narrow focus (β = 0.31, HDI = [0.10, 0.51], ROPE = 0.00, MPE = 1.00) declaratives. There was no evidence that empathy level predicted response accuracy for yes/no questions (β = −0.02, HDI = [−0.12, 0.09], ROPE = 0.98, MPE = 0.62), however for wh- questions (β = 0.18, HDI = [0.05, 0.32], ROPE = 0.10, MPE = 1.00), broad focus declaratives (β = 0.23, HDI = [0.05, 0.43], ROPE = 0.06, MPE = 0.99), and narrow

highest sensitivity to the declarative utterances, followed by wh- and yes/no questions. These exploratory analyses are reported in the supplementary materials (See Table 3 and Figure 9).

focus (β = 0.24, HDI = [0.07, 0.42], ROPE = 0.03, MPE = 1.00) declaratives we find compelling evidence that the effect is positive.

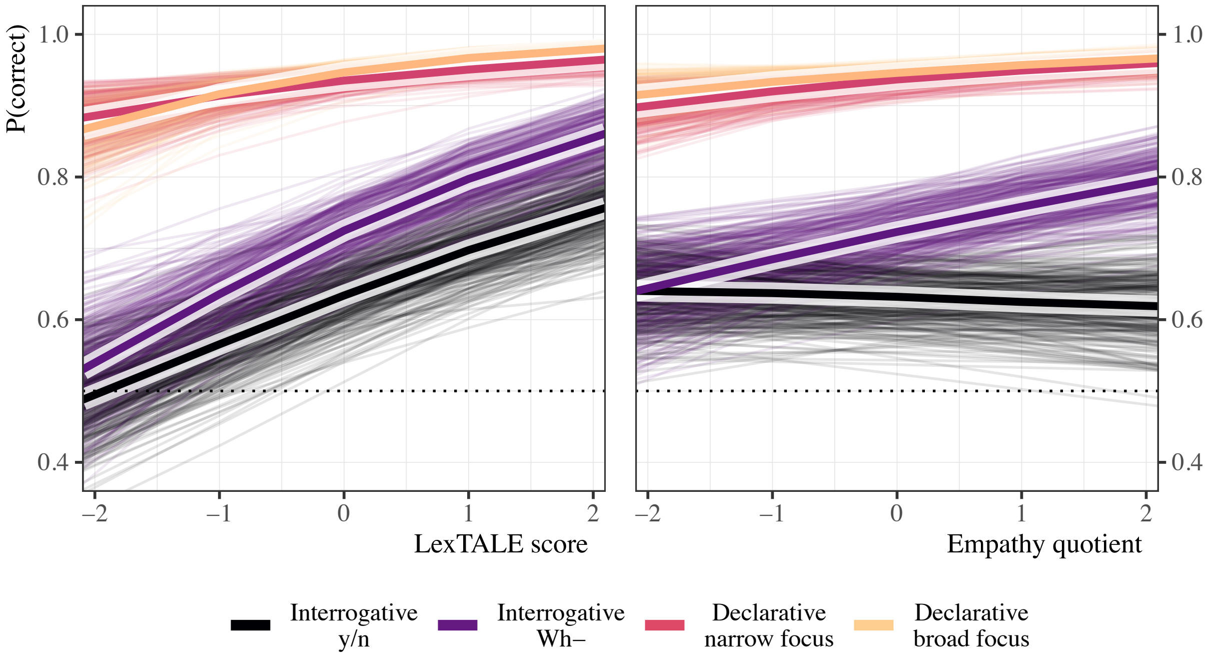

Figure 3. Conditional effects of a correct response as a function of proficiency (LexTALE score) (left panel) and empathy quotient (right panel) for each utterance type. Thin lines represent 300 draws from the posterior distribution for each condition and illustrate uncertainty (95% HDI) around the posterior medians (thick lines).

The omnibus model also estimated the proficiency × empathy quotient simple interaction for each utterance type. We used the posterior distribution to estimate the probability that this effect was non-zero for each utterance type. We found evidence that the proficiency effect was modulated by empathy quotient scores for wh- questions (β = 0.22, HDI = [0.05, 0.39], ROPE = 0.06, MPE = 0.99), though not for yes/no questions (β = 0.02, HDI = [−0.09, 0.14], ROPE = 0.92, MPE = 0.65), broad focus declaratives (β = 0.10, HDI = [−0.14, 0.35], ROPE = 0.46, MPE = 0.80), nor narrow focus declaratives (β = 0.04, HDI = [−0.17, 0.25], ROPE = 0.65, MPE = 0.64). This relationship is illustrated in Figure 4. Specifically, we plot conditional effects of response accuracy as a function of proficiency and empathy quotient for the yes/no and wh- interrogatives. In the left panel of Figure 4, one observes a positive correlation between response accuracy and proficiency that remains constant at standardized empathy quotient values of −1, 0 and +1 for the yes/no questions. For the wh- questions (right panel), on the other hand, we see that the slope of the proficiency effect increases for higher empathy quotient values. That is to say, for wh-questions, at a given proficiency level, learners with higher empathy (black lines) tended to respond more accurately.

