Bilingual social cognition: Investigating the relationship between bilingual language experience
and mentalizing

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Abstract

Mentalizing is a dynamic form of social cognition that is strengthened by language experience and proficiency. Similarly, bilingual children and adults consistently outperform monolinguals on traditional tasks. Here, we probe the relationship between bilingual language experience and mentalizing by investigating first (L1) versus second language (L2) mentalizing, and whether individual differences in language diversity continuously pattern with mentalizing judgments. We tested sixty-one bilingual adults on an on-line reading and inference task that compared mental state and logical inferences. We find that all readers judge mental state inferences as less coherent than logical inferences, but L2 readers make this judgment for mental state inferences faster than L1 readers. Moreover, L2 readers overmentalize logical inferences compared to L1 readers. In addition, greater language diversity patterns with higher mentalizing for mental state inferences across all readers. Together, we find evidence in favor of a positive relationship between bilingual language experience and mentalizing.

Keywords: Mentalizing, Bilingualism, Inferences, Theory of Mind, Social Cognition, Pragmatics, Language Diversity

Mentalizing is a dynamic and flexible form of social cognition that aids the understanding of others' intentions and actions. Its dynamic nature arises from nuances in situational context or life experience that, even during adulthood, alter mentalizing in some way (e.g., Dumontheil, Apperly, & Blakemore, 2010). As such, mentalizing is thought to exist on a continuum (Bateman, & Fonagy, 2019). For example, in some situations, such as confrontations with extreme out-group members, mentalizing may be knowingly or inadvertently withheld, resulting in dehumanization (Harris, 2017). Conversely, mentalizing may be strengthened through experiences such as reading fiction (Kidd & Castano, 2013), behavioral synchrony (Baimel, Birch, & Norenzayan, 2018), targeted therapies or trainings (Valle et al., 2016), and other individual differences (Conway et al., 2020; Repacholi & Slaughter, 2003). Among children, adolescents, and adults, greater language proficiency (i.e., general and specific to mental state vocabulary) boosts mentalizing performance (Milligan, Astington, & Dack, 2007; Pyers & Senghas, 2009; Warnell & Redcay, 2019). Nevertheless, the link between mentalizing and individual differences in language experience, particularly bilingual language experience, remains an open question. In this paper, we broach this question by examining mentalizing among bilingual adults.

Mentalizing, which is involved in Theory of Mind, manifests through mental state inferences, or deductions of the thoughts, feelings, beliefs, and goals of another person (Frith & Frith, 1999; Harris, 2017). Many have suggested that mentalizing extends beyond the mere recognition of other minds (e.g., mind perception: Hackel, Looser, & Van Bavel, 2014), and is important in shaping inferences and predictions of others' behaviours (Apperly, 2008; Premack & Woodruff, 1978). Accordingly, mentalizing, through mental state inferences, answers the question of *why* someone may do or say something (or *not* do or say something). As a result,

mentalizing is directly implicated in many real-world scenarios, ranging from the detection of sarcasm in casual conversation (Tiv, Rouillard, Vingron, Wiebe, & Titone, 2019; Tiv, Deodato, Rouillard, Wiebe, & Titone, 2020) to maintaining secure relationships during the COVID-19 pandemic (Schimmenti, Billieux, & Starcevic, 2020).

Past work has largely relied on a limited number of tasks or measures to evaluate mentalizing among adults. These have included questionnaires (e.g., Baron-Cohen & Wheelwright, 2004; Davis, 1980; Jolliffe & Farrington, 2006), false belief tasks (Sally and Anne task; Baron-Cohen et al., 1985), false belief stories (e.g., Conway et al., 2019; Fletcher et al., 1995; Kanske, Böckler, Trautwein, Parianen Lesemann, & Singer, 2016; Pino & Mazza, 2016; Saxe & Kanwisher, 2003), Reading the Mind in the Eyes task (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001), the Director Task (Dumontheil et al., 2010), Attribution of Intentions task (Sarfati, Hardy-Baylé, Besche, & Widlöcher, 1997), the Multifaceted Empathy Test (Dziobek et al., 2008), and others (e.g., Todd, Simpson, & Tamir, 2016). Although the majority of these works has used linguistic stimuli to assess mentalizing (e.g., stories, conversations, essays), few have addressed mentalizing from a linguistic perspective (e.g., Ferstle & von Cramon, 2002). Indeed, mental state inferences are “first and foremost inferences” (Harris, 2017) – meaning that they are conclusions reached by integrating prior evidence, which often take shape as text or speech.

Inference-making occurs automatically at all levels of language processing. Locally, inferences contribute to the coherence between words, aiding in pronoun-antecedent bridging and case role assignment of nouns. Beyond building microstructure, inferences can be elaborative and relate to the global structure of the text, thereby contributing to meaning that is pragmatically “between the lines” (reviewed in Snow, 2002). These pragmatic inferences often

occur across sentences and involve using prior knowledge to fill in missing information that is implied by the text to build coherence (Harris & Monaco, 1978; Johnson-Laird, 1993; Kispal, 2008). Indeed, prior knowledge for coherence may be based in logical, non-social aspects of the context, including general world knowledge (e.g., if X then Y). However, coherence may also be achieved by drawing upon mentalizing or privileged information in an actor's mind that is subsequently used to explain her observable behaviours in reality (e.g., she did X because Y) (Astington & Gopnik, 1988; Gaudreau et al., 2015). Distinguishing these two forms of inferences (logical vs. mental state) is critical in understanding the unique contributions of mentalizing, as opposed to non-mental coherence building.

