Language exposure and online processing efficiency in bilingual development

Relative versus absolute measures

Theres Grüter[1], Nereyda Hurtado[2], Virginia A. Marchman[2] & Anne Fernald[2]
[1]University of Hawai'i at Mānoa / [2]Stanford University

This chapter summarizes what we know so far about the development of online processing skill in young bilingual children, with a focus on the relation between individual differences in language exposure and processing skill. We discuss evidence from studies with Spanish-English bilingual children in California, showing clear contingencies between language exposure and both vocabulary size and online processing efficiency as measured in the looking-while-listening (LWL) procedure. However, the strength of these contingencies is critically affected by whether the constructs are operationalized in relative or absolute terms. While *relative* amount of language exposure is only weakly related to *absolute* processing speed, we find a more solid association when both exposure and outcome are cast in relative terms. Finally, we consider the advantages, as well as the challenges, of using absolute measures for both language exposure and outcome measures. Our ongoing studies explore ways to capture variation in the absolute amount of talk that young bilinguals hear from their caregivers, presenting preliminary evidence that variation in caregiver engagement is critical for language outcomes in bilingual children, as many earlier studies have shown for monolinguals.

1. Introduction

The nature of a child's linguistic experience is a key component in language acquisition and growth, regardless of the number of languages a child is learning. Early language experience is a major contributor to language outcomes and growth in monolingual children, demonstrated most famously by Hart and Risley's (1995) finding that the total number of words toddlers heard from caregivers at home was predictive of the number of words they knew at age 3 years. Other studies, almost all conducted with children in monolingual English-speaking environments, have

reported similar relations between measures of the amount of speech children hear and language outcomes (Hoff 2003, 2006; Huttenlocher, Haight, Bryk, Seltzer & Lyons 1991; Vasilyeva, Waterfall & Huttenlocher 2008; see Hurtado, Marchman & Fernald 2008, for evidence from Spanish-speaking children).

The linguistic experiences of children growing up in bi- or multilingual environments are distributed over two or more languages. While some children's language exposure is relatively balanced across the two languages, other children hear relatively more of one language than the other. It is hardly surprising that the variability across children in the *relative* amount of exposure to one language compared to the other is related to the number of words bilingual children know in one of their languages compared to the other. For example, Pearson, Fernández, Lewedeg, and Oller (1997) showed that in a group of Spanish-English bilinguals aged 8 to 30 months, parents' global estimates of relative exposure to each language were significantly related to the proportion of words these children were reported to know in Spanish vs. English. This relationship between relative exposure and relative vocabulary size has since been replicated in a number of bilingual populations (e.g. Gathercole & Thomas 2009; Patterson 1998; Place & Hoff 2011).

However, the extent to which relative amount of exposure is related to the development of linguistic skills other than vocabulary size is less well understood. Some studies using behavioral measures have maintained that relative amount of exposure to each language predicts grammar as well as vocabulary outcomes (Elin Thordardottir, this volume; Elin Thordardottir, Rothenberg, Rivard & Naves 2006; Gutiérrez-Clellen & Kreiter 2003; Hoff et al. 2012; Hoff, Welsh, Place & Ribot, this volume; Marchman, Martínez-Sussmann & Dale 2004), although others argue that syntactic development is less influenced by exposure patterns than is vocabulary (e.g. Paradis & Genesee 1996; Unsworth, this volume).

More recently, studies have begun to explore relations between exposure patterns and language skill using online measures which capture children's efficiency at comprehending language in real time. In a study of online spoken language comprehension with infants predominantly exposed to Spanish, the amount of maternal speech that 18-month-olds heard during a 12-minute play session predicted how quickly those children could identify the referent of a simple sentence (e.g. *¿Dónde está el perro?*; 'Where is the doggie?') at 24 months (Hurtado et al. 2008). This line of research has been extended to bilinguals in two recent studies of children learning English and Spanish at the same time (Marchman, Fernald & Hurtado 2010; Hurtado, Grüter, Marchman & Fernald 2014).