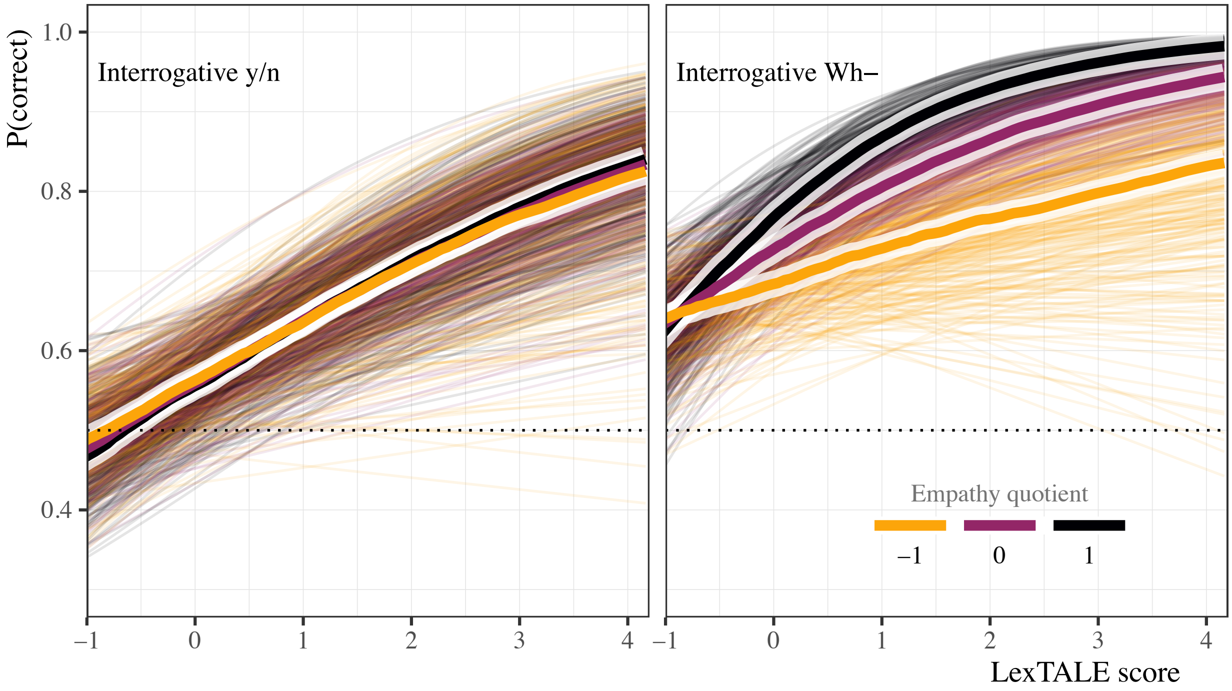

Figure 4. Probability of a correct response as a function of LexTALE score while holding empathy quotient scores constant at −1, 0 and +1 standard deviations from the mean for each question type. Thin lines represent 300 draws from the posterior distribution and indicate uncertainty (95% HDI) around the posterior medians (thick lines).

With regard to response accuracy and response time differences based on speaker variety, we used the speaker variety grouping effect from the omnibus model to obtain posterior estimates (See Figure 5). As was the case with the monolingual Spanish pilot data, learners were least accurate when responding to the Cuban variety and most accurate when responding to the Peninsular-Madrileño and Mexican varieties. Response accuracy to a given variety did not correlate with response times. For instance, although learners were least accurate when responding to the Cuban stimuli, they had average response times similar to the grand mean for this variety.

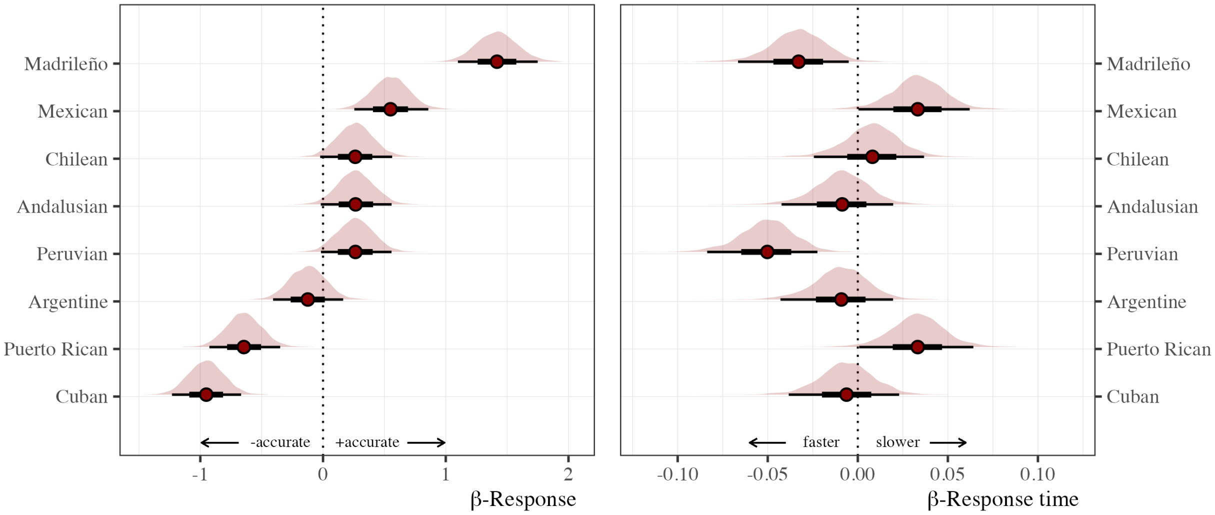

Figure 5. Grouping-level estimates of response accuracy and response time as a function of speaker variety. Red points represent posterior medians ±66% and 95% highest density credible intervals. The vertical dotted lines indicate the grand mean.

Drift diffusion models

As described previously, we fit a drift diffusion model to each participants' data in order to obtain estimates for boundary separation (α) and drift rate (δ). Specifically, we fit two Bayesian measurement error models with the same functional form: boundary separation or drift rate as a function of utterance type, proficiency (LexTALE score), and empathy quotient. Given the high accuracy on declarative utterances, we focus our analyses on yes/no and wh-interrogatives. Figure 6 provides a forest plot summarizing the two models.

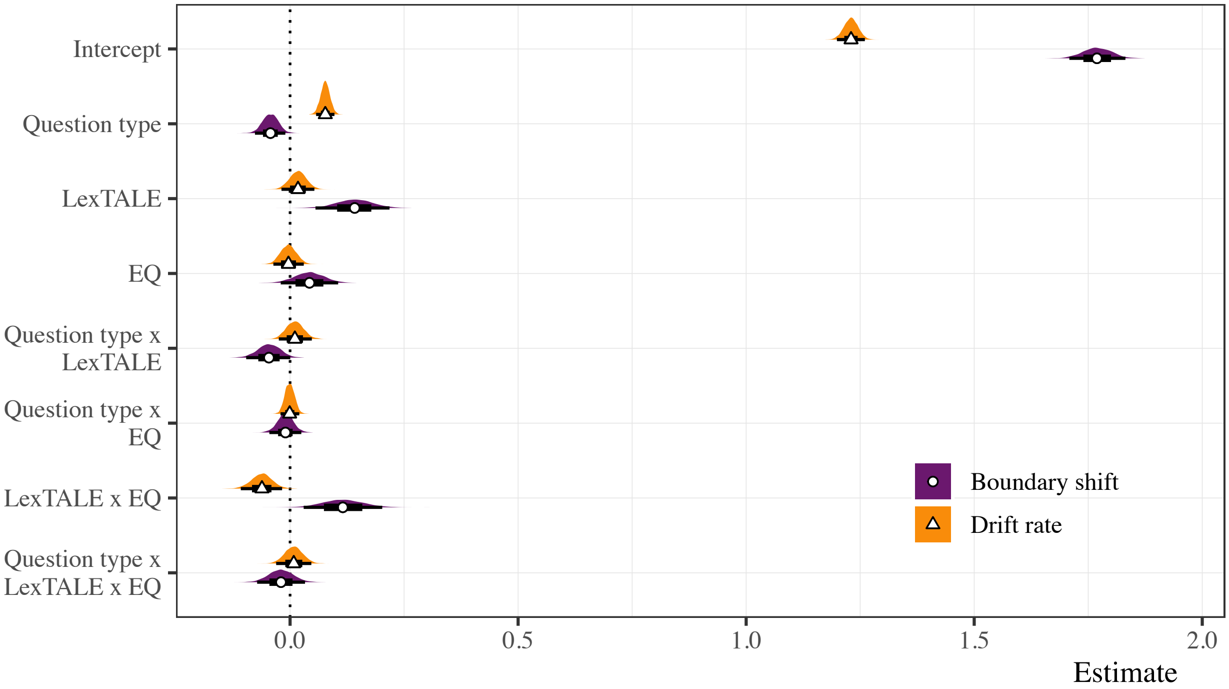

Figure 6. Forest plot summary of boundary separation (α, white circles under purple distributions) and drift rate (δ, white triangles under orange distributions) error measurement models.

