What do bilingual infants actually hear? Evaluating measures of speech input to bilingual-
learning 10-month-olds

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Conflict of Interest Statement

The authors have no conflict of interest to declare.

Data Sharing

The data that support the findings of this study are available on request from the corresponding author (Orena, Adriel John).

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Research Highlights:

- Daylong recordings from bilingual families revealed wide variability in how bilingual 10-month-old infants experience dual language exposure, even within the same community
- Caregivers can reliably estimate their bilingual child's proportional exposure to each language
- Caution should be taken about sampling infants' language experiences within a limited observation period, as their language input can vary widely by speaker and by day
- Infants' bilingual exposure includes both infant-directed and overheard speech, which may differ in how often each language is used

Abstract

Examining how bilingual infants experience their dual language input is important for understanding bilingual language acquisition. To assess these language experiences, researchers typically conduct language interviews with caregivers. However, little is known about the reliability of these parent reports in describing how bilingual children actually experience dual language input. Here, we explored the quantitative nature of dual language input to bilingual infants. Further, we described some of the heterogeneity of bilingual exposure in a sample of French-English bilingual families. Participants were twenty-one families with a 10-month-old infant residing in Montréal, Canada. First, we conducted language interviews with the caregivers. Then, each family completed three full-day recordings at home using the LENA (Language Environment Analysis) recording system. Results showed that children's proportion exposure to each language was consistent across the two measurement approaches, indicating that parent reports are reliable for assessing a bilingual child's language experiences. Further exploratory analyses revealed three unique findings: (1) there can be considerable variability in the absolute amount of input among infants hearing the same proportion of input, (2) infants can hear different proportions of language input when considering infant-directed versus overheard speech, (3) proportion of language input can vary by day, depending on who is caring for the infant. We conclude that collecting naturalistic recordings is complementary to parent-report measures for assessing infant's language experiences and for establishing bilingual profiles.

Keywords: Language input, LENA, Bilingualism, Language experience, Infancy, Parent reports

1. Introduction

Children's speech and language outcomes depend, in part, on how their caregivers provide language input. For example, the amount of infant-directed speech and turn-taking that children experience predicts their speech and language development (e.g., Ramírez-Esparza, Garcia-Sierra & Kuhl, 2014; Romeo et al., 2018). Another source of variability is the number of languages that they hear. Indeed, the language environments of monolingual and bilingual infants are characteristically different from each other (Byers-Heinlein & Fennell, 2014). Bilingual infants have to learn and represent the linguistic properties of two language systems that sometimes conflict with one another (e.g., Gervain & Werker, 2013; Orena & Polka, 2019). To date, growing research in the field has revealed competencies that are both comparable and different between monolingual and bilingual infants (see Höhle, Bijeljac-Babic & Nazzi, 2019 for a recent review).

While group-level comparisons between monolingual and bilingual infants have laid important groundwork for showing the impact of dual language exposure, a different approach to investigating bilingual development is exploring how individual patterns of bilingual exposure affect language outcomes. Indeed, there is also wide variability in dual language exposure *among* bilingual infants. For example, families adopt a variety of language use patterns – whether intentionally or incidentally: some families use the “one-parent, one-language” practice, where each caregiver speaks only one language to the infant (King, Fogle, & Logan-Terry, 2008); in other families, one or both caregivers speak both languages to their infant. Indeed, prior work suggests that language mixing to infants can be quite common, especially in bilingual communities (Byers-Heinlein, 2013). These experiential factors (and others) may affect a child's speech and language outcomes, highlighting the importance of examining the effects of bilingualism beyond group-level comparisons (de Bruin, 2019; Luk & Bialystok, 2013; Titone & Baum, 2014).

One predictor variable that has received much attention is a bilingual child's relative amount of experience with each of their languages. For practical reasons, this variable is typically assessed through parent reports – either via daily diaries filled out by caregivers (Place & Hoff, 2011), or detailed interviews with them (DeAnda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016; Byers-Heinlein et al., 2019). Caregivers are asked to document or estimate the languages that infants hear directly from speakers in their environment. Indeed, a number of studies have reported different performance in language tasks as a function of language dominance (i.e., having more exposure to one language over the other; e.g., Bijeljac-Babic, Serres, Höhle, & Nazzi, 2012; Unsworth, Chondrogianni, & Skarabela, 2018), or as a function of amount of exposure (i.e., proportion exposure to Language A versus Language B; e.g., Thordardottir, 2011; Marchman, Martínez, Hurtado, Grüter, & Fernald, 2016).

While it is common in developmental research to use parent reports as a proxy for child assessments (e.g., Theunissen et al., 1998), their usage in assessing bilingual input is not without criticism – specifically with regards to their accuracy and reliability, as well as their content and construct validity. Indeed, it is possible that the reason researchers find relations between language exposure and language outcomes is that caregivers' reports of children's exposure to each language might be colored by their observation and interpretation of their child's communicative competence in each language. Further, it is possible that a bilingual child's relative exposure to each language is confounded with other aspects of language experience. Thus, it is important to critically examine our methodologies in assessing language input to bilingual infants.

Accuracy and reliability of language questionnaires

Regarding the accuracy and reliability of parent reports, some researchers have questioned whether the average bilingual speaker is able to track their use of different languages (Carroll,

2015). In certain contexts, language mixing can occur frequently, which may hamper caregivers' ability to provide accurate information about their child's language environment. Further, infants typically spend time with different caregivers, and in many cases, reports about all caregivers' input are gathered from the primary caregiver (typically the mother). Does a parent's reports of language exposure reliably represent only their own talk to their children, or do they also capture the language input spoken by other people (e.g., other caregivers, siblings, grandparents)? Mothers tend to provide the vast majority of the input to their child in North America (Bergelson et al., 2019), but the language input from other family members (e.g., fathers, siblings, grandparents) also matters for language outcomes (Bridges & Hoff, 2014; Pansofar, 2011). This issue is especially relevant for bilingual families, as infants may hear different languages from different caregivers.