Mentalizing and mental state inferences are rooted in language processing, and greater language experience may pattern with, and give rise to stronger mentalizing capacities (Rutherford, Wareham, Vrouva, Mayes, Fonagy, & Potenza, 2012). For example, stronger language ability correlates with better mentalizing performance among monolingual children (Milligan, Astington, & Dack, 2007; Warnell & Redcay, 2019). In a similar example, Pyers and Senghas (2009) examined two cohorts of monolingual Nicaraguan Sign Language users. The older cohort, who used a less developed form of the language than the younger cohort, initially produced significantly fewer mental state terms and performed more poorly on a non-verbal false belief task than the younger cohort. However, following a mental state language learning intervention for the older cohort, the two groups showed no difference on either task. Following from this work, to the extent that mastery of a single language nurtures mentalizing, developing expertise in a second language ought to further nurture this capacity, particularly given the wider array of pragmatic competencies that come into play when bilinguals assess when and how to

use the different languages they know (e.g., Genesee, Boivin, & Nicoladis, 1996; Sundaray, Marinis, & Bose, 2018).

Despite established links between mentalizing and language, only a small handful of studies have empirically tested the link between bilingualism and mentalizing, but they have done so using the traditional false belief paradigm, which some believe to insufficiently capture all aspects of mentalizing (e.g., Bloom & German, 2000). Among children, bilinguals outperform monolinguals in the classic Sally-Anne false belief task across a wide array of language pairs and regions (e.g., Goetz, 2003; Kovács, 2009; Rubio-Fernández & Glucksberg, 2012). A meta-analysis of 16 Theory-of-Mind studies comparing monolingual to bilingual children revealed a small bilingual advantage, which grew to a medium-sized effect when controlling for differences in language proficiency between the groups (Schroeder, 2018). Among adults, bilinguals also exhibit less egocentric bias than monolinguals in a visual world version of the Sally-Anne false belief task (Rubio-Fernández & Glucksberg, 2012) and more recently in a spatial perspective-taking task (Navarro & Conway, 2020). Other evidence stemming from psycholinguistics demonstrates that bilingual older adults in Singapore maintain accuracy and efficiency when forming pragmatic inferences, but monolinguals in the United Kingdom demonstrate an age-related decline in making pragmatic inferences (Sundaray, Marinis, & Bose, 2018; though see Antoniou and Katsos, 2017 for no differences among monolingual and bilingual children). Lastly, Hsin and Snow (2017) found that language-minority students in the US utilized more perspective-invoking language in academic writing than English-only students. Together, these works provide preliminary evidence linking bilingual experience with mentalizing, although the nature of this relationship remains largely unknown.

A natural question arising from these findings is whether mentalizing and mental-state inferences differ during L1 and L2 reading among bilinguals. This question also draws on research revealing that low L2 fluency relates to greater difficulty in making complex inferences during text reading. However, high proficiency L2 readers are more likely to draw pragmatic and complex inferences from the text than low proficiency L2 readers (Foucart, Romero-Rivas, Lottie, & Costa, 2016; Horiba, 1996; Tang, 1997; Zwaan & Brown, 1996). Based on these findings, L2 inference-making would be expected to be inferior to L1 inference-making; however, most of this work has relied on logical or linguistic inferences that do not require mentalizing, or integration of social information.

If mental state inferences are cognitively taxing and compel additional mental resources, then mentalizing could be exacerbated in the L2. Conversely, given that mentalizing is a *social* cognitive process, it may be boosted in the L2 if domain-general social or contextual information can compensate for any language-specific challenges in inference-making (see Ramírez-Esparza, García-Sierra, & Jiang, 2020 for a review of the social benefits of bilingualism). For example, research on bilingual discourse processing has found that L2 complex text comprehension is facilitated by topic cues (e.g., photographs) that convey context on the general theme of the text, particularly for low proficiency L2 readers (Groba, De Houwer, Mehnert, Rossi, & Obrig, 2018; Hammadou, 1991). This work suggests that other, potentially social or contextual, information (e.g., “paralinguistic cues”) may compensate for low language proficiency during inference making of complex texts in the L2. As such, L2 mentalizing might match, or exceed, L1 mentalizing, whereas non-mental state inferences could be hindered during L2 reading.

Given the importance of social information in mentalizing, it follows to examine the extent to which greater experience of navigating dual-language social environments (i.e., greater

language diversity) may also facilitate mentalizing capacities among bilinguals. This involves going beyond a narrow categorization of bilingual experiences to consider the continuous heterogeneity that can exist, such as quality, frequency, and context of language use. For example, across two works, Tiv et al. demonstrated that greater second language proficiency patterned with greater self-perceptions of general sarcasm use and faster responses to ironic statements (2019; 2020). DeWaele and Wei (2012) found that multilinguals with greater self-reported frequency of foreign language use also scored higher on the cognitive empathy factor of the Empathy Quotient questionnaire. Similarly, Mepham and Martinovic (2018) demonstrated that speaking more languages promoted cognitive flexibility, which acted as a mediator to less ethnocentrism and greater out-group acceptance.

Additional work by Ikizer and Ramírez-Esparza (2018) tested whether U.S. and Canadian bilingual adults' social interactions were mediated by increased social flexibility, or the ability to switch with ease and adapt between different social environments, as compared to U.S. and Canadian monolingual adults. The results showed that bilinguals self-report greater social flexibility, compared to monolinguals, and this difference mediated the frequency of their subsequent social interactions. Taken together, converging evidence suggests that having more opportunities to engage in novel social situations through the regular exercising of multiple languages, or greater language diversity, may expand one's understanding of the world and in turn their mentalizing capacity (reviewed in Ramírez-Esparza et al., 2020). Indeed, even passive exposure to greater language diversity in the environment promotes mentalizing capacities among functionally monolingual children raised in multilingual areas (Fan, Liberman, Keysar, & Kinzler, 2015).