Our goal here is to review recent and ongoing research on the development of online processing skill in young language learners, focusing on how variation in language exposure relates to individual differences in early processing efficiency in bilingual children. We begin by outlining how the two critical

constructs – *processing efficiency* and *language exposure* – have been operationalized. Then we draw attention to a critical difference in how 'language exposure' is typically measured in studies of monolingual versus bilingual children. Using hypothetical data from four bilingual children, we illustrate how the choice of absolute versus relative measures of language exposure, combined with absolute versus relative measures of language outcomes, critically affects the relation observed between exposure and outcomes. We then review what studies have shown regarding links between language exposure and language processing skill by young English-Spanish bilinguals. While this relation may appear weak and/or inconsistent if relative exposure is considered in conjunction with absolute measures of processing speed, a more solid link emerges when both sides of the equation are defined in relative terms. Finally, we present preliminary evidence suggesting that an even more accurate picture could be obtained if estimates of bilingual language exposure were captured in terms of the *absolute* amounts of speech that different children hear from caregivers.

2. The role of online processing efficiency in early language development

Although real-time measures of language comprehension play a central role in psycholinguistic research on adult language processing, many experimental paradigms, such as those involving reading, or a button-press to measure reaction time (RT), are not suitable for use with young children. However, real-time measures have recently been developed for use with infants and toddlers. For example, in the "looking-while-listening" (LWL) procedure, children sit on their parent's lap and look at pictures on a screen while listening to speech naming one of the objects in the visual display (e.g. *Where's the doggie?*). Their eye movements are video-recorded and later coded without sound using custom software by highly trained observers blind to location of the target object. The resulting patterns of eye-movements reveal the precise moment when listeners initiate a shift in attention from the distracter to the named picture (Fernald, Pinto, Swingley, Weinberg & McRoberts 1998; Fernald, Zangl, Portillo & Marchman 2008). This paradigm, like the so-called "visual world" paradigms used in adult psycholinguistics (e.g. Tanenhaus & Trueswell 1995), yields a record of a child's eye movements in response to language that can be used to derive fine-grained measures of the time course of lexical comprehension. Moreover, because this task simply requires that children fixate the pictures, it can be used effectively at much younger ages than would be possible using standard behavioral tasks, such as those requiring children to comply with simple commands or to point at pictures. The LWL paradigm yields two measures of spoken language comprehension: (1) *accuracy*, the mean proportion

of time a child spends looking at the named object, and (2) *reaction time* (*RT*), the latency to initiate a shift in gaze from the distracter to the target picture as it is being named. In most of what we review here, we focus specifically on RT as a measure of language processing efficiency, although most findings are comparable when accuracy is used as a measure of efficiency.

Studies using the LWL paradigm with monolingual English-speaking children show that over the second year of life infants become faster and more accurate in identifying referents of familiar words presented in continuous speech (Fernald et al. 1998). Moreover, children's early processing efficiency is associated both with faster vocabulary growth and with long-term language and cognitive outcomes (Fernald, Perfors & Marchman 2006; Marchman & Fernald 2008). Recent LWL studies with predominantly Spanish-speaking children raised in California report similar findings (Hurtado, Marchman & Fernald 2007; Marchman, Fernald & Hurtado 2013). The predictive validity of these measures of early processing efficiency has been further confirmed with English-speaking late talkers, for whom processing skill at 18 months was a significant predictor of risk status at 30 months (Fernald & Marchman 2012). Such links demonstrate that early efficiency in real-time processing is an important factor in language development for children across a variety of learning contexts.

In the first study using the LWL procedure with bilingual children, Marchman et al. (2010) investigated the role of early processing efficiency in the language development of Spanish-English simultaneous bilinguals aged 30 months. In that study, information about children's language experience was collected through a language background interview (e.g. Marchman et al. 2004). Vocabulary knowledge was assessed through parent-report instruments in Spanish: *Inventario del Desarrollo de Habilidades Comunicativas: Inventario II* (Jackson-Maldonado, Thal, Marchman, Bates & Gutiérrez-Clellen 2003), and English: *MacArthur-Bates Communicative Development Inventory: Words & Sentences* (Fenson et al. 2007). To assess children's skill at online language comprehension, each child took part in separate LWL sessions in Spanish and in English, in which the procedure and stimuli were designed to be maximally similar across the two languages. Target words consisted of translation equivalents for ten nouns typically familiar to Spanish- and English-learning children at this age (e.g. *la galleta,* 'the cookie'). In both sessions, children listened to speech referring to one of two objects displayed on the screen (e.g. ¿*Dónde está la galleta?*; or 'Where's the cookie?'), and their accuracy and RTs were derived as outlined above. Marchman et al. (2010) found relations between RT and vocabulary knowledge within each of the child's languages. In other words, the efficiency with which children processed spoken language in Spanish was related to the size of their production vocabulary in Spanish, and the efficiency with which they processed words in English was related to the size of