Averaging over utterance type and holding proficiency and empathy quotient constant at the distribution means, posterior medians were positive for both boundary separation (β = 1.77, HDI = [1.70, 1.83], MPE = 1) and drift rate (β = 1.23, HDI = [1.20, 1.26], MPE = 1). Boundary separation was slightly lower in wh- questions (β = −0.04, HDI = [−0.08, −0.01], MPE = 0.99), suggesting that, overall, learners needed less information in order to make a decision when presented with interrogatives of this type. Drift rate, on the other hand, was higher for wh-questions (β = 0.08, HDI = [0.06, 0.10], MPE = 1), which indicates that learners arrived at the decision threshold at a faster rate, and, thus, found this type of utterance to be easier. This corresponds with the finding that overall learners were more accurate responding to wh-questions than yes/no questions by approximately 10% (Mean difference: β = 9.30, HDI = [3.69, 13.99], ROPE = 0.00, MPE = 1.00). Taken together, we can surmise that the 'average' learner has a lower threshold of required information in order to make a decision and arrives at this threshold at a faster rate for wh- questions in comparison with yes/no questions.

Crucially, in both models we also find evidence for a proficiency × empathy quotient interaction. For both question types, boundary separation increased as a function of proficiency, but the association was conditional on empathy quotient score ($\beta = 0.12$, HDI = [0.03, 0.20], MPE = 1), with low empathy individuals seeing little to no change in estimated α. The effect was reversed for drift rate. In this case, estimated δ increased as a function of proficiency in low empathy individuals, and higher empathy individuals, particularly those with higher proficiency levels, saw decreases in drift rate ($\beta = -0.06$, HDI = [−0.11, −0.02], MPE = 1). To illustrate more clearly the practical relevance of these interactions, we ran 2,000 simulations from the drift diffusion model. Figure 7 plots the simulations for each interrogative type at low/high proficiency and empathy levels (±2 standard deviations). Individual lines represent random walks. The walk ends when enough evidence is accumulated and a decision threshold (horizontal, discontinuous grey lines) is reached. The upper threshold indicates a decision leading to a correct response and the lower threshold an incorrect response. Thick red lines indicate the simulation average for correct/incorrect responses in each condition. Focusing on the lower row of plots (high empathy), moving from left to right (low proficiency to high proficiency) within each question type, one observes (a) an increase in boundary separation (α), i.e. a greater distance between thresholds, via the horizontal grey lines, and (b) a decrease in drift rate (δ), i.e., a slower rate of information accumulation leading to a decision, via the horizontal distance of the red lines. In practical terms, this implies that high proficiency, high empathy learners required more information to reach a decision and responded at a slower rate, particularly with regard to low empathy learners (top row), regardless of proficiency level.

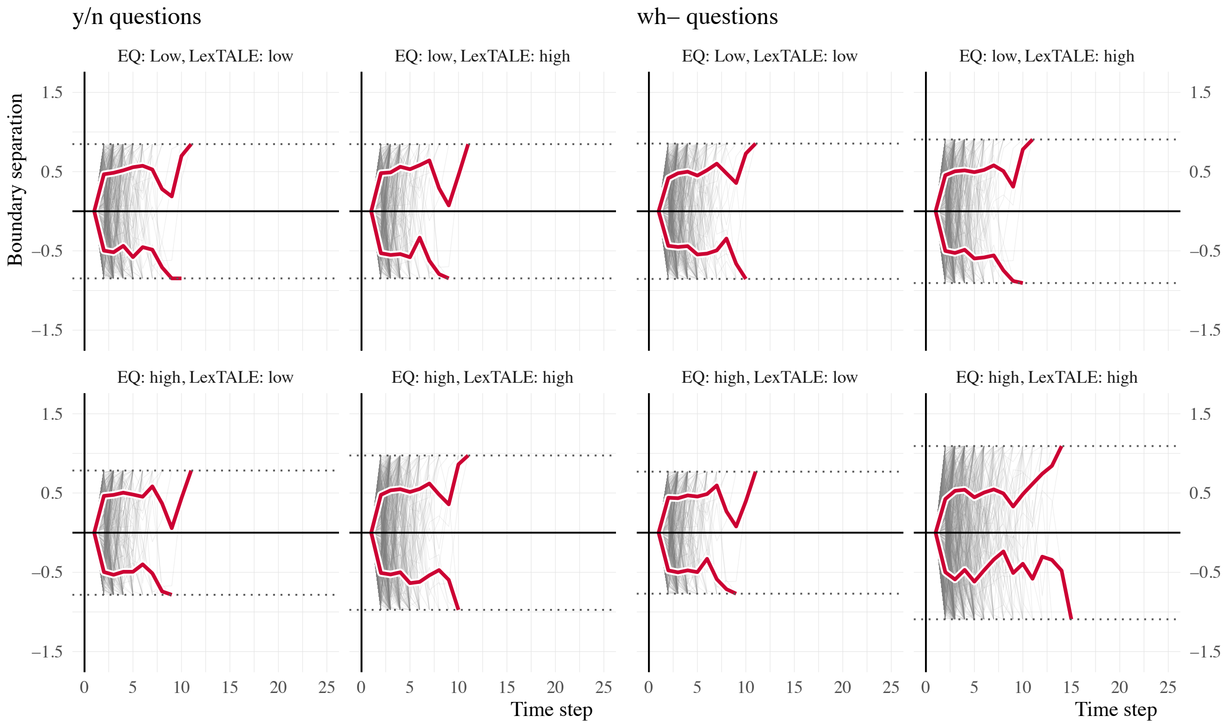

Figure 7. Two-thousand simulations of the drift diffusion model for interrogative utterances as a function of empathy quotient (low/high) and LexTALE score (low/high). Low and high levels represent ±2 standard deviations above/below the mean. Horizontal, discontinuous grey lines indicate decision thresholds and dark red lines represent the simulation averages.