Recent work suggests that mothers are fairly reliable in reporting which languages they themselves speak to their child (e.g., in short sessions: De Houwer & Bornstein, 2016). In a more comprehensive study, Marchman and colleagues (2016) examined caregivers' accuracy in estimating their child's language experiences through daylong recordings. These recordings were collected via a small recording device (developed by the LENA research foundation) that fits into a baby-friendly vest or T-shirt. The LENA system also includes software that estimates the total number of words the child hears. Their results showed a positive, moderate relationship between parent reports of language exposure and the observed proportion of exposure to each language in the recordings [$r(16) = .46, p < .06$], suggesting that parent reports – although far from perfect – show some reliability in capturing the variability of everyday language input.

Content and construct validity of language questionnaires

There are also some concerns about the content and construct validity of language exposure questionnaires. In research with monolingual infants, the quantitative variable that appears to be highly predictive of language development is the *absolute* amount of input directed towards the child (Gilkerson & Richards, 2008). However, recall that most parent questionnaires about bilingual language environments assess *proportion* exposure to each language. These two measures would provide similar information if all caregivers were equally talkative; however, we know that this is not the case (e.g., Hart & Risley, 1995). Indeed, these two variables tap into different aspects of bilingual input: the proportion amount of input pits the two languages against each other and examines whether language dominance is the driving force in shaping a child's language processing abilities, while the absolute amount of input examines whether the amount of input in each language is responsible for the child's processing capabilities in each of their respective languages. Both of these variables play important roles in predicting speech and language outcomes, but recent research suggests that the *absolute* amount of input in each language holds higher predictive power than *proportion* of input in each language for early language processing and vocabulary development (De Houwer, 2011; Marchman et al., 2016).

Additionally, caregivers are typically asked to report only on speech directed towards their infants (as opposed to all speech heard by the infant, including overheard speech), which is grounded by research showing that speech directed towards infants has the biggest influence on language development (e.g., Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015). However, infants also learn from overheard speech (Oshima-Takane, Goodz, & Derevensky, 1996; Shneidman, Buresh, Shimpi, Knight-Schwarz, & Woodward, 2009). In bilingual environments, the language that caregivers speak to their infant can sometimes differ from the language they use with others. For example, a bilingual infant might hear two languages in equal proportions in speech directed

towards her, but hear only one of the languages in overheard speech. In such a hypothetical case, the bilingual infant may be assessed as having “balanced exposure”, but acquisition of one of her languages may progress more rapidly due to her exposure to the overheard language. Thus, it is important to document how often these two variables (proportion amount of input *directed towards the child* versus *in overheard speech*) are decoupled.

Finally, it is important to consider the nature of the variable of proportion measures, especially since parent-report measures typically yield a single estimate that is intended to encapsulate the child’s lifetime of language experience. Indeed, there is an implicit assumption a bilingual child’s relative exposure to each language is fairly consistent across different days in their lifetime (barring unique events in a child’s life, e.g., starting daycare, relatives visiting). But, is this really the case? Are bilingual caregivers consistent in speaking the same language(s) to their child across different days, and do infants hear the same language breakdown across weekdays and weekends? To date, these questions have yet to be explored.

Research questions

In this paper, we investigated the language experiences of French-English bilingual infants from Montréal, Québec, as part of a larger project examining the effects of language input on speech processing at 10-months-of-age. Examining the language input at this age is useful, given that many speech processes develop around this age (see Werker & Curtin, 2005 for a review). The bilingual population in Montréal is unique in that the two dominant languages (French and English) co-exist in many cultural and political contexts. Over half of the population in Montréal reports being fluent in both French and English (55.1%; Statistics Canada, 2016), and language mixing is prevalent in many social contexts. Here, we addressed five main research questions:

Q1: How reliable are parent reports in assessing a bilingual infant's proportion exposure to each language? Only a handful of studies have addressed whether caregivers can accurately estimate their child's language experiences (De Houwer & Bornstein, 2016; Marchman et al., 2016). However, in these studies, the recordings were mostly conducted in one context (i.e., one weekday at home, or one session at the lab) and with caregivers who tended to speak one language to their child, which limits generalizability. Here, we addressed this question with a more heterogeneous bilingual population and with a wider range of language experiences (three full days of recordings). Further, we conducted a language interview both before and after the recordings were made in order to examine whether the observed measures matched caregivers' report of their child's lifetime exposure to each language, and whether caregivers could accurately recall their child's exposure to each language on days that have passed.

Q2: How reliable are caregivers in reporting their own language use and the family language practices implemented at home? Children in bilingual homes experience bilingualism through different combinations of language and speakers. We examined whether caregivers are reliable in reporting the languages that they use with their child. For example, prior studies suggest that caregivers are not very good at strictly adhering to the one-parent, one-language strategy (De Houwer, 2016; Goodz, 1989), but it is not well-documented how much caregivers deviate from their stated language use patterns.

Q3: How well do proportional measures of language input correspond to absolute amount of input in each language? While much of the data in this paper concerns the *proportional* amount of language exposure, it is important to also consider *absolute* amount of language exposure. Marchman et al., (2016) showed that these two variables do not always align with one another. However, their study was conducted with Spanish-English families that were

mostly Spanish-dominant. Thus, it is important to examine whether these variables are also decoupled in a more heterogeneous bilingual population.

Q4: How consistent is infant's bilingual exposure when considering infant-directed versus overheard speech? Here, we sought to provide direct evidence of whether infants' relative exposure to each language is similar when considering speech directed towards them versus speech they overhear in their environment.

Q5: How consistent is language exposure to bilingual infants between weekdays and weekend days? Even in parent-report measures, caregivers usually note differences between weekdays and weekends – often due to differences in child care arrangements. However, it is not well-documented whether caregivers themselves are consistent in the languages that they speak to their infant from day to day. Thus, we asked whether caregivers are consistent in their language use when speaking to their infant across different days, and whether bilingual infants' exposure to each of their native languages is consistent across different days.