their vocabulary in English. These relations remained significant after controlling for children's relative exposure to Spanish versus English. These results suggested that at this age, efficiency of online comprehension of English or Spanish words is tied to a child's level of skill in that particular language.

The primary goal of the Marchman et al. (2010) study was to test whether the links between vocabulary knowledge and processing skill that had been observed in monolingual children were generalizable to bilingual populations. Indeed, the consistent within-language relations observed between processing efficiency and vocabulary size were parallel to previous findings with monolingual children, suggesting that the ability to process spoken words efficiently is closely linked with vocabulary size, regardless of whether a child is learning one language or two. Below we revisit the Marchman et al. study, with the goal of exploring the role of children's relative language exposure in accounting for the within-language relation between vocabulary size and processing efficiency. Although this was not central to the original goals of Marchman et al. understanding how early processing efficiency relates to language exposure in bilingual language development is a critical question.

3. Relative versus absolute measures of language experience and language outcomes

It is well established that features of children's language learning environments play an important role in both monolingual and bilingual language development. However, it is not straightforward to determine how to operationalize the construct of 'input', and thereby, to capture meaningful variability in the features of those environments. One approach deriving from classic studies of early child language is to count the frequency with which particular expressions or constructions occur during a naturalistic play session and then to convert those frequency counts to *proportions* (e.g. Newport, Gleitman & Gleitman 1977). Measures of this sort capture the relative frequency of the different features of interest within the language sample from a particular participant, allowing comparisons across features (e.g. directives occurred 30% of the time compared to 10% for descriptions) or across caregivers (e.g. directives occurred 30% of the time for caregiver A, but only 10% of the time for caregiver B). Advantages of converting raw numbers to proportions include the ability to compare across recording sessions of different lengths and to equate across speakers who might produce a different number of utterances during the session.

At the same time, converting frequency counts to proportions glosses over important differences among caregivers that have a substantial impact on children's

development (Hoff-Ginsberg 1992; see also De Houwer 2011, this volume). Indeed, over the past two decades, a number of studies exploring the role of environment in monolingual development have captured input in *absolute* terms, for example, the total number of times a particular feature of talk occurred during a caregiver-child interaction (e.g. Huttenlocher et al. 1991; Hurtado et al. 2008). In a seminal study, Hart and Risley (1995) conducted 1-hour long home recordings once per month and then extrapolated estimates of the total number of words addressed to the child in an average day. These estimates revealed substantial individual differences in the absolute amount of caregiver speech that children from various social backgrounds heard and importantly, these differences were strongly associated with child vocabulary growth and later linguistic and cognitive outcomes.

Although the use of absolute measures of child-directed speech have been revealing in studies of language growth by monolingual children, research on the role of input in bilingual development has relied almost exclusively on *relative* measures of language exposure, that is, as the proportion of a child's waking hours during which they are regularly exposed to one language versus another language. Moreover, these proportion scores are typically derived from detailed parent interviews (e.g. Marchman et al. 2004; Pearson et al. 1997) or diary records kept by parents for the purpose of the study (Place & Hoff 2011), rather than being based on direct observation of parent-child interaction.