Here, we operationalize language diversity through language entropy. Introduced by Gullifer and Titone (2019), language entropy is based on Shannon's Information Theory and quantifies the social diversity of language use (also used in Bice & Kroll, 2019; De Bruin, 2019). A low entropy value indicates low diversity in language use and characterizes the language user as limited to one language (functional monolingual). A high entropy value indicates high diversity in language use and characterizes the language user as juggling many languages. For example, an individual may have grown up learning both English and French. If they maintain balanced usage of these languages at the time of testing, they demonstrate high language entropy, but if they exclusively use English at the time of testing, they demonstrate low language entropy. Importantly, entropy is independent of the particular languages, meaning that an entropy score of zero could indicate functional monolingualism in *any* of the languages, rather than in a particular language, thus providing a general index of bilingualism. Taken together, entropy provides a robust measure of the dynamic balance of a bilingual's languages and sheds light on the extent to which a bilingual might encounter diverse social situations on the basis of language.

Present Study

As we just reviewed, mentalizing involves mental state inferences that in turn feed a prediction mechanism aimed at understanding human actions. Past work has demonstrated that greater expertise of one language, as well as the development of a second language, pattern with stronger mentalizing capacities across a variety of task designs. Despite this trend, few works have directly examined the relationship between bilingual language experience and mentalizing.

Thus, we pose two overarching questions aimed at filling this knowledge gap. First, does mentalizing differ for L1 vs. L2 readers? Here, we compare coherence and mentalizing judgments and reaction times to written logical and mental state inferences. We expect that L1

readers may surpass L2 readers in detecting coherence among logical inferences, but that L2 reader's reliance on social information will facilitate their detection (i.e., higher ratings and faster reaction times) of coherence among mental state inferences, as well as their recognition of mentalizing. Second, does the extent to which L1 and L2 readers experience social diversity in their languages, as measured through language entropy, alter mentalizing? Here, we predict that regardless of L1 vs. L2 reading, greater language diversity will pattern with better recognition (i.e., higher ratings and faster reaction times) of mentalizing and coherence to mental state inferences.

Methods

Participants

Sixty-six healthy bilingual adults were recruited from the Greater Montreal area. Following data preprocessing, we discarded five individuals who demonstrated excessively long or short response times (see Data Preprocessing). This left us with sixty-one bilingual adults aged 18-35 (mean age = 21.7 years). Of this sample, 47 identified as female, 10 as male, and 4 as queer or non-binary. The majority of participants were enrolled in an undergraduate program (51), whereas three had completed a high school or college education, and seven were in or completed their graduate studies. The racial-ethnic composition of the sample was predominantly White (40). Of the remainder, seven identified as East Asian, three Black, two Middle Eastern, one Southeast Asian, and seven Multiethnic (one individual preferred not to respond).

Thirty-one participants reported being exposed to English in their first year of life, and they acquired knowledge of one or more additional languages later in life. They made up the first language (L1) English group. The remaining thirty participants reported being exposed to a

language other than English in their first year of life and acquiring English (and sometimes additional languages) later in life. Among them, twenty-seven had French as their first language, one had both French and Arabic as the first languages, and two others were exposed to Mandarin or Bengali in their first year of life. Altogether these individuals made up the second language (L2) English group. All participants self-reported a comfortable working proficiency of English, which was the language of the task, and only differed in whether they acquired language in the first year of life (L1) or following the first year of life (L2). In total, twenty-eight participants reported knowing two languages in total, twenty-two reported knowing three languages, and eleven reported knowing four languages.

All participants were recruited from, and lived in the linguistically diverse city of Montreal, which is situated in Quebec, Canada. Quebec's provincial government is officially French speaking (i.e., French is the legal language). At the national level, Canada has two official languages: English and French. As a result of this – among other factors, such as proximity to the northern states of the U.S.A. where English is a dominant language, as well as Indigenous nationhood, globalization, urbanization, and immigration – many languages can be overheard in Montreal. Nevertheless, legal mandate from the province directs that all businesses, street signs, and advertisements predominantly feature French. Taken altogether, most inhabitants of the city experience some degree of exposure to multiple languages, even if they themselves do not use these languages to communicate within their network.

Materials

The text materials were mostly created for this experiment, though some were slightly adapted from past work (e.g., Ferstl & von Cramon, 2002; Nadig & Ozonoff, 2007, Lavoie,

Vistoli, Sutliff, Jackson, & Achim, 2016). The text consisted of 138 sentence pair item sets in three inference type conditions.

Each item was composed of two sentences: the context and the action. The first, context sentence was unique across the three condition types whereas the second, action sentence was identical across the three condition types. The context sentence described a situation involving a character. The action sentence described an action that was either somehow related to the first sentence or unrelated to the context. This design gave rise to 552 unique sentences (414 unique contexts + 138 unique actions) with an average of 13 words across both sentences. The gender of the character was controlled within items to account for any potential intergroup effects. These items are available in Supplementary Materials.

The critical difference across the three conditions was the type of inference required to connect the context and action sentences. In the logical condition, the context and action sentences could be connected through a general, non-social, logical, or deductive inference. Some of these inferences involved physical cause/effects and others involved a logical action sequence. For example, in, “Jane had very little in the kitchen. She cooked the stale food right then.”, the logical inference may be that the choice of what to cook is limited due to the scarcity of products in the kitchen.

In the mental state condition, the context and action sentences could be connected through an inference involving an understanding of the character’s mental state, emotions, intentions, goals, and beliefs. Critically, the action was identical to the logical inference, but the context differed. For example, in, “Jane invited the lying friend to dinner. She cooked the stale food right then.”, one might infer that Jane’s mind is preoccupied with thoughts of revenge or retaliation, which are motivating her to cook something unpleasant for the lying friend.