2. Methods

2.1. Participants

Twenty-one families with a 10-month-old infant (13 boys, 8 girls; age range = 289–319 days, $M = 303$ days) took part in this study. We recruited infants who heard both French and English between 25% and 75% of the time, without exposure to another language more than 10% of the time. We explained the premise of the study to the parents by phone. During this initial contact, we conducted a brief screening questionnaire to target children who met our inclusion criteria, and we confirmed that parents were willing to commit to three full days of recording at home.

Family information

All recruited families consisted of one father and one mother. Nine of the infants were single-born children, ten had one older sibling, and two had two older siblings (sibling age range = 2-8 years; $M = 4$). These families were from mid- to high- socioeconomic backgrounds, with an average Hollingshead score of 52.2 (range: 31 - 66 out of a possible score of 66; Hollingshead, 1975). Most of the infants were cared for at home with one or both of the primary caregivers ($n=16$), while some were with a nanny during the weekdays ($n=2$) or were enrolled in full-time daycare ($n=3$).

All caregivers had knowledge of both French and English (see *Supplementary materials* for more information about caregivers). With regards to speech directed towards their infant, families reported three types of family language use patterns (see Table 1): each parent spoke a different language to their infant (i.e., one parent, one language strategy; $n=4$), one parent spoke both languages while the other spoke only one of the two languages to their infant ($n=8$), and both caregivers spoke both languages to their infant ($n=9$).

2.2. Procedure and measures

The study consisted of three sessions: the initial laboratory visit, the home recordings, and the final visit. During the family's initial laboratory visit, we conducted a comprehensive language environment interview with one ($n=17$) or both ($n=4$) caregivers (described in more detail below). Parents then completed three full day recordings at home: two on the weekdays and one on a weekend day. All but two families followed this schedule; one family did the recordings on one weekday and two weekend days, while another family did the recordings on three weekdays. Note that for families with children enrolled in daycare, the recordings were completed on days when the child stayed at home. At the end of each recording day, caregivers filled out a daily activity diary, detailing the infant's general activities throughout the day. Finally, we visited the family at

their homes or at our laboratory to collect the recording devices and complete language and demographic questionnaires with one ($n=2$) or both ($n=19$) caregivers.

Reported measures of language exposure

Here, we examined two measures of reported language exposure: the *pre-study lifetime estimate*, and the *post-study estimate*. In both cases, the estimates are defined as the proportion of total words heard in language X out of total words heard in all languages (see Table 2 for description of input variables used in this manuscript).

The *pre-study lifetime estimate* was obtained during the interview portion of the initial laboratory visit. We asked caregivers a series of questions that are typical of other language interview formats from other laboratories (Bosch & Sebastián-Gallés, 2001; DeAnda et al., 2016), following established practices for conducting the language interview (Byers-Heinlein et al., 2019). To help caregivers recall what languages their child typically hears at home, we first asked them a range of questions, including what languages each member of the household speaks to each other, what languages their child is exposed to in different contexts (television, play time, meal time, book reading, songs), and what languages other members of their family or community speak to them (grandparents, family friends, neighbours, day care teacher). We also asked them what family language practices they adopted at home, if any. Then, we asked caregivers to describe their child's typical day and estimate what languages their child hears on weekdays and weekends, on a month-to-month basis, from birth to the present day (see *Supplementary materials* for more details). We asked caregivers to consider only speech directed towards their infant, and not speech from the TV or radio nor overheard speech. During this process, we asked caregivers to consider any situations when the language proportion might be different, including whether one or both caregivers were at home or at work, whether they went on long trips abroad, or whether they had

long-term visitors at their home. Finally, we asked caregivers for a global estimate of language exposure to French, English and any other present languages by asking the following question: “If you could put a tape recorder up to your child’s ear and counted all the words he/she heard spoken directly to him/her in his/her whole life, what percentage do you think would be in each language?”. We took the average of their month-to-month estimate and their global estimate to obtain the pre-study lifetime estimate of proportion exposure to each language.

The *post-study estimate* was obtained during the final visit. We asked caregivers the following question: “Think about the days that you recorded. If you counted all the words your child heard in the recordings, what percentage do you think would be in each language?” Caregivers were given a chance to review the daily activity diary that they filled out at the end of each recording day. For each recorded day, caregivers gave an estimated percentage for English, French and any other languages.

Observed measures of language exposure

Caregivers were asked to complete three full days of recording using the LENA recording system. They were instructed to dress their child with a custom-made vest and to insert the recording device into the pocket of the vest. Caregivers were asked to carry on with daily activities and speak to their child as they would on a typical day. They were asked to keep the recording device running for the entire day, until the recording device automatically stopped after 16 hours. To ensure that incidental study participants also provided consent, caregivers were required to ask other individuals around the infant to sign a consent form. They were also instructed to pause the recording if they were overhearing strangers’ voices when outdoors, or to note down the time of day so that the relevant portion could be deleted for analyses. At the end of each recording day, caregivers were asked to complete a daily activity diary.

In total, the families produced 1008 hours of audio recordings (21 families X 3 days X 16 hours). The LENA algorithms estimate several characteristics of the input, including word counts from adults. Prior work has shown that the LENA algorithms are equally reliable at estimating the number of words in both English and French, even when the two languages are present in the same recording (Orena, Byers-Heinlein & Polka, 2019).

To extract more information about the language input from the recordings, we constructed a coding scheme that was inspired by the infant Social Environment Coding of Sound Inventory (SECSI; Ramírez-Esparza, García-Sierra, & Kuhl, 2014). First, we divided the recordings into 30-second segments via Audacity Software Version 2.1.1 (Audacity Team, 2014). We then matched these segments with the LENA-generated Adult Word Count using LENA software. A large majority of the recordings contained no adult speech – either due to sleeping or alone time; thus, we discarded all segments that had zero word counts from analyses. On average, each recording contained 625.4 segments of speech ($SE = 26.6$), for a total of 39,402 segments (or 328.4 hours) from the 21 families. Based on pilot analyses, we determined that coding half of the recordings with speech was sufficient to obtain stable measures of the language proportion breakdown in the recording. As such, we decided to code every other 30-second segment that contained speech. Thus, all absolute values represented in this manuscript only constitute half of each infant's speech-filled day. In total, we coded 19,701 segments of speech (or 164.2 hours) from the 21 families.