Estimating the amount of language a child hears in a particular language through direct observation rather than through interviews or parent diary places very different demands on the researcher. Moreover, relatively little is known about the degree to which these two methods offer comparable pictures of a bilingual child's learning environment (e.g. Place & Hoff 2011). A typical language environment interview with parents of a bilingual child can normally be conducted in about 30 minutes or less. In contrast, direct observation involves not only recording the child for a given period of time, but also transcribing and coding these recordings, a lengthy and laborious process. This approach remains feasible in a research study if the recorded observation is relatively short. For example, Hurtado et al. (2008) used transcriptions of 12-minute play sessions between Spanish-speaking mothers and infants to estimate maternal input. The significant relations they observed between this measure of language exposure and children's early processing efficiency suggest that even a small slice of directly observed data from a laboratory observation can provide a meaningful estimate of the amount of speech that is typical of a child's language experience.

However, note that evidence for the validity of exposure estimates based on laboratory naturalistic observations may not necessarily extend to children growing up in bilingual environments. It is difficult to imagine how a short play session between the child and one or even multiple caregivers could provide a

representative sample of a bilingual child's experience with the two languages in her life. For many children growing up in bilingual environments, their two languages are used with different speakers in different social contexts, possibly at different times of day, and the complexity of such diverse scenarios cannot possibly be captured in a brief laboratory observation. Thus, it is important to continue to explore the degree to which parent reports of language environments reflect the actual nature of children's linguistic environments. It is also critical to explore new ways to capture the absolute amounts of exposure to each language experienced by a particular child over the course of a typical week. To do so, it may be necessary to record and transcribe interactions during an entire day or even across multiple days, and to sample broadly across the contexts in which children have regular interactions with speakers of different languages, both within and outside the home.

Clearly, the challenges involved in collecting these kinds of data are substantial. We do not know of any such studies with bilingual children at this point, although later we present some preliminary findings from an ongoing project of this sort. The difference in how estimates of language experience have been measured in monolingual versus bilingual learning contexts may thus be due, at least in part, to practical limitations on the feasibility of collecting representative data on children's exposure patterns in different language environments. Yet as Hoff-Ginsberg (1992) demonstrated for caregiver speech to monolingual children, absolute and relative measures can yield substantially different pictures of the relation between language input and outcomes. Below we demonstrate how defining exposure to two languages in relative versus absolute terms has important implications for the patterns of relations that emerge between exposure and particular outcome measures, such as vocabulary knowledge, in bilingual children as well.

Another issue is whether the measures of exposure and child outcomes are defined in parallel ways. For example, in studies of bilingual children which assess exposure in relative terms, sometimes those relative measures are examined in relation to *relative* outcome measures, such as relative vocabulary size (e.g. Pearson et al. 1997), but at other times, to *absolute* outcome measures, such as vocabulary and grammatical complexity scores derived from the *MacArthur-Bates Communicative Development Inventories* (e.g. Hoff et al. 2012, this volume; Place & Hoff 2011), standardized test scores (e.g. Elin Thordardottir 2011, this volume), or reaction times in a real-time lexical comprehension task (Marchman et al. 2010). However, what is often overlooked is that the decision to compare an absolute to an absolute measure, a relative to a relative measure, or a relative to an absolute measure can also alter the observed relations that emerge from these analyses. We illustrate this point using hypothetical data from four

Spanish-English bilingual children- Julian, Luis, Alexa, and Kamila (see also De Houwer 2011, this volume).

Let's assume that for each child we have two different measures of language exposure, and a measure of vocabulary size in each language, summarized for each child in Table 1:

1. the number of hours per day the child is reported to spend with speakers of each language, from which the *relative* amount of exposure to the two languages is typically derived
2. the actual numbers of words in Spanish and English spoken in proximity to the child on a typical day, based on audio recordings, representing the *absolute* exposure to the two languages
3. the numbers of words the child can say in each language, estimated from parent report