Discussion

The present work explored how the comprehension of intonation develops in adult L2 learners of Spanish. We used a two-alternative forced-choice task in which participants determined whether or not utterances presented in auditory stimuli were questions. Our study represents a conceptual replication of Brandl et al. (2020), but extends this research to address recent findings suggesting that individual pragmatic skill—in the context of the present work, empathy—plays a role in the process of forming sound-meaning associations. We used Bayesian methods, in particular Drift Diffusion modeling (Ratcliff & McKoon, 2008), to analyze data from 225 L2 learners. We find that perception and processing of intonation develops in tandem with proficiency in the target language and is, to some degree, modulated by the construct empathy. This study set out to address three pre-registered research questions that we will now revisit.

The first question, *Is perceptional development in L2 Spanish modulated by proficiency and intonation type?*, was developed as a direct result of the previous literature examining the acquisition of Spanish prosody (i.e., Brandl et al., 2020; Trimble, 2013b). Response accuracy to all utterance types was positively correlated with proficiency, as measured by LexTALE scores. This corroborates the general finding that development of L2 intonation is positively correlated with target language proficiency, for both production (Craft, 2015; Henriksen et al., 2010; Thornberry, 2014; Trimble, 2013a, among others) and perception (Brandl et al., 2020; Nibert, 2005, 2006; Trimble, 2013b). In contrast with previous studies, our analyses conceptualized proficiency as a continuous variable, obviating the need to arbitrarily assign learners to proficiency groups. This operationalization will benefit future research interested in quantifying the effect of proficiency on perceptual development by allowing for more transparent designs with regard to statistical power and sample sizes. In line with previous studies (e.g., Brandl et al., 2020), we found that total interrogatives (i.e., yes-no questions) were most difficult for L2 learners of Spanish, followed by partial interrogatives (i.e., wh-questions) and declarative broad focus and narrow focus statements. An exploratory analysis using d' found that learner sensitivity to the utterance types followed the same pattern.

Additionally, our study addressed the question *Do pragmatic skills—specifically, empathy—modulate the rate of development in L2 prosody?* This question was motivated by a line of research showing that empathy influences language processing in monolingual populations (Esteve-Gibert et al., 2016, 2020; Orrico & D'Imperio, 2020). Though the construct *empathy* has been considered in the SLA literature, the current body of research is limited to studies on pronunciation accuracy (i.e., Guiora et al., 1972; Rota & Reiterer, 2009, among others). Thus, we extend research on empathy to L2 phonological acquisition as it relates to speech perception. Using a cross-sectional design, we show (1) that empathy, as measured by the empathy quotient (Baron-Cohen & Wheelwright, 2004), did indeed modulate response accuracy and the decision-making process, and (2) *how* empathy affected sentence processing was related to L2 proficiency. Specifically, we found response accuracy increased as a function of proficiency, independent of empathy for yes/no questions, but not wh- questions. In the case of the latter, empathy had a compounding effect on the correlation between accuracy and proficiency, such that higher empathy individuals showed more accuracy at lower proficiency levels when compared with their lower empathy counterparts. This is taken as evidence suggesting that pragmatic skill can modulate the rate of development in L2 prosody. That is to say, higher empathy individuals may develop L2 prosody at an earlier stage than lower empathy individuals.

In addition to addressing response accuracy, we also show that for high proficiency, high empathy learners (1) more information was necessary to reach a decision and (2) responses came at a slower rate when compared with low empathy learners at any proficiency level. This interaction effect on sentence processing was found for both partial and absolute interrogatives. Previous research on monolingual populations has shown that higher empathy individuals are more sensitive to intonation cues in the process of forming sound-meaning associations than lower empathy individuals. Our findings support the notion that this is also true for adult L2 learners, though we show that increased sensitivity does not necessarily imply increased processing speed. Given that empathy comprises the cognitive process of identifying the emotional state of another living being as well as the affective process of experiencing a similar sensation within oneself, it is plausible that higher empathy individuals showed more sensitivity to intonation cues and unconsciously devoted cognitive efforts to this process because they tended to require more information during decision-making. On the contrary, other individuals, which did not require as much information for reaching a decision, likely did not employ the same cognitive and affective processes related to empathy.

Our third research question addressed the effect of speaker variety on L2 perceptual development. Specifically, we asked *Does speaker variety affect perception accuracy and processing speed?* This question was motivated by Brandl et al. (2020), who raised the possibility that dialectal or sociolectal variation could have influenced participants' responses in their data. Their study included stimuli from eight varieties of Spanish, though this factor was not considered in their analysis. Building on Brandl et al. (2020), our auditory stimuli also included eight distinct varieties of Spanish. We found that, generally, speaker variety did indeed affect response accuracy. As was the case with our pilot data from monolingual Spanish speakers, learners were most accurate responding to stimuli from the speaker of Peninsular-Madrileño Spanish, and least accurate when responding to the Cuban variety. Interestingly, accuracy with a given variety did not correlate with response times in a straightforward way. For instance, participants did not respond faster to the Peninsular-Madrileño variety even though they were more accurate in their responses to this speaker.

The results of our study suggest that speaker variety does affect perception accuracy, though this does not necessarily map directly on to processing speed. One possibility put forward in the literature is that the variety matters insomuch that it is familiar to the listener (see Perry, Mech, MacDonald, & Seidenberg, 2018; Trimble, 2013b). In other words, learners may be more accurate and process speech faster when listening to a variety they know well. Our study took into consideration familiarity, though the variety that was cited as being the most familiar, U.S.

Spanish (34.67% of 225 responses), was not one of the varieties presented in the stimuli. Mexican (20.89%) and Peninsular-Madrileño (19.56%) Spanish were reported as being the second and third most familiar varieties, and no participants indicated Cuban Spanish as being the variety they were most familiar with. Thus, familiarity with the target variety may account for variety-specific response accuracy.

Another plausible explanation for variety-specific difficulties lies in cross-linguistic differences in the prosodic realizations of the distinct utterance types. Absolute interrogatives in Peninsular-Madrileño Spanish, for example, have the common final rise found in many other varieties of Spanish, as well as Standard American English. Caribbean Spanish, on the other hand, has a distinctive nuclear hat pattern (See Hualde & Prieto, 2015). Our experimental design does not allow us to say definitively whether dialectal variation at the suprasegmental level accounts for variety-specific difficulties (as opposed to additional variation at the level of the segment, for example), though this reasoning is in line with previous studies, i.e., Trimble (2013b).

A final possibility is that speech rate differences associated with the speakers of the stimuli we used may have resulted in some varieties being more or less difficult for the learners (See Baese-Berk & Morrill, 2019). In an exploratory analysis of the auditory stimuli, we found that speech rate had no effect on response accuracy, as some of the varieties to which participants responded most accurately were also the fastest (e.g., the stimuli from our Mexican speaker). See Figure 11 of the supplementary materials for visualizations and further discussion.