Per the coding scheme, trained research assistants listened to each segment and tagged them for social context (e.g., *Infant is alone*, *With one other individual*, or *With two or more individuals*), speaker context (i.e., who is speaking and to whom: *Mother*, *Father*, *Sibling*, *Infant*, *Other*), and language context (i.e., what language was being spoken: *English*, *French*, *Mixed*,

Unknown). Coders had access to the daily activity diary provided by the caregivers, which assisted in the identification of speakers in the recordings. Seven research assistants completed this time-intensive process. All research assistants were highly proficient simultaneous French-English bilinguals from Québec, Canada, and were undergraduate students majoring in Linguistics or Psychology. Each completed a training file before coding the data files for this project. Inter-coder reliability was assessed in these training files for both tagging the speaker and tagging the language. In both cases, we found high reliability across coders ($M = 94.2\%$ match, $Range = 91.8 - 96.4\%$ for speaker context, and $M = 92.4\%$ match, $Range = 88.1 - 96.1\%$ for language context).

Table 2 lists the different measures calculated for the present study. Unless otherwise stated, we only considered speech that was directed towards the infant (as opposed to overheard speech), given that our reported measures of language input was also focused on speech directed towards the infant. To estimate the number of words in each language, we summed the LENA-generated adult word counts that were coded as each language in the 30-second segments. To calculate the observed language proportions, we divided the amount of word counts tagged in each language by the total adult word count tagged in both languages. The resulting dataset is a rich description about the child's language experiences during the recordings.

3. Results

Below, we describe the analyses pertaining to our five research questions, separated into two sections: i) Parent-report versus observed measures, and ii) Nature of bilingual language exposure. The correlation analyses are also summarized in Table 3.

3.1. Parent-report versus observed measures

Q1: How reliable are parent reports in assessing a bilingual infant's proportion exposure to each language?

First, we examined the accuracy of parent reports in estimating the observed language exposure in the LENA recordings. Recall that we gathered two reported measures of language exposure: the *pre-study lifetime estimate*, and the *post-study estimate*. The observed measure here is the average language proportion across the three days of recording directed towards the infant. Figure 1 plots the relation between reported and observed measures of language proportion.

Results indicate that caregivers' initial assessment of their child's language environment closely matched the language proportions heard in the recordings. Pearson's correlation analysis revealed a strong, positive relation between the pre-study lifetime estimate and the observed measure [$r = .76, p < .001$]. The mean absolute difference between these two variables was 14.3% ($Range = .2 - 27.7$). Figure 1a shows that, apart from five participants, the dominant language (i.e., most-heard language directed towards the infant) according to parent report was also the dominant language in the recordings.

Analysis of the post-study estimates also indicate that caregivers can reliably describe their child's language exposure from the recent past (see Figure 1b). Recall that, at the end of the study, caregivers were asked to estimate the language proportion of each day; we took the mean of these reported language proportions across the three days for each participant. Pearson's correlation analysis showed that this post-study estimate was significantly correlated with the observed measure [$r = .78, p < .001$]. The mean absolute difference between these two variables was 14.5% ($Range = .3 - 40.2$).

Q2: How reliable are caregivers in reporting their own language use and the family language practices implemented at home?

Here, we evaluated the accuracy of parent reports of their own language use. During the pre-study language interview, we asked caregivers to identify what languages both parents speak,

and what languages they speak to their infant. Note that all caregivers in our dataset had some fluency in both French and English, but not all caregivers reported speaking both languages to their infant: of all caregivers, twenty-seven (64%) reported speaking both languages to their infant, while fifteen (36%) reported speaking only one language to their infant (see Figure 2).

We first examined the cases in which caregivers reported speaking only one language to their infant. A strict definition of “speaking one language” would be that caregivers did not say even a single utterance in the other language to their child. However, our observed data shows that all caregivers spoke at least one utterance in both languages to their infant. A looser definition of “speaking one language” would be that caregivers produced the vast majority of their input in a single language. Indeed, when caregivers reported speaking only one language to their infant, they were mostly consistent in using their target language (Mean of using their target language = 97%; $SD = 3\%$; $Range = 92 - 99\%$). On the other hand, when caregivers reported speaking both languages to their infant, we observed greater variability in how much caregivers used each language (Mean of using their dominant language = 84%; $SD = 16\%$; $Range = 51 - 99\%$). Interestingly, almost half of the caregivers who reported using both languages fell into the range of the caregivers who reported using only one language ($n=12/27$). These results suggest that different caregivers might have different interpretations of what is meant by speaking one or two languages to their infant.

Another interesting observation is that very few caregivers were balanced in using their two languages when speaking to their 10-month-old: only 6 out of 42 caregivers spoke each language 25%-75% of the time (see Figure 2). Interestingly, five out of these six caregivers reported that they spoke more English than French. This is consistent with the socio-cultural trend in nearby communities (Ottawa-Hull) wherein English-dominant bilinguals tend to switch their

languages more often than French-dominant bilinguals in a French-dominant environment (Poplack, 1988).

In a more global analysis, we examined how well families followed the language practice that they reported at home. Table 1 shows the matrix of reported versus observed family language practices for our set of families. Given that virtually all caregivers spoke both languages to their infants (at least minimally), we set a liberal criterion of speaking a language if the caregiver used that language at least 10% of the time. Consistent with findings from Goodz (1989), this table shows that caregivers who reported doing the one-parent, one-language strategy were consistent in doing so (4 out of 4 families matched): all caregivers spoke their “target” language at least 93% of the time to their infant. For families who reported that one caregiver spoke both languages while the other caregiver spoke one language to their infant, families were not as reliable in following the language practice that they reported (4 out of 8 families matched). Families who reported that both caregivers spoke both languages were more unreliable when considering our criteria for “speaking a language” (2 out of 9 families matched).