The third condition served as a baseline control for situations in which no inference could easily connect the context and action sentences. In this incoherent condition, the context was created to be wholly disconnected from the action, which was still identical to the logical and mental state conditions. For example, in, “Jane had fun at the school dance. She cooked the stale food right then.”, no clear inference will aid in connecting the context and action sentences.

Procedures

All participants first completed the inference reading task, which involved reading the text materials described above, and making two judgments about each item. Prior to the start of this task, all participants completed six practice trials and were ensured by the researcher to have understood the instructions. In this task, participants were first presented with the item, which appeared in full on the computer screen. Participants were instructed to silently read for comprehension and press the spacebar when they had done so. There was no upper time limit for global reading time, which coarsely measured comprehension time for the entire item. Following the press of the spacebar, the first judgment question appeared below the item which remained on the screen. Here, participants were asked to rate whether there was a relationship between the sentences, from 1 (not at all) to 5 (completely). This first judgment question aimed to measure the linguistic coherence between the context and action sentences. Participants indicated their choice by pressing a number on the keyboard, and we measured their response time to this probe. From there, a second judgment question replaced the first question on the screen, while the item still remained on the screen. Here, participants were asked to rate to what extent the relationship between the sentences relied on mentalizing. Mentalizing was defined to all participants at the start of the task as meaning that the thoughts, beliefs, emotions, and goals of the story character must be considered. Again, participants rated the need for mentalizing on a scale of 1 (not at all)

to 5 (completely) by pressing a number on the keyboard while the response time was measured. At that point, participants moved on to the next item and repeated this exercise for all 138 items.

Afterwards, participants completed a short language history questionnaire, which probed various aspects of their language experience and demographic background. For example, the questionnaire assessed at what age each language was first acquired, what percent of each day each language is used, and whether each language is still being used. We calculated general language entropy from the continuous usage responses using the `languageEntropy` package in R (Gullifer & Titone, 2018). Language entropy is used as a measure of language diversity in which low entropy speakers are functional monolinguals (i.e., individuals who use one language regularly), and high entropy speakers report balanced usage of their multiple languages.

All participants provided written consent prior to participating in the experiment. The materials and procedures in this experiment were approved by the McGill Research Ethics Board.

Results

Data Preprocessing

Prior to data analysis, we undertook a series of item-level, subject-level, and trial-level preprocessing steps. These steps yielded the removal of three out of 138 total full item sets (resulting in 135 analyzed items), one full participant, four participants' reaction times, and single trials that were slower than 10 seconds or faster than 500 ms. This left us with 61 participants (31 English L1, 30 English L2) for the judgment responses, and 57 (29 English L1, 28 English L2) for global reading time and the judgment reaction times. Specific details on these steps may be found in Supplemental Materials.

Data Analysis

All data were analyzed with linear mixed-effects regression models (LMM) using the *lme4* package in R (Bates, Maechler, Bolker, & Walker, 2014). To first assess L1 vs. L2 differences, we coded for the interaction between inference type (3 levels: logical, mental state, and incoherent) and language group (L1 vs. L2 English) to predict each dependent variable (global reading time, coherence rating/RT, mentalizing rating/RT). Here, language group was treatment coded with L1 English as the baseline. The three-level inference type variable was Helmert coded, such that the first contrast reflected the difference between the mean of logical and mental state inferences vs. incoherent, and the second contrast reflected the difference between logical vs. mental state inferences. This approach allows us to examine general differences between sentence pairs that were created to make sense (logical or mental state inferences) from those that were not (incoherent). Following this, we then assessed subtle differences between logical and mental state inferences. Continuous trial order (scaled) was added as a covariate to all models.

Next, to assess individual differences, we added language diversity (scaled) to the interaction of inference type and language group to predict each of the dependent variables. Trial order (scale) was retained as a covariate, and percent daily English use (scaled) was also added as a covariate in these models.

In these multilevel models, random effects structures were built for both subjects and items so that we could generalize beyond our sample and item set. For the first analysis (L1 vs. L2), we aimed to build maximal random effects structures, but upon receiving convergence errors, random slopes were dropped until convergence was achieved. Ultimately, this resulted in the random slope for condition by-subject in the models for coherence rating, coherence log-RT, and mentalizing log-RT. The remaining two models (global reading time and mentalizing rating)

retained the random intercepts. For the second analysis (individual differences), we calculated all models with random intercepts-only, given that our aim was to affirmatively test for the role of subject-level individual differences in language diversity. Full model outputs are available in Supplementary Materials, and analyses are available on the Open Science Framework:

<https://osf.io/m2h93/>

Global Reading Time

We computed LMMs to predict global reading time (i.e., the total time it took to read both sentences), which was standardized to account for length differences across items (total reading time (ms) /total number of characters), and log-transformed for normality.

A model was first constructed to compare L1 vs. L2 reading. This model did not converge with maximal random effects, and only did so with an intercepts-only model. We did not detect any reading time differences across conditions, between the L1 and L2 group, or any interactions involving these variables. As computed with the `r.squaredGLMM` function from the MuMIn package in R (Bartoń, 2018), the fixed effects of this model accounted for 6.6% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 41% of variance of the data (conditional R^2).

We next added an interaction with language diversity to assess the role of individual differences. In this model, we detected a significant effect of language diversity ($\beta = -0.198$, $SE = 0.092$, $t = -2.16$, $p = 0.035$), which suggests that readers with high language diversity were faster at reading all items, as compared to readers with low language diversity. No other significant effects were detected. The fixed effects of this model accounted for 9.1% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 41% of

variance of the data (conditional R^2), which are both greater than or equal to the values estimated in the first model.