In sum, the present work contributes to our knowledge of an understudied construct, empathy, as it pertains to speech. Additionally, this is the first time, to our knowledge, that drift diffusion models have been used to analyze behavioral data relating to empathy in SLA. We also underscore the general need for models of L2 phonology, such as the SLM-r (Flege & Bohn, 2021), PAM-L2 (Best & Tyler, 2007), L2LP (Van Leussen & Escudero, 2015), etc., to address the acquisition process beyond the level of the segment. There is still a paucity of research with regard to how perception of intonation develops in L2 learning, particularly with regard to how individual pragmatic differences account for learner outcomes. A complete model of speech learning should account for both causal prediction and imputation at the segmental and suprasegmental levels. The present study aimed to address this gap in the literature by examining the perception and processing of intonation during adult L2 phonological acquisition.

While the findings of our research suggest there is a relationship between target language proficiency and empathy, it is important to underscore that we do not make any claims about causality. Future research would benefit from considering the learnability of empathy (i.e., Bertrand, Guegan, Robieux, McCall, & Zenasni, 2018; Lam, Kolomitro, & Alamparambil, 2011) as it relates to L2 outcomes. Furthermore, the cross-sectional design of the present work is not ideal for addressing how empathy levels affect the rate at which perception of L2 intonation develops. Only longitudinal data can appropriately address this issue. On that note, at this time, research on speech perception and empathy is limited to intonation. A fruitful avenue for novel research ought to examine how empathy is related to perception and spoken word recognition at the segmental level. Other topics of interest include the relationship between empathy and variation in speech processing with regard to dialectal differences in monolinguals and L2 learners.

Conclusion

The present study investigated the development of L2 perception of intonation. Specifically, this study explored the relationship between target language proficiency and an individual pragmatic skill, empathy, in the process of learning Spanish as a second language by analyzing the perception and processing of intonation in questions and statements. We find that perception and processing of intonation develops in tandem with proficiency in the target language and interacts with individual empathy levels, supporting the general conclusion that higher empathic individuals, in comparison with lower empathic individuals, appear to be more sensitive to intonation cues in the process of forming sound-meaning associations. Importantly, increased sensitivity does not necessarily entail increased processing speed. The results motivate the inclusion of measures of pragmatic skill, such as empathy, to better account for intonational meaning processing and sentence comprehension in second language acquisition research.

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On-line supplementary material

Traditional analyses

This section contains additional information regarding the response accuracy and response time analyses, as well as tables reported but not included in the main text.

Learner response accuracy. The population effects of the response accuracy model were specified in the following manner:

$$\begin{aligned} \text{is\_correct}_{ij} &\sim Bernoulli(p_{ij}, m_{ij}) \\ \text{logit}(p_{ij}) &= \beta_0 + \beta_1 * question\_type + \beta_2 * LexTALE + \beta_3 * EQ + \\ &\quad \beta_4 * question\_type * LexTALE * EQ \end{aligned}$$

We employed the `0 + Intercept` syntax of `brms` and set weakly informative priors as follows:

$$\begin{aligned} \beta &\sim Normal(0{,}0.3) \\ \sigma &\sim Cauchy(0{,}0.1) \\ \rho &\sim LKJcorr(2) \end{aligned}$$

The summary of the response accuracy model is available in Table 1. The information provided in this table is equivalent to the left panel of Figure 2 in the manuscript.

Table 1: Summary of the posterior distribution modeling response accuracy as a function of utterance type, LexTALE, and Empathy quotient. The table includes posterior medians, the 95% HDI, the percentage of the HDI within the ROPE, and the maximum probability of effect (MPE).

Parameter	Median	HDI	% in ROPE	MPE	Rhat	ESS
Intercept	0.53	[0.23, 0.83]	0.00	1.00	1.00	2099
Int. wh-	0.43	[0.17, 0.65]	0.00	1.00	1.00	2723
Dec. narrow focus	2.13	[1.86, 2.40]	0.00	1.00	1.00	2608
Dec. broad focus	2.34	[2.06, 2.60]	0.00	1.00	1.00	2576
LexTALE	0.28	[0.15, 0.41]	0.00	1.00	1.00	5245
Empathy quotient	−0.02	[−0.12, 0.09]	0.98	0.62	1.00	5351
Int. wh-:LexTALE	0.12	[−0.05, 0.30]	0.42	0.90	1.00	4977
Dec. narrow focus:LexTALE	0.02	[−0.17, 0.22]	0.72	0.58	1.00	8450
Dec. broad focus:LexTALE	0.19	[−0.02, 0.42]	0.18	0.96	1.00	9482
Int. wh-:EQ	0.20	[0.03, 0.36]	0.10	0.99	1.00	4912
Dec. narrow focus:EQ	0.26	[0.08, 0.43]	0.02	1.00	1.00	8389
Dec. broad focus:EQ	0.24	[0.05, 0.43]	0.05	0.99	1.00	8180
LexTALE:EQ	0.02	[−0.09, 0.14]	0.92	0.65	1.00	5954
Int. wh-:LexTALE:EQ	0.19	[0.00, 0.40]	0.16	0.97	1.00	5604
Dec. narrow focus:LexTALE:EQ	0.02	[−0.20, 0.23]	0.67	0.56	1.00	8344
Dec. broad focus:LexTALE:EQ	0.08	[−0.16, 0.33]	0.51	0.74	1.00	8698

Drift diffusion models

Drift Diffusion Models (DDM), also referred to as Wiener Diffusion Models and Decision Diffusion Models, represent our preferred method for analyzing the data from our 2AFC task. DDMs are rarely used in SLA research, though they are commonplace in psychology. The primary selling point of using a DDM is related to the parameters the model estimates: boundary separation (α), drift rate (δ), bias (β), and non-decision time (τ). Together these parameters give rich information about the processes believed to underpin decision-making. Specifically, a DDM requires decision data, e.g., “left” or “right” choices, correct or incorrect responses, etc., and response times associated with said decisions. In linguistics, particularly in psycholinguistics, data of this nature derived from 2AFC tasks are often analyzed using separate models, one for responses, and another for response times (as we have done in our so-called ‘traditional analyses’).[3] As mentioned, a DDM uses both of these dependent variables—responses and response times—to estimate the 4 aforementioned parameters. The estimates can then be scrutinized in subsequent models, if one estimates the parameters for each participant (i.e., the approach taken in the present work), and/or used for simulations. For our purposes, we employ the Bayesian implementation of the DDM, thus we sample from a posterior distribution of plausible estimates for α, δ, β, and τ for each participant. We then summarize and report these posterior distributions for statistical inferences.