Q3: How well do proportional measures of language input correspond to absolute amount of input in each language?

Similar to Marchman and colleagues (2016), we examined the correlation between infants’ reported proportional measures of language input and their observed absolute measures of input. We took the average of each child’s input in each language across the three days to represent the child’s absolute measure of input in each language. Visual inspection of scatterplots revealed substantial heteroskedasticity: the variation around the regression line was greater as input increased (see Figure 3a and 3b). Thus, we examined the correlations between these variables using the Spearman’s Rank-order correlation. We detected moderate to strong correlations

between absolute exposure and proportion exposure for both French [$r_s(19) = .56, p < .001$] and English [$r_s(19) = .70, p < .001$], suggesting that the reported proportional measures of input captures some of the variability that is reflected in the absolute amount of input that infants hear in each of their languages. When we divide our sample by language dominance, we find a moderate correlation between these two variables within infants' non-dominant language [$r(19) = .50, p = .02$], but not in their dominant language [$r(19) = .24, p = .28$].

Nevertheless, this finding does not imply that these two variables are interchangeable. Indeed, these two variables are measuring different facets of bilingual input. Even in our dataset, among infants who heard similar proportions of exposure to English or French varied widely in the absolute number of words they heard in each language. As an extreme example, one child in our sample who was reported to hear English 57% of the time heard 10,098 English words per day on average, while another child who was reported to hear English 59% of the time heard only one-tenth the absolute input by comparison: 1,184 English words per day on average. Thus, while our data shows a tighter coupling of proportion and absolute measures of bilingual input than reported in previous research, it is still the case that children with similar relative amounts of exposure to each language can experience very different absolute amounts of exposure.

3.2. Nature of bilingual language exposure

Q4: How consistent is infant's bilingual exposure when considering infant-directed versus overheard speech?

In this section, we examined infants' exposure to speech directed towards them versus overheard speech. Indeed, our sample of infants was exposed to more overheard speech than infant-directed speech [$V = 208, p < .001$]. On average, they heard overheard speech 1.66 times

($SD = .82$, $range = .37 - 3.81$) more often than infant-directed speech; only three infants heard more infant-directed speech than overheard speech.

First, we examined whether caregivers changed their language use when speaking to their infant versus other individuals in the recordings. Figure 4a plots the locally weighted regression curves for the proportion of English use when directed towards the infant versus directed towards others. Spearman's rank correlational analyses suggest that caregivers are consistent in their language use regardless of the addressee [$r_s = .65$, $p < .001$]. Note, however, that this correlation is likely driven by caregivers who use only one language at home, both with their infant and with other individuals (see Figure 4a). Indeed, there is large variability in whether or not caregivers changed their language proportion: the mean absolute difference in language use by addressee is 22.5% ($range = 1.0\% - 79.7\%$). These data highlight that even though infants are only hearing their parent speak one language to them, they may be hearing the same parent speak other languages to other members of the household.

Indeed, when considering the input landscape more broadly, our sample of infants tended to hear their language in different proportions when we compare infant-directed and overheard speech. Figure 4b plots the differences in language exposure between these two types of speech for each infant. Spearman's rank correlational analyses reveal no significant relationship between language exposure via infant-directed speech and overheard speech [$r_s = .28$, $p = .22$]. The mean absolute difference in language use by addressee is 25.3% ($range = 1.7 - 59.1\%$).

Q5: How consistent is language exposure to bilingual infants between weekdays and weekend days?

Here, we examined the consistency of infant's language exposure from each parent across the different days. We excluded two families from these analyses, since they did not complete the

requested two weekdays and one weekend day of recording. We computed proportions for each parent separately for weekends and weekdays (weekday scores were averaged across the two recording days). Figure 5a shows a monotonically increasing relationship between weekend and weekday input, which was not always linear. Indeed, there was a robust consistency in the proportion that caregivers used each language to their child on the weekdays versus weekend [$r_s = .94, p < .001$], showing that caregivers who spoke proportionally more English on weekdays also spoke proportionally more English on the weekends. The mean absolute difference in language use proportion between weekdays and the weekend day is only 5.5% ($range = .2 - 22.1\%$). Thus, when looking across weekdays and weekends, most caregivers were consistent in the languages they spoke to their infant.

Note, however, that even though caregivers are consistent in their language use when speaking to their infant, a child's overall input to each language depends on the amount of time spent with each parent speaking those languages. As previously mentioned, some of the infants in our sample were cared for at home by the primary caregiver, while the other caregiver was at work. Thus, we also examined infant's overall exposure to each language across the different days. Here, we considered only the speech directed towards the infant. Data analyses show a significant Spearman's rank correlation between an infant's language exposure on weekdays and the weekend day [$r_s = .71, p < .001$]. Nevertheless, note the wide individual variability shown in Figure 5b. The mean absolute difference in language exposure between weekdays and the weekend day was 17.8% ($range = 1.1 - 60.2\%$). These data remind us that bilingual infants' language experiences can vary widely by day especially when different caregivers are present.

4. Discussion

The general aim of the current study was to explore the quantitative nature of dual language input to bilingual infants. To do so, we collected daylong recordings from French-English bilingual families in Montréal, along with parent-report measures of infants' language experiences. Following the five research questions raised in this paper, we summarize the main contributions of this paper below. These findings provide new insights on how infants in bilingual environments experience language input, which can inform both research and clinical assessments with bilingual children.