Coherence

Rating

We next computed LMMs to predict coherence rating (1 = no coherence, 5 = full coherence), where participants were asked whether there was a relationship between the two sentences of the item.

First, we constructed a model to compare coherence rating among L1 vs. L2 readers. This model did not converge with maximal random effects, and only did so with the random slope for condition by subject and item, which returned three findings. We first detected a significant difference between incoherent items and the mean of the other two conditions ($\beta = -1.07$, $SE = 0.029$, $t = -37.5$, $p < 0.001$), which suggests that the incoherent items were perceived as less coherent than the other two conditions, as expected. We also detected a significant difference between logical and mental state inferences ($\beta = -0.227$, $SE = 0.038$, $t = -5.94$, $p < 0.001$), which indicates that mental state inferences were perceived as less coherent than logical inferences by all readers. In addition, we detected a significant interaction between the inference type and L1 group when comparing the mean of logical and mental state inferences to the incoherent condition ($\beta = 0.103$, $SE = 0.038$, $t = 2.70$, $p = 0.008$). As seen in Figure 1, the distinction between items that are coherent (logical and mental state inferences) and items that are incoherent is attenuated for second language readers. Follow-up t-tests on only incoherent and logical/mental state subsets reveal that averages for both subsets change across L1 and L2 readers (Incoherent: $t(2445.1) = -3.01$, $p = 0.003$; Logical and mental state: $t(5037) = 8.09$, $p < 0.001$). Thus, incoherent items were rated more coherent and the mean of logical and mental

state inferences were rated less coherent, by L2 readers compared to L1 readers. The fixed effects of this model accounted for 72.2% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 81.6% of variance of the data (conditional R^2).

Next, we added an interaction with language diversity to the first LMM to assess the role of individual differences in bilingual language experience on coherence rating. This model did not return any significant effects or interactions involving language diversity.

Reaction Time.

We then computed LMMs to predict reaction time (ms) to the coherence rating, which we log-transformed for normality.

First, we constructed a model to compare reaction times among L1 vs. L2 readers. This model did not converge with maximal random effects, and only did so with the inclusion of the random slope of condition by subject. We report three results from this model. First, we detected a significant difference between incoherent items and the mean of the other two conditions ($\beta = -0.095$, $SE = 0.022$, $t = -4.42$, $p < 0.001$), which indicates that coherence reaction times were faster for the incoherent items than the logical and mental state inferences. We also detected a significant difference between logical and mental state inferences ($\beta = 0.072$, $SE = 0.015$, $t = 4.90$, $p < 0.001$), such that coherence reaction times were slower for mental state inferences than logical inferences. To this end, we also detected a significant interaction between inference type and L1 group, specifically between the logical and mental state inferences ($\beta = -0.046$, $SE = 0.021$, $t = -2.17$, $p = 0.033$). Here, the reaction time difference in finding coherence for logical versus mental state inferences is smaller for second language readers than it is for first language readers (Figure 1). To determine whether this pattern was the result of the logical inference getting slower, the mental state inference getting faster, or both, we conducted two follow-up t-

tests on only logical and only mental state subsets. Among logical inferences, there was not a significant difference between L1 and L2 readers ($t(2343) = -1.373$, $p = 0.17$). Among mental state inferences, there was a significant difference between L1 and L2 readers ($t(2350) = 2.232$, $p = 0.026$). Taken together, the interaction between inference type and L1 group among logical vs. mental state inferences seems to be driven by second language readers demonstrating faster reaction times at judging coherence of mental state inferences compared to first language readers. The fixed effects of this model accounted for 7.5% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 33.3% of variance of the data (conditional R^2).

Next, we added an interaction with language diversity to the first LMM to assess the role of individual differences in bilingual language experience on coherence reaction time. Here, we detected two effects involving language diversity. The first is a two-way interaction between inference type and language diversity, specifically in comparing incoherent items to the mean of logical and mental state inferences ($\beta = -0.026$, $SE = 0.009$, $t = -3.04$, $p = 0.002$). This interaction is qualified by a three-way interaction also involving L1 group, indicating that the relationship between language diversity and reaction times to incoherent and coherent items varies by language group ($\beta = 0.061$, $SE = 0.012$, $t = 5.14$, $p < 0.001$). As can be seen in Figure 1, among L1 readers, greater language diversity patterns with slower coherence reaction time to logical and mental state inferences, compared to incoherent items. Among L2 readers, greater language diversity also patterns with slower coherence reaction time, but to all three inference conditions. The fixed effects of this model accounted for 10.3% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 28.4% of variance of the data (conditional R^2). Here, the fixed effects account for greater variance than the model estimates from the first

model, but the fixed and random effects together account for slightly less (4.9%) variance than the model estimates from the first model.

Figure 1. (A) Model-predicted coherence rating and (B) model-predicted coherence reaction time by conditions and language groups. (C) Model-predicted coherence reaction time by condition, language group, and language diversity. Error lines represent plus or minus one standard error of the mean.

Mentalizing

Rating

From there, we computed LMMs to predict mentalizing rating (1= no mentalizing, 5 = full mentalizing), where participants were asked to what extent the relationship between the sentences depended on mentalizing, or understanding the character's thoughts, behaviors, goals, and emotions.