The no-pooling models were fit using the following specification in `brms`:

```
  rt_raw | dec(is_correct) ~ 0 + sentence_type,
  bs ~ 0 + sentence_type,
  ndt ~ 0 + sentence_type,
  bias ~ 0 + sentence_type
```

and the priors were:

```
prior("normal(0, 1)", class = "b"),
prior("normal(0, 5)", class = "b", dpar = "bs"),
prior("normal(0.2, 1)", class = "b", dpar = "ndt"),
prior("normal(0.5, 1)", class = "b", dpar = "bias")
```

The complete code used to fit the models are available in `09_ddm.R` in the r scripts directory.

Measurement-error models. The measurement error models fit to the boundary separation and drift rate data were specified to include the standard error around each posterior median for α and δ:

[3] Given how relatively uncommon DDMs are in linguistics, the present work includes both approaches, though it is reasonable to assume that this practice will diminish as DDMs become more well-known and the resources for implementing them become more user-friendly.

$$\begin{aligned}\alpha &\sim Normal(\alpha_{n,TRUE}, SE_{\alpha})\\ \delta &\sim Normal(\delta_{n,TRUE}, SE_{\delta})\end{aligned}$$

The priors for the drift rate model were:

$$\begin{aligned}\alpha &\sim Normal(1{,}0.5)\\ \beta &\sim Normal(0{,}0.3)\\ \tau &\sim Cauchy(0{,}0.3)\\ \sigma &\sim Cauchy(0{,}0.1)\\ \rho &\sim LKJcorr(2)\end{aligned}$$

and the priors for the boundary separation model were:

$$\begin{aligned}\alpha &\sim Normal(2{,}0.5)\\ \beta &\sim Normal(0{,}0.5)\\ \tau &\sim Cauchy(0{,}0.3)\\ \sigma &\sim Cauchy(0{,}0.1)\\ \rho &\sim LKJcorr(2)\end{aligned}$$

To specify this type of model in `brms` we use the `resp_se` function, as follows:

```
estimate | resp_se(se, sigma = TRUE) ~ 1 + # Criterion
  q_sum * lextale_std * eq_std +           # Population-level effects
  (1 + q_sum * lextale_std * eq_std | participant) # Group-level effects
```

The model summary is available in Table 2, which is equivalent to Figure 6 in the main document.

Table 2: Summary of the posterior distribution modeling boundary separation and drift rate as a function of question type, LexTALE, and Empathy quotient. The table includes posterior medians, the 95% HDI, the percentage of the HDI within the ROPE, and the maximum probability of effect (MPE).

Model	Parameter	Median	HDI	MPE	Rhat	ESS
Boundary	Intercept	1.77	[1.70, 1.83]	1.00	1.00	3407
separation	Question type	−0.04	[−0.08, −0.01]	0.99	1.00	3676
	LexTALE	0.14	[0.06, 0.22]	1.00	1.00	3460
	EQ	0.04	[−0.02, 0.11]	0.91	1.00	3585
	Question type:LexTALE	−0.05	[−0.09, 0.00]	0.97	1.00	3594
	Question type:EQ	−0.01	[−0.04, 0.03]	0.73	1.00	3993
	LexTALE:EQ	0.12	[0.03, 0.20]	1.00	1.00	3912
	Question type:LexTALE:EQ	−0.02	[−0.07, 0.03]	0.77	1.00	3580
Drift rate	Intercept	1.23	[1.20, 1.26]	1.00	1.00	3814
	Question type	0.08	[0.06, 0.10]	1.00	1.00	3584
	LexTALE	0.02	[−0.02, 0.05]	0.83	1.00	3276
	EQ	0.00	[−0.03, 0.03]	0.59	1.00	4063
	Question type:LexTALE	0.01	[−0.02, 0.05]	0.70	1.00	3846
	Question type:EQ	0.00	[−0.02, 0.02]	0.53	1.00	4123
	LexTALE:EQ	−0.06	[−0.11, −0.02]	1.00	1.00	4114
	Question type:LexTALE:EQ	0.01	[−0.03, 0.05]	0.66	1.00	3733

Supplementary analyses

In this section we present supplementary analyses, all of which are exploratory in nature.

D'. Figure 9 and Table 3 represent an exploratory analysis of d' scores as a function of utterance type and speaker variety. One observes similar patterns to those from the accuracy analysis presented in the manuscript. The primary takeaway is that the analysis of learners' sensitivity to Spanish prosody mirrors that of their accuracy. That is to say, learners are more sensitive to (and accurate with) statements (declarative broad focus, declarative narrow focus) than questions (interrogative wh-, interrogative yes/no) (left panel of Figure 9. Learner sensitivity to the different Spanish varieties represented in the stimuli pattern in the same manner, i.e., more sensitivity to the Peninsular variety and less sensitivity to the Cuban variety (right panel of Figure 9). Table 3 summarizes the posterior of these exploratory analyses.

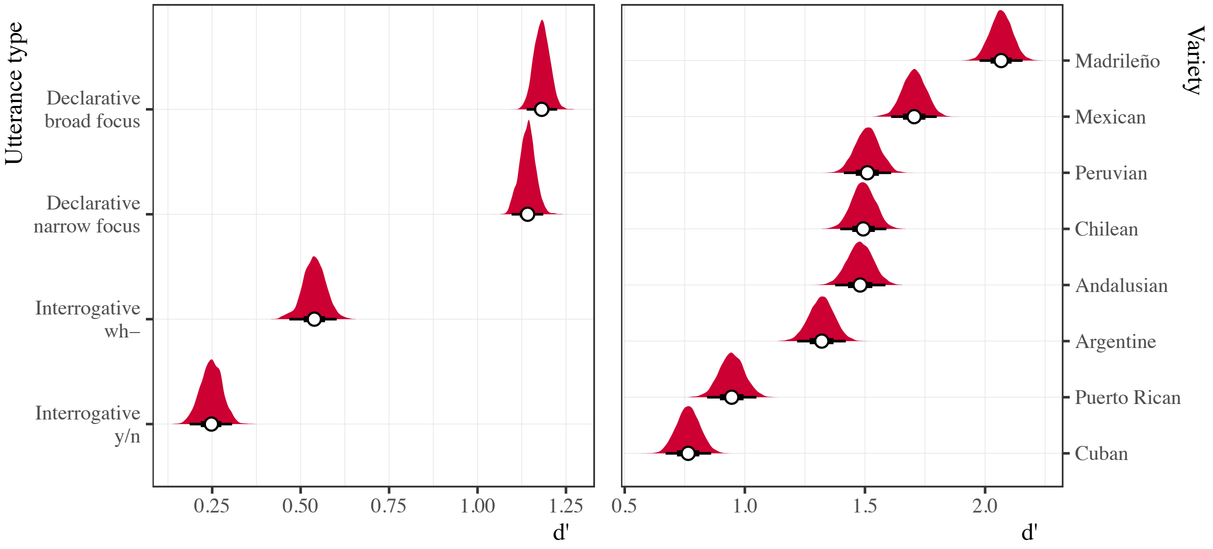


Figure 9. Exploratory analysis of d' as a function of utterance type and speaker variety. Points represent posterior medians ±66% and 95% credible intervals.