Q1: Caregivers are reliable in assessing their bilingual infants' proportion exposure to each language

An important methodological question in bilingualism research concerns how caregivers' perceptions of their children's language input correspond to what children actually hear at home. Our study reveals that language interviews can elicit reliable quantitative information about a bilingual infant's language environment. This finding expands on previous research (Marchman et al., 2016) by showing this pattern in both a predictive and retrospective direction. Our approach was to conduct a language interview both before and after the recordings were made (i.e., pre-study lifetime estimates and post-study estimates, respectively). By showing this relationship in both directions, we can deduce that i) for most families, recordings conducted at ten months of age are fairly representative of the child's lifetime exposure to each language, as reported by the parent, and that ii) caregivers can accurately estimate the language proportion of days that have passed.

It is important to note that the pre-study lifetime estimate considered the language proportion from birth to present day, while the observed measure indexes only the language proportion during the recent three recorded days. Given that the proportion of language exposure

could change from birth to present day (e.g., if one caregiver goes back to work, if the child begins daycare, or if relatives visit for a long period of time), the calculation for the pre-study lifetime estimates may have included language proportions that were no longer current or relevant. Indeed, per parent reports, a small number of infants in our sample ($n=5$) had a different dominant language at ten months of age compared to their first month of life. Further, the pre-study lifetime estimates involved the language proportion through a typical week (5 weekdays and 2 weekend days), while the recordings only involved two weekdays and one weekend day. Despite this difference in operationalization, the two variables were still closely related, suggesting that parent-report measures of language exposure may be sufficiently stable for describing a child's current proportional exposure at this age.

We nonetheless still observed some small discrepancies between the parent-report and observed measures of language proportion. Some of these discrepancies are likely due to non-systematic measurement error, which is an inherent part of any measurement. For example, some infants' language input patterns may change quite often due to vacations or visiting family members, while some infants have more stable language input across their lifetime. In addition, some infants have more family members living with them than others (siblings, grandparents), who may each speak different languages to the infant. All of these experiential factors may affect caregivers' reports in different ways, which varies the amount of discrepancy between the parent-report and observed measures of language proportion.

Q2: The reliability of caregivers' report of family language practices is variable

Second, we were interested in the correspondence between caregivers' reported language practices (i.e., whether they used one or two languages with their child) and their actual language practices. Generally, caregivers were accurate in reporting how many languages they used with

their child (although all caregivers used their other language at least a small proportion of the time). Nevertheless, there was considerable overlap between caregivers who reported speaking one and two languages to their child. This is likely due to caregivers having different interpretations of what is meant by “speaking a language with their child”. Future research might develop more nuanced ways of asking caregivers about their language use, as well as examining what influences on individuals’ ability to track and accurately report their language use.

It is interesting to note that even though most caregivers in the present study were fluently bilingual, very few caregivers actually used both languages in a balanced proportion when speaking to their 10-month-old infant. It would be of interest to examine how language use might change over time, as the child begins to understand and produce words in both of their languages. It is possible that caregivers are more likely to stick to one language when interacting with younger infants, but that this may change over time in response to children’s emerging proficiency in comprehending and producing words in each language.

Q3: There is substantial variability in the absolute amount of input among infants hearing the same proportion of input

While much of the data in this paper concerns the *proportional* amount of language exposure, we were also interested in the relationship between proportional and *absolute* amount of language exposure. In our dataset, the proportional measures of language exposure correlated with the absolute measures of input when considering the input to the child in both French and English. However, recall that when analyzing the data by language dominance, we observed a moderate correlation between these two variables in infants’ non-dominant language [$r(19) = .50, p = .02$], but not in their dominant language [$r(19) = .24, p = .28$]. This pattern of correlations mirrors previous findings by Marchman and colleagues (2016): in their data with Spanish-

dominant/English bilinguals (range = .51-.98 proportion exposure to Spanish), there was a moderate correlation between these two variables in English (non-dominant language) [$r(16) = .49, p = .03$], but not in Spanish (dominant language) [$r(16) = -.04, p = .87$].

One possible explanation for these different patterns pertains to the heterogeneity of the sample being analyzed. When conducting the analysis on our full sample (i.e., a more heterogeneous sample), we find a strong correlation between the proportional and absolute measures of input. Indeed, the correlation coefficients decrease when considering a more homogeneous sample of bilinguals – as in the Spanish-dominant bilinguals in Marchman et al., (2016), or when we split our sample into “dominant” and “non-dominant” groups. Indeed, a restricted range often limits the detection of a correlation. Moreover, we observed greater variance as the amount of input increased, indicating the heteroskedastic nature of these variables. Certainly, the heteroskedasticity in this dataset likely reflects the mathematical fact that differences between absolute and proportion exposure get multiplied as the number of hours of input increases. In other words, there is greater numerical discrepancy in the number of words when comparing infants’ dominant language than their non-dominant language, which decreases the correlation coefficient.

Taken together, our analyses show that even though there is a general, positive correlation between absolute and proportional exposure to language in bilinguals, there can still be a decoupling between absolute and proportional exposure to language in bilinguals, just as monolinguals who receive 100% of their exposure in a single language can hear vastly different absolute numbers of words. This is an important finding to consider for future studies when examining how these two types of input measures interact with proficiency levels in both languages. Prior work has suggested the absolute amount of language input is a better predictor of

language outcomes in bilinguals than proportional measures of language exposure (De Houwer, 2011; Marchman et al., 2016). Nonetheless, competition models of bilingualism also point to the importance of relative exposure (Hernandez, Li & MacWhinney, 2005).

Q4: Infants hear different proportions of language input when considering infant-directed versus overheard speech

We found that many caregivers used their languages in one way with their infants, but in another way with others in the household. This finding suggests that there is some speaker-specificity to language use among caregivers. Indeed, it is possible that caregivers speak differently to their infants than to other adults because they are using specific strategies to promote language acquisition or bilingualism in their infants. It may also be the case that implementing infant-directed speech in a non-dominant language is more effortful than in a dominant language, resulting in caregivers largely using their dominant language when speaking to their infant.