Table 1. Summary of input and output measures in hypothetical sample

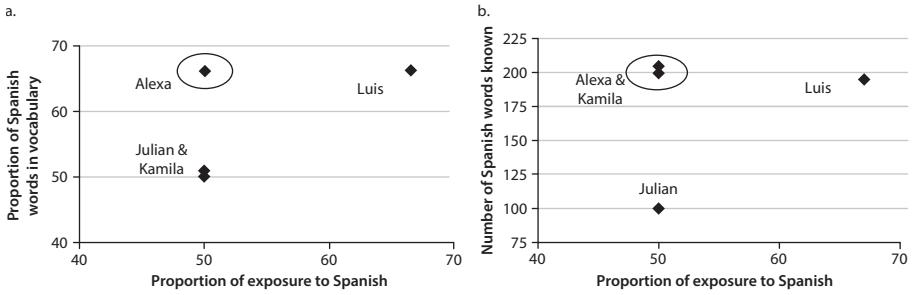
	Julian	**Luis**	**Alexa**	**Kamila**
% Time with Spanish speakers	50	67	50	50
% Time with English speakers	50	33	50	50
Total Spanish words heard per day	5,000	10,000	10,000	10,000
Total English words heard per day	5,000	5,000	5,000	10,000
Total Spanish words in productive vocabulary	100	200	200	200
Total English words in productive vocabulary	100	100	100	200

These hypothetical case studies are constructed to be consistent with the assumption that there is a perfect alignment between the absolute number of words a child *knows* in a language and the absolute number of words she *hears* in that language, on average, every day. This assumption is based on studies with monolingual children showing robust positive correlations between the amount of child-directed speech in the early language environment and the size of children's vocabularies (e.g. Hart & Risley 1995; Huttenlocher et al. 1991). However, this is clearly an idealization, glossing over a number of factors known to be influential in the real world, such as the number of different speakers in a child's life and whether or not those speakers have native-like proficiency (Place & Hoff 2011; see also Armon-Lotem, Joffe, Abutbul-Oz, Altman & Walters, this volume; Hoff et al. this volume). It is also possible that the relation between amount of child-directed speech experienced and the children's productive vocabulary is non-linear, such that differences in amount of exposure may matter more at lower than at higher levels of exposure (Pearson et al. 1997; Elin Thordardottir 2011, this volume). We

leave aside these other potentially relevant factors here in order to illustrate the extent to which absolute and relative measures of exposure and outcomes can be used to test the (idealized) hypothesis of a one-to-one relation between language input and lexical knowledge in bilingual children. Using these hypothetical data, let us consider how this relation is captured when language experience, language outcomes, or both are measured in relative versus absolute terms.

Figure 1a presents the relation between proportion exposure and proportion Spanish to English vocabulary size, both relative measures. For three of the four children, this operationalization works quite well. Julian and Kamila are both balanced in their exposure to Spanish and English, and their vocabulary outcomes in Spanish and English reflect that balance. The expected alignment between exposure balance and vocabulary size also applies to Luis. He spends relatively more hours hearing Spanish, and a relatively larger portion of his vocabulary is in Spanish. However, this relation does not align for one child in Figure 1a, Alexa, who knows more Spanish words than her relative exposure to Spanish versus English would predict. Comparing Alexa to both Julian and Kamila, all three spend 50% of their time with English speakers. However, the Spanish speakers in Alexa's life provide more child-directed speech than do the English speakers, enabling her to learn more Spanish than English words. This variation in the verbal engagement of caregivers in Alexa's life results in her hearing just as many Spanish words each day as Luis, despite the difference in the *proportion* of exposure to Spanish between the two children.

Figure 1b displays data for the same four children, with exposure again measured in relative terms, but now linking exposure to the *absolute* number of words known in Spanish. Unfortunately, this scenario appears to have weakened the link between relative language exposure and vocabulary size. In Figure 1b, both Alexa and Kamila now know more Spanish words than we would predict based on their relative exposure to Spanish. There are two possible reasons: First, although



Figures 1a and b. The relation between proportion exposure to Spanish (a relative measure based on parent interview) and (a) proportion Spanish vocabulary (relative vocabulary size) and (b) number of Spanish words known (absolute vocabulary size)

Alexa spends about the same amount of time with Spanish as English speakers, the Spanish speakers in her life talk to her more than the English speakers do, and hence, she learns more Spanish words than English words during these interactions. Second, differences in the amount of child-directed speech account for Kamila's change in relative position as well. In her case, *both* the Spanish- and English-speakers in her life are more verbally engaged with her than are the caregivers of the other children. She hears 10,000 words in each of her languages, a total of 20,000 words a day, more than any of the other children hear in their two languages combined. Yet since Kamila hears more words *overall* than the other children, the 10,000 Spanish words make up only 50% of all the words she hears.