Table 3: Summary of the posterior distribution modeling d' as a function of question type or speaker variety. The table includes posterior medians, the 95% HDI, and the maximum probability of effect (MPE).

Model	Parameter	Median	HDI	MPE
Utterance type	Declarative broad focus	1.18	[1.14, 1.23]	1.00
	Declarative narrow focus	1.14	[1.10, 1.19]	1.00
	Interrogative wh-	0.54	[0.47, 0.61]	1.00
	Interrogative y/n	0.25	[0.19, 0.31]	1.00
Variety	Andalusian	1.48	[1.38, 1.59]	1.00
	Argentine	1.32	[1.22, 1.42]	1.00
	Chilean	1.49	[1.40, 1.59]	1.00
	Cuban	0.76	[0.67, 0.86]	1.00
	Mexican	1.70	[1.61, 1.80]	1.00
	Madrileño	2.07	[1.98, 2.15]	1.00
	Peruvian	1.51	[1.42, 1.61]	1.00
	Puerto Rican	0.95	[0.85, 1.05]	1.00

Randomization check across participants. For the purposes of our research questions, it was important that every participant be presented with stimuli from all of the Spanish varieties to which we had access. Recall that the 2AFC task contained 64 items, 16 of each utterance type. Using javascript we assigned each variety an equal probability of being selected in a given trial (0.125). To ensure that our randomization worked as planned (i.e., with each variety represented approximately equally across all trials and all participants), we calculated the average number of times each variety was presented in the data set (n = 225, and 14400 trials). One can observe in Figure 10 that this is indeed the case.

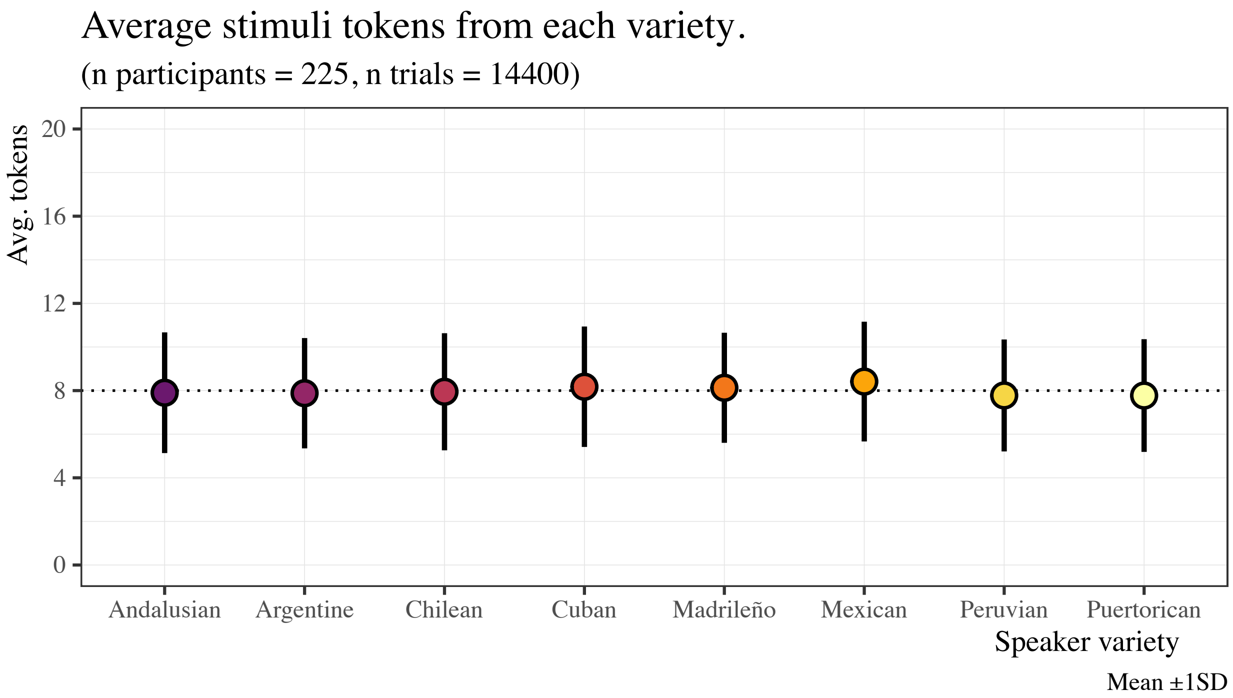


Figure 10. Average number of tokens (±1 SD) presented from each speaker variety across all 14,400 trials. The experiment was programmed such that each of the 8 varieties had an equal probability of being presented (12.50%) across 64 experimental trials.

Auditory stimuli. The auditory stimuli consisted of 8 varieties of Spanish: Cuban, Peninsular-Madrileño, Peninsular-Andalusian, Puerto Rican, Chilean, Argentine, Mexican, and Peruvian. Table 4 contains demographic information about the speakers.

Table 4: Demographic information for the eight varieties of Spanish represented in the auditory stimuli.

Country	City/Variety	Gender	Age
Argentina	Buenos Aires	Male	27
Chile	Valparaíso	Female	42
Cuba	Havana	Female	55
Mexico	Mexico City	Female	30
Peru	Lima	Male	30
Puerto Rico	Ponce	Female	35
Spain	Cádiz (Andalusia)	Female	35
Spain	Madrid	Female	29

Speech rate. In order to evaluate the possibility that the speech rate of the talkers in our stimuli may have affected response accuracy, we calculated the articulation rate (syllables spoken per second during phonation time) for all items (64 items × 8 speakers = 512 utterances). Figure 11 plots the posterior medians ±66% and 95% HDI of standardized articulation rate for each variety. The plot shows that, generally, there was not a lot of variability between varieties. Though some of the slower varieties are also those in which we see higher response accuracy (compare with Figure 5), that was not always the case. That is, some of the faster varieties also had high response accuracy, e.g., Mexican Spanish.