This finding motivates future research to examine how overheard speech might affect infants' early speech and language skills. To date, prior work has largely focused on infant-directed speech, especially given the large body of work showing its importance on speech perception and language outcomes (see Golinkoff et al., 2015). However, the relative importance of overheard speech for infants' language acquisition remains an open question (e.g., Sperry, Sperry, & Miller, 2018). Our data reveals that, in this community, infants "hear" more speech from their caregivers addressed to other members of their household than to themselves (with the caveat that the recordings cannot explicitly tell us whether infants are paying attention to the overheard speech). Certainly, some studies indicate that young monolingual children can learn aspects of their native language from overheard speech (e.g., Shneidman et al., 2009). Thus, it would be interesting to

consider how overheard speech (in addition to infant-directed speech) might play a role on bilingual infants' speech perception and processing abilities.

Q5: Proportion of input can vary by day, depending on who is caring for the infant

Finally, we examined the consistency in which infants hear different languages across different days of the week. While there can be wide variability in the amount of adult speech across the day (d'Apice, Latham & von Stumm, 2019), our dataset reveals that bilingual caregivers are consistent in their language use across typical weekdays and weekends within a short time period. This consistency of language input from caregivers supports the idea that infants might use external factors, such as speaker identity, to aid them in discriminating their two languages (Kandhadai, Danielson & Werker, 2014). Indeed, most of the caregivers in our sample largely spoke only one language to their infant. It would be interesting to examine whether languages are also tied to different activities or contexts during the day (e.g., meal time, book reading, etc.).

Nevertheless, caregivers tend to spend different amounts of time with the infant across different days of the week (typically due to caregivers' work status). Thus, the language breakdown that the child hears on different days can differ quite widely, as a function of who is spending time with the infant. While this is not a novel insight on the bilingual experience, our study describes this variability in naturalistic home recordings in a more direct and detailed way. These findings caution us about sampling bilingual infants' language experiences within a single day, or within a more limited observation period, as doing so may provide an incomplete picture of a child's language experiences. This issue is compounded when infants hear their different languages from different speakers (e.g., one-parent, one-language approach).

Limitations and Conclusions

There are some limitations to the generalizability of our findings. First, we acknowledge that even though we sampled three full days of recordings (including two weekdays and one weekend day), these may still not be representative of infants' full range of language experiences. Some of the caregivers did note that they felt more inclined to stay at home during the recordings so that they did not need to worry about obtaining consent from other individuals who might happen to get recorded. Further, as previously mentioned, families who enrolled their child in daycare opted to complete the recordings at home; thus, the recordings contributed by these infants ($n=3$) may not be representative of their typical days. These are inherent challenges in collecting daylong recordings from bilingual families (see discussion in Orena, Byers-Heinlein & Polka, 2019), and motivate more in-depth examination of the bilingual input in different contexts.

Second, our sample of French-English bilingual families may not be wholly representative of all bilingual families' ability to report their child's language environment. Indeed, the topic of *language* is prominent in the social context of Montréal; thus, it may be that caregivers in Montréal may be more aware of the languages being spoken to and around their child. Further, the current experiment required caregivers to be willing to record two weekdays and one weekend of their daily lives. Indeed, our sample of families were of mid- to high-SES, and most of the infants were being cared for at home (not at daycare). While this is a typical set-up for many families in Montréal with children of this age (given parental leave policies in Canada), the study may still have self-selected families who would have more opportunities to be aware of their child's language environments. Indeed, caregivers who care for their child at home spend more time with their children, and they would be more aware of what languages their child hears from the different speakers in their lives. Thus, these results might not generalize as well to those who are enrolled in daycares, or to those who spend more time with other individuals (including grandparents and

older children). Nevertheless, even within our own sample, the primary caregiver (who tended to be the person to participate in the language interview) was not always around the child throughout the day, suggesting that caregivers can also estimate what their child hears from other speakers.

Similarly, in interpreting the current data on variability of bilingual experiences, we caution in generalizing to other bilingual communities outside of Montréal. Indeed, bilingual communities around the world differ in many socio-cultural dimensions, and various sociolinguistic differences have been shown to play a role in language acquisition (Smithson, Paradis, & Nicoladis, 2014; Vihman, Thierry, Lum, Keren-Portnoy, & Martin, 2007). Indeed, some of our findings may be directly tied to the sociolinguistic context in Montréal. For example, since both French and English are widely spoken between adults in Montréal, infants may be more likely to overhear two languages in adult conversations, compared to infants from other environments with a single majority language. As our field collects more daylong recordings of infants' language experiences from other bilingual communities, it would be interesting to compare and contrast infants' bilingual experiences. Identifying different "bilingual profiles" would be a critical step towards understanding how different language experiences affect language acquisition.

In sum, the present study examined the quantitative nature of dual language exposure in young bilingual infants. Specifically, it provides support for conducting language interviews for assessing a child's language environment, but it also motivates the need to examine the bilingual experience beyond proportional measures. Indeed, our findings highlight the individual differences in bilingual experience, even in a small sample of bilingual infants learning the same two languages in the same city. Future research could be directed towards linking more fine-grained aspects of input and language outcomes in bilingual infants. Examining these different types of bilingual input is important for our understanding of input effects in bilingual acquisition.

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Table 1. Matrix of reported and observed family language use patterns

		Reported				
		Both caregivers speak same language	Each caregiver speaks different language	One speaks both; one speaks one language	Both caregivers speak both languages	Total
Observed	Both caregivers speak same language	<u>0</u>	0	2	2	4
	Each caregiver speaks different language	0	<u>4</u>	1	2	7
	One speaks both; one speaks one language	0	0	<u>4</u>	3	7
	Both caregivers speak both languages	0	0	1	<u>2</u>	3
	Total	0	4	8	9	21

Note: Underlined cells represent matched observed and reported family language use patterns. Caregivers were determined to “speak a language” if they used that language at least 10% of the time.