First, we computed a model to compare mentalizing ratings of L1 vs. L2 readers. This model, which did not converge with maximal random effects, and only did so with random intercepts only, returned four significant effects: first, we detected a significant difference between incoherent items and the mean of the other two conditions ($\beta = -0.366$, $SE = 0.014$, $t = -25.7$, $p < 0.001$), which indicates that incoherent items were considered to involve less mentalizing than the logical and mental state items together. We also detect a significant difference between the logical and mental state inferences ($\beta = 0.747$, $SE = 0.025$, $t = 30.3$, $p < 0.001$), such that mental state inferences were perceived as higher in mentalizing than logical inferences, as expected. Next, and of relevance to our research questions, we also detected an interaction between these two contrasts and L1 group. The difference between incoherent and the mean of logical and mental state inferences was found to be greater for second language readers than first language readers ($\beta = -0.092$, $SE = 0.020$, $t = -4.53$, $p < 0.001$); however, the difference between logical and mental state inferences is smaller for second language readers than it is for first language readers ($\beta = -0.086$, $SE = 0.035$, $t = -2.42$, $p = 0.015$). In order to understand the nature of this interaction (i.e., are responses to logical or mental state inferences changing as a function of L1 group?), we conducted two follow-up t-tests on logical vs. mental state items. L1 group was significant among logical items ($t(2550) = -4.742$, $p < 0.001$), but not mental state

items ($t(2625) = -1.659, p = 0.097$), indicating that logical, but not mental state, inferences were perceived as higher in mentalizing by second language readers than first language readers. Thus, the difference in mentalizing ratings of logical and mental state inferences between L1 and L2 readers is driven by second language readers attributing more mentalizing to logical items than first language readers. Moreover, a third follow-up t-test indicates that there is no difference in mentalizing ratings to incoherent items between L1 and L2 readers ($t(2625.6) = 1.933, p = 0.053$). The fixed effects of this model accounted for 26.3% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 36.7% of variance of the data (conditional R^2).

Next, we added an interaction with language diversity to the first LMM to assess the role of individual differences in bilingual language experience on mentalizing rating. We report three results involving language diversity. The first involves an interaction between inference type and language diversity among incoherent items and the mean of logical and mental state inferences ($\beta = -0.073, SE = 0.017, t = -4.165, p < 0.01$). This interaction is qualified by a higher order three-way interaction involving L1 group ($\beta = 0.114, SE = 0.024, t = 4.798, p < 0.01$). This interaction, as can be seen in Figure 2, is such that the difference between incoherent items and the mean of logical and mental state inferences grows with language diversity for L1 readers but is diminished for L2 readers. The third result involves the interaction of inference type and language diversity between logical and mental state inferences, which directly relates to our research questions ($\beta = 0.086, SE = 0.031, t = 2.83, p = 0.004$). Here, regardless of whether one is a first or second language reader, greater language diversity patterns with greater perceived mentalizing to mental state inferences. Follow-up simple linear regressions on the logical and mental state inference subsets indicate that language diversity is only related to changes in

mentalizing rating of mental state ($\beta = 0.121$, $SE = 0.027$, $t = 4.56$, $p < 0.001$) and not logical inferences ($\beta = 0.034$, $SE = 0.028$, $t = 1.22$, $p = 0.221$). The fixed effects of this model accounted for 26.8% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 37% of variance of the data (conditional R^2), which are both similar, though slightly greater, than the model estimates from the first analysis.

Reaction Time

We then computed LMMs to predict reaction time (ms) to the mentalizing judgment, which was log-transformed for normality.

First, we constructed a model to compare reaction times among L1 vs. L2 readers. This model did not converge with maximal random effects, and only did so with the inclusion of the random slope of condition by subject. We only detected a significant difference between incoherent items and the mean of logical and mental state inferences ($\beta = -0.147$, $SE = 0.027$, $t = -5.37$, $p < 0.001$), which indicates that the incoherent items were responded to more quickly than the logical and mental state inferences. No other significant differences were detected. The fixed effects of this model accounted for 11.5% variance of the data (marginal R^2), and the fixed and random effects of this model accounted for 48.8% of variance of the data (conditional R^2).

Next, we added an interaction with language diversity to the first LMM to assess the role of individual differences in bilingual language experience on mentalizing reaction time. Here, we detected only one effect involving language diversity. We found a significant interaction between L1 group and language diversity ($\beta = 0.305$, $SE = 0.142$, $t = 2.151$, $p = 0.035$), such that in general – regardless of condition – greater language diversity patterned with faster mentalizing judgments for L1 readers and slower mentalizing judgments for L2 readers. The fixed effects of this model accounted for 16.6% variance of the data (marginal R^2), and the fixed and random

effects of this model accounted for 42.2% of variance of the data (conditional R^2). Here, the fixed effects account for greater variance than the model estimates from Analysis 1, but the fixed and random effects together account for slightly less variance than the model estimates from the first analysis.

Figure 2. (A) Model-predicted mentalizing rating by conditions and language groups. (B) Model-predicted mentalizing rating by condition and language diversity (across both L1 and L2 readers). Error lines/bands represent plus or minus one standard error of the mean.

Discussion

Our goal was to evaluate the potential relationship between mentalizing and bilingual language experience. To accomplish this, we implemented two specific goals: First, compare judgements and reaction times to the coherence and mentalizing of logical vs. mental state inferences among L1 vs. L2 readers. Second, compare judgments and reaction times to the coherence and mentalizing of logical vs. mental state inferences as a function of language diversity. In what follows, we aim to achieve these goals by reviewing the findings.

L1 vs. L2 Reading

The first broad question that this work aimed to address is whether mentalizing varies during L2 reading compared to L1 reading. Past work has found that L2 readers struggle with making complex inferences (e.g., Foucart et al., 2016); however, this work has not accounted for different forms of complex inferences such as logical and mental state inferences. Our results from the coherence ratings demonstrate that whereas all readers judge logical inferences as more coherent than mental state inferences, L2 readers demonstrate less dissociation between coherent (logical and mental state inferences) and incoherent items compared to L1 readers who exhibit crisp separation. Nevertheless, there is no L1 vs. L2 difference in coherence between logical and mental state inferences, both judging mental state inferences less coherent than logical inferences. The results from the coherence reaction time further indicates that while determining the coherence of mental state inferences takes more time than that of logical inferences (consistent with findings that ironic statements take longer than literal statements to process; Tiv et al., 2020), L2 readers are faster than L1 readers. Taken together, both L1 and L2 readers judge mental state inferences as less coherent than logical inferences, but L2 readers are faster than L1

readers at determining coherence of mental state inferences in particular, suggesting a possible automatization of L2 mental state inference making, compared to logical inference making.