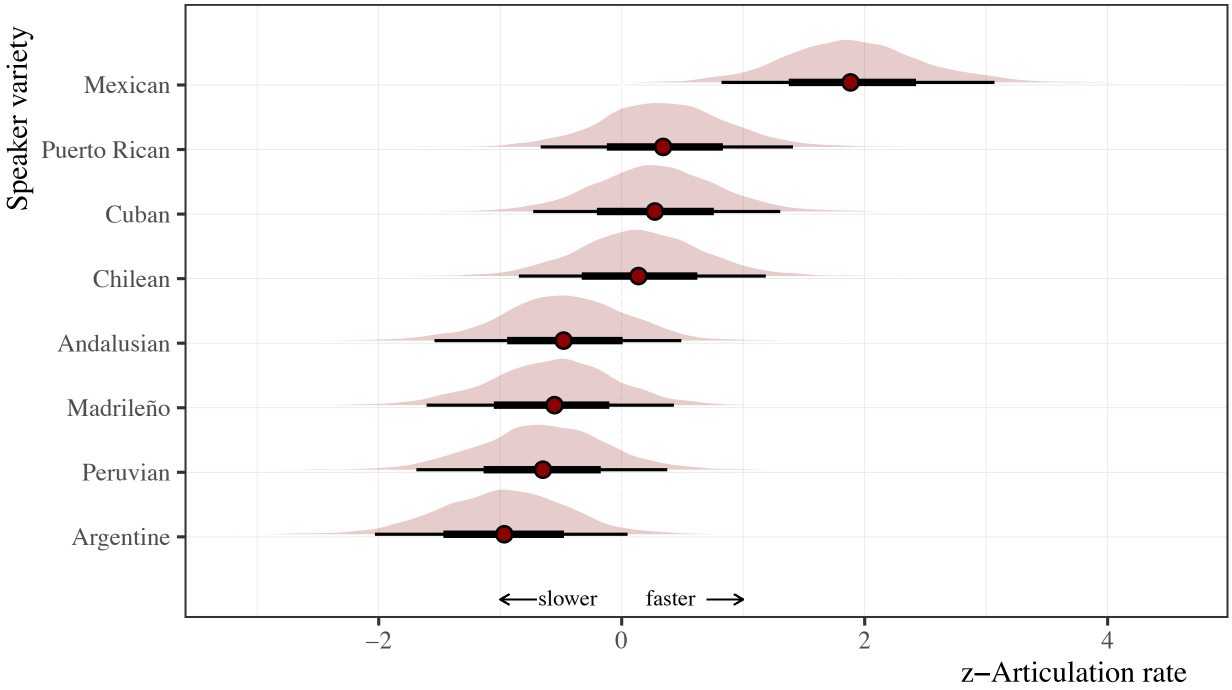
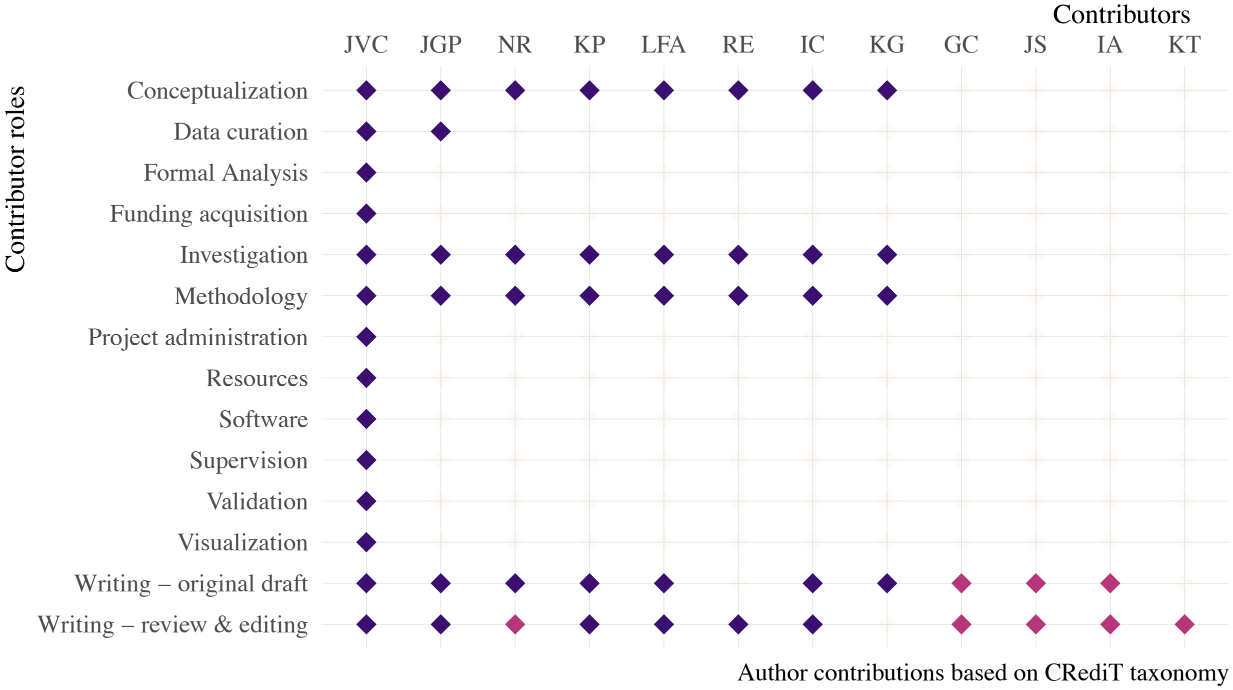


Figure 11. Standardized articulation rate as a function of speaker variety. Points represent posterior medians ±66% and 95% HDI.

Author contributions



	JVC	JGP	NR	KP	LFA	RE	IC	KG	GC	JS	IA	KT
Conceptualization	◆	◆	◆	◆	◆	◆	◆	◆				
Data curation	◆	◆										
Formal Analysis	◆											
Funding acquisition	◆											
Investigation	◆	◆	◆	◆	◆	◆	◆	◆				
Methodology	◆	◆	◆	◆	◆	◆	◆	◆				
Project administration	◆											
Resources	◆											
Software	◆											
Supervision	◆											
Validation	◆											
Visualization	◆											
Writing – original draft	◆	◆	◆	◆	◆		◆	◆	◇	◇	◇	
Writing – review & editing	◆	◆	◇	◆	◆	◆	◆		◇	◇	◇	◇

Figure 8. Author contributions according to the CREDiT author roles taxonomy. Contributions are indicated as being substantial (dark diamonds) or moderate (light diamonds).

Reproducibility information

About this document

This document was written in RMarkdown using `papaja` (Aust & Barth, 2018).

Session info

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Rttf2pt1               1.3.9 2021-07-22
scales                 1.1.1 2020-05-11
sessioninfo            1.2.2 2021-12-06
shiny                  1.7.1 2021-10-02
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threejs                0.3.3 2020-01-21
tibble                 3.1.6 2021-11-07
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tidyr                  1.1.4 2021-09-27
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V8                     4.0.0 2021-12-23
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vipor                  0.4.5 2017-03-22
vroom                  1.5.7 2021-11-30
withr                  2.4.3 2021-11-30
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xts                   0.12.1 2020-09-09
yaml                   2.2.2 2022-01-25
zoo                    1.8-9 2021-03-09
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