Table 2. Input variable names and definitions

Variable name	Variable definition	Research Q
Proportion exposure	Proportion of exposure to one language, by dividing exposure to one language by exposure to all languages	
Reported English proportion	Proportion of infant-directed speech in English, as reported via parent interview	
i. Pre-study lifetime estimation	Interview before the recordings were conducted.	1
ii. Post-study estimation	Interview after the recordings were conducted	1
Observed English proportion	Proportion of infant-directed speech in English, measured via speech in recordings and coded by research assistants. Note that only half of each day was coded	
i. Proportion by speaker	Observed English proportion from i) Mother and ii) Father, across the three recorded days	2
ii. Proportion to infant / Infant-directed speech	Infant-directed speech across the three recorded days	1, 3, 4
iii. Proportion to others / Overheard speech	Overheard speech (i.e., speech directed towards individuals other than the infant) across the three recorded days.	4
iv. Proportion on weekdays	Infant-directed speech, on weekdays only, from i) Mother, ii) Father, and iii) All speakers	5
v. Proportion on weekends	Infant-directed speech, on weekends only, from i) Mother, ii) Father, and iii) All speakers	5
Absolute exposure	Absolute number of words heard in each language from adults averaged across the three days; total number of words were estimated by LENA software, which were then coded as English and French by research assistants. Note that only half of each day was coded	3

Note: The column "Research Q" indicates the research questions to which each variable pertains

Table 3. Summary of main correlational analyses

Variables	Analysis	Correlation	Mean and range of difference
<u>Question 1: Relationship between reported and observed language exposure</u>			
Coded English proportion vs. Reported English proportion	Pre-study lifetime estimation (Fig 1a)	$r = .76, p < .001$	14.3% (0.2 - 27.7)
	Post-study lifetime estimation (Fig 1b)	$r = .78, p < .001$	14.5% (0.3 - 40.2)
<u>Question 2: Relationship between proportion and absolute language exposure</u>			
Proportion exposure vs. Absolute exposure	French (Fig 3a)	$r = .56, p < .001$	n/a
	English (Fig 3b)	$r = .70, p < .001$	n/a
<u>Question 4: Relationship between language exposure from infant-directed and overheard speech</u>			
Coded English proportion: for infant-directed speech vs. for overheard speech	Per parent (Fig 4a)	$r = .65, p < .001$	22.5% (1.0 - 79.7)
	Per infant (Fig 4b)	$r = .28, p = .22$	25.3% (1.7 - 59.1)
<u>Question 5: Relationship between language exposure during the weekdays and weekend</u>			
Coded English proportion: on weekdays vs. on weekends	Per parent (Fig 5a)	$r = .94, p < .001$	5.5% (0.2 - 22.1)
	Per infant (Fig 5b)	$r = .71, p < .001$	17.8% (1.1 - 60.2)

Figure 1. Relationship between observed and reported language exposure, where observed language estimate is the coded proportion exposure to English, and the reported exposure to English was the: a) Pre-study lifetime estimation, and b) Post-study estimate by day. Dotted line represents a perfect 1:1 match between variables on the x- and y-axis. The blue solid line represents the best-fitting regression line, and the shaded region represents the 95% confidence interval.

Figure 2. Observed and reported languages spoken to infant, where the observed languages spoken was the coded proportion exposure to English across the three recorded days, and the reported languages spoken were the language(s) that each caregiver reported that they spoke to their child; each dot represents one caregiver.

Figure 3. Relationship between reported and observed language exposure in a) French and in b) English, where the observed language exposure is the coded absolute number of words per day directed towards the infant, while the reported estimate was the pre-study lifetime estimation. Note that we only coded half the day per recording. The blue solid line represents the best-fitting regression line, and the shaded region represents the 95% confidence interval.

Figure 4. a) The relationship between infants' proportion exposure to English from each parent when speech is directed towards the infant versus overheard speech, where each dot represents one parent; b) The relationship between infant's proportion exposure to English from all talkers when speech is directed towards the infant versus overheard speech, where each dot represents one infant. Dotted line represents a perfect 1:1 match between variables on the x- and y-axis. The blue solid line represents the LOWESS line (Locally weighted scatterplot smoothing), and the shaded region represents the 95% confidence interval.

Figure 5. a) The relationship between infant's proportion exposure to English from each parent during the weekdays and the weekend, where each dot represents one parent; b) The relationship between infant's proportion exposure to English from all speakers during the weekdays and the weekend, where each dot represents one infant. Dotted line represents a perfect 1:1 match between variables on the x- and y-axis. The blue solid line represents the LOWESS line (Locally weighted scatterplot smoothing), and the shaded region represents the 95% confidence interval.

Supplementary Table 1. Demographic and language information of caregivers

	Mothers		Fathers	
	<u>Mean (SD)</u>	<u>Range</u>	<u>Mean (SD)</u>	<u>Range</u>
Age (years)	34.6 (2.9)	30 - 41	35.7 (4.0)	27 - 42
Years in Montréal	17.9 (9.4)	6 - 33	20.3 (11.4)	7 - 39
% of life in Montréal	53% (28)	17 - 100	57% (31)	21 - 100
Current exposure to English	51% (15)	18 - 90	54% (20)	20 - 80
Current exposure to French	47% (15)	10 - 80	46% (20)	20 - 80
Bilingual Dominance Scale ¹	-1.9 (11.3)	-19 - 17	7.8 (12.9)	-18 - 21
Language mixing scale ²	13.37 (9.2)	0 - 30	8.9 (7.8)	0 - 23

Note that self-report data were missing for one mother and one father (of separate infant participants) who were not present during the interview.

¹ Bilingual Dominance Scale (Dunn & Fox Tree, 2009): scale of -30 to 30, where 0 represents a completely balanced bilingual, -30 represents an English-dominant bilingual, 0 represents a balanced bilingual, and +30 represents a French-dominant bilingual

² Language Mixing Scale (Byers-Heinlein, 2013): scale of 0 to 30, where 0 represents no language mixing, and 30 represents frequent language mixing to their infant