In determining whether mentalizing is necessary to connect the context and action sentence, all readers attribute more mentalizing to mental state inferences compared to logical inferences, as expected; however, L2 readers attribute more mentalizing to logical inferences than L1 readers do. This result is interesting because it suggests that L2 readers may be *over-mentalizing* in cases where mentalizing is not necessarily needed for the inference (or may not be the main source of the inference), whereas mentalizing for mental state inferences does not change. Interestingly, whereas coherence reaction times do vary for L1 vs. L2 readers, mentalizing reaction times do not subtly vary between logical and mental state inferences.

Thus, L2 readers spend the same time as L1 readers determining the need for mentalizing, and they ultimately over-mentalizing for logical inferences. Past work from clinical samples has referred to the over-attribution of mentalizing as *hypermentalizing* and has linked this behavior to excessive attention to external cues stemmed in feelings of vulnerability (Bateman, & Fonagy, 2019). Whereas the present sample did not report a history of clinical disorders, it is possible that the experience of reading or operating in a non-native language may also trigger additional attention to external cues if that language induces vulnerability in any way. For example, the English framing of the task (instructions, conversations with experimenters, language of the text) may have prompted some L2 English readers to implicitly begin seeking additional cues in the text to help them understand, which gave rise to the higher mentalizing rating of logical inferences. Additionally, there was no difference in L1 and L2 mentalizing ratings to incoherent items. Thus, it is not the case that L2 simply tended to rate all

items higher in mentalizing, regardless of coherence. Instead, they over-mentalized only among coherent items that were based on logical inferences.

These results have important implications for past and ongoing research on L1 vs. L2 reading and language processing. As expected, both L1 and L2 readers judge mental state inferences as less coherent than logical inferences, L2 readers particularly judge the coherence of mental state inferences more rapidly than L1 readers, which implies some sensitivity to mental state inferences over logical inferences. L2 readers also attributed *more mentalizing* to logical inferences than L1 readers. Taken together, there is some evidence that the L2 readers demonstrate heightened sensitivity to mentalizing and mental state inferences, which might arise from the L2 context demanding more mentalizing and becoming more automatized over time. A limitation of the between-subjects design of the current investigation is that it does not allow for a comparison of the same individual reading in their L1 and L2, which would provide insight on whether switching from L1 to L2 reading increases mentalizing. Although this is the topic of ongoing research from our group, the inclusion of language diversity in our second research question begins to shed light on whether greater bilingual language experience (i.e., greater language diversity), is related to greater mentalizing.

Language Diversity

The second broad question that this work aimed to address is whether individual differences in language diversity, or the extent to which multiple languages are used regularly, relate to mentalizing. Prior work on self-reported language frequency and number of languages known has demonstrated a clear positive association between greater bilingual experience and stronger cognitive empathy or mentalizing abilities (DeWaele & Wei, 2012; Mepham & Martinovic, 2018). Thus, we expected that greater language diversity would also be associated

with greater mentalizing abilities during this reading task, which is what we found. Language diversity did not co-vary with ratings of coherence, but – as expected – greater language diversity patterned with higher mentalizing ratings of only mental state inferences. Mentalizing ratings to logical inferences did not change with language diversity, suggesting that greater language diversity, an index of regularly using multiple languages and potentially encountering novel social situations, selectively exercises the recognition of mentalizing when it is needed to understand the actions of a character.

We did not detect strong evidence that language diversity plays a role in shaping reaction times to logical vs. mental state inferences; however, we did find that greater language diversity patterns with faster global reading time for all readers, as well as faster mentalizing judgments among L1 readers and slower mentalizing judgments among L2 readers (across all inference types). It might be the case that readers with greater language diversity generally encounter more text, as a function of regularly using multiple languages, compared to a functional monolingual who might be limited by the primary use of a single language. As a result, they may develop greater paralinguistic and metalinguistic awareness, which may facilitate overall reading time and determining whether social inferences need to be made (e.g., Rankin et al., 2009). Mentalizing ratings between L1 and L2 readers indicate that L2 readers have a tendency to over-mentalize, specifically in response to a logical inference. Taken together, the proclivity to over-mentalize might actually slow down high language diversity L2 readers on the mentalizing judgment, in comparison to L1 readers with high language diversity. Indeed, there might be other, stronger explanations for why language diversity generally accelerates mentalizing ratings of high language diversity L1 readers, while hampering L2 readers, but overall it does seem clear that this process does not subtly discern between inference types.

These results, specifically the link between greater language diversity and higher mentalizing ratings of mental state inferences, mirror past findings that greater second language proficiency relates to more sensible judgments of ironic statements (Tiv et al., 2020). Irony, which is used to convey a positive or negative attitude with the opposite set of words, is commonly examined as a form of language that depends on mentalizing and social cognition for successful comprehension (Banasik, 2013; Filippova & Astington, 2010). In that work, bilingual adults from Montreal read short stories in English (their L1) that ended with an ironic, literal, or incoherent statement and were instructed to indicate whether the final statement made sense or not. Bilinguals with greater self-reported L2 proficiency indicated that the ironic statement made more sense than bilinguals with weaker self-reported L2 proficiency (functional monolinguals). Thus, greater bilingual experience (regularly using more than one language) seemed to globally (i.e., not specific to operating in one language) promote greater pragmatic awareness and attention to social information. In a similar way, the present work indicates that readers who regularly use more languages are also demonstrating more flexible social cognition, as measured by greater recognition of mentalizing. Indeed, the fixed effects of all individual difference models accounted for more statistical variance (marginal R^2) than the respective models comparing L1 and L2 readers.

These results are also consistent with social psychological research demonstrating that identifying self-other differences (i.e., parsing one's own mental state from another's) is a critical component of successful mentalizing (Decety & Sommerville, 2003; Higgins, 1981; Mitchell, 2009; Tamir & Mitchell, 2010). Todd and colleagues contend that recognizing self-other similarities in mental state may be a crucial first step in mentalizing, but in order to formulate accurate inferences, differences in mental state must also be computed. In other words,

successful mentalizing involves a comparative process to analyze the similarities and differences between the perceiver and the one being perceived (Todd et al., 2011, 2016). Bilinguals who experience greater language diversity may be also experience other forms of diversity in their daily lives (e.g., racial, gender, class, nationality). Encoding these environmental differences may cue high language diversity readers to exercise greater mentalizing than low language diversity readers.

We acknowledge that there are limitations to this work. First, we utilized a between-subjects design, which does not allow us to compare L1 vs. L2 reading within the same individual. As a result, there might be confounding differences between our two groups that contribute to the results. We strove to mitigate this possibility by including daily percent English use in our statistical models, to control for usage of the language of the task. Second, we did not explicitly probe comprehension of the items, instead we used coherence as an indicator of whether readers understood the item. The rationale was that if the correct inference is made (i.e., what the experimenters intended), then that would be reflected in the coherence score. Nevertheless, it is possible that readers made a different inference than what the experimenters intended, which could give rise to a weaker or stronger coherence. The current design does not offer insight on the specific inference that the reader made, but this will be the focus of follow-up work. Third, we did not assess whether inferences resulting from negative or positive contexts give rise to different scores or reaction times, as past work has found with irony (Tiv et al., 2020). This will be the subject of follow-up work disentangling the relationship between bilingualism and social cognition. Lastly, our global reading time measure coarsely captured reading time across two full sentences, which may not have been sensitive enough to potentially capture the nuances between different inference types (i.e., no reading time differences between

conditions was detected). Ongoing work using eye tracking will address whether inference types give rise to varying reading times in a more granular manner.

Despite these limitations, we also highlight several strengths of present study. First, these broad questions bridge traditions and methods from social cognition and the language sciences (bilingualism, discourse processes) to address inference making as a simultaneously linguistically and socially rooted process. In merging these lines of inquiry, we present a task design that is familiar to most participants: reading short stories. Whether it be reading text messages, emails, articles, books, or city signs, most literate individuals read in some capacity on a daily basis. In targeting inference-making through reading, we capitalize on a natural and ecologically valid method of measuring real-time inference making. Moreover, this design exclusively engages mentalizing, whereas others (e.g., Sally and Anne task, Director task) have faced criticism for involving other, non-social processes, such as spatial perspective taking (e.g., Bloom & German, 2000; Ferguson, Apperly, Ahmad, Bindemann, & Cane, 2015). Ongoing work from our group is utilizing eye tracking to measure on-line inference making to better discern the time course of logical and mental state inferences.

Additionally, our study did not include a monolingual group, which was decided on for several reasons. First, despite visibility in the United States, monolinguals make up a small proportion of the world's language users (Grosjean, 2010), which does not warrant the tethering of results back to a default monolingual "control" group, which has been referred to as monolingual hegemony (Ortega, 2018; Tiv, Kutlu, & Titone, accepted; Vaid & Meuter, 2016; 2017). Second, monolinguals and bilinguals often have many differences between them beyond the simple number of languages known (e.g., culture, education, SES), which could serve as confounds in their task performance. Altogether, instead of comparing our bilinguals to a

monolingual sample, both of our analyses compare bilinguals to themselves. First, we compare bilinguals reading in their first language to bilinguals reading in their second language, and next we compare bilinguals who use mainly one language to bilinguals who juggle multiple languages. Through this continuous assessment, we find that augmenting bilingual experience co-varies with stronger mentalizing scores, much like past work that has revealed bilingual children and adults outperform monolinguals on mentalizing and Theory of Mind tasks (Navarro & Conway, 2020; Rubio-Fernandez & Glucksberg, 2012; Schroeder, 2018).

In conclusion, the present work establishes a link between bilingual language experience and mentalizing. Our main results indicate that all readers judge mental state inferences as less coherent than logical inferences, but L2 readers make this judgment for mental state inferences faster than L1 readers. Moreover, L2 readers rate logical inferences as higher in mentalizing than L1 readers. In addition, greater language diversity patterns with higher mentalizing for mental state inferences across L1 and L2 readers.

Whereas much of bilingualism research has been dominated by the debate of cognitive advantages and executive functions, these results contribute to a growing body of work (see Ramírez-Esparza et al., 2020) that aims to highlight the positive *social benefits* that are related to bilingualism, such as mentalizing and social cognition. Mentalizing humanizes people – it breaks us out of our own minds and brings us into the minds of others. Though it has been historically understudied in the field of bilingualism, mentalizing may provide a mechanism to explain why bilinguals demonstrate attenuated other-race effects (Burns, Tree, Chan, & Xu, 2019) and less racial bias (Singh, Quinn, Qian, & Lee, 2020). These nascent areas of interdisciplinary investigation are promising not only for their scientific novelty, but also for carrying important real-world implications such as mitigating intergroup conflict.

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