This crucial difference among the children in the richness of their learning contexts went unnoticed when both language exposure and vocabulary outcomes were measured in relative terms (Figure 1a). However, using an absolute measure in the assessment of vocabulary (Figure 1b) revealed that Kamila's Spanish vocabulary was *larger* than those of the other children with similarly balanced exposure in the two languages. Since Kamila lives in a "denser" linguistic environment than the other children, a relative measure of her exposure will *underestimate* the absolute amount of input in each language that she experiences, and consequently will also underestimate the actual number of words she should know. In most studies of childhood bilingualism, however, exposure to each language in absolute terms is unknown. Moreover, since caregivers vary in the extent to which they are verbally engaged with the child, cases like Alexa and Kamila are common. Yet the variability they add to the relation between language exposure and language outcomes in childhood bilingualism is not considered as long as exposure is measured in relative terms.

In sum, the hypothetical case studies discussed here illustrate that looking at links between *relative* amount of exposure and *absolute* language outcomes is the least optimal scenario for testing the hypothesis that language exposure is meaningfully related to language outcomes in bilingual development. This is due to the fact that two kinds of variation cannot be captured with relative measures: (1) variation among children in the overall amount of child-directed speech they hear from caregivers (e.g. Julian vs. Kamila), and (2) variation in verbal engagement between caregivers who address the child in one language versus the other (e.g. Julian vs. Alexa). At least the first type of variability can be controlled for by keeping both measures – exposure and outcomes – in relative terms, as we have illustrated in Figure 1a. This is desirable and appropriate in studies of bilingual vocabulary development seeking to understand the role of *balance* of exposure to two languages in the development of a bilingual lexicon (e.g. Pearson et al. 1997). However, differences in the variability in verbal engagement across different speakers within a child's life remains entirely uncaptured in any comparison using

standard measures of exposure in relative terms. And, as we have seen in the case of Alexa, this variability contributes important information regarding both balance and absolute levels of language exposure. Disregarding it not only eliminates information about sources of meaningful individual variation, but also adds noise to relational analyses in any terms.

Another issue to consider is that it is not straightforward to think of how to compute a bilingual child's level of skill in their two languages for aspects of language other than lexical knowledge. For example, if we sum all of the words that a child can say in English versus Spanish, the idea that their total vocabulary consists of 60% words in one language versus 40% in the other is nicely intuitive, since what can be defined as a "word" can generally be operationalized in similar types of units across languages. The situation is more difficult when it comes to defining a bilingual child's relative skill in grammar, for example. Grammatical knowledge is instantiated in a wide variety of ways, both within and across languages, making it difficult to derive comparable indices for computing a relative measure of grammatical skill in children learning two languages. The challenge of deriving outcome measures that are comparable across languages will have to be considered separately for each outcome measure under investigation. In the next section, we illustrate our attempt to meet this challenge in relation to lexical processing efficiency as the language outcome measure of interest.

4. The relation between language exposure and processing efficiency in relative terms

Hurtado et al. (2014) investigated the contribution of *relative* amount of exposure to *relative* vocabulary size and *relative* processing efficiency in the LWL task. The goal of this study was to define all three measures – exposure, vocabulary size and processing efficiency – in relative terms. As in earlier studies, relative exposure was defined as the total number of hours the child was reported to hear Spanish out of total English and Spanish waking hours, based on a comprehensive parental interview. To facilitate comparison with the other measures, this proportion was then converted to a Spanish-to-English (S:E) ratio. Relative vocabulary was computed as the ratio dividing the raw number of Spanish words by the raw number of English words that the child was reported to produce. For processing efficiency, a relative measure was also computed, by dividing each child's mean RT in Spanish by his or her mean RT in English (S:E ratio). While perhaps less intuitively obvious, this measure captured each child's relative facility of online processing in their two languages. As such, an S:E RT ratio of > 1:1 indicates that a child was relatively slower to interpret Spanish than English words, whereas a ratio < 1:1 reflects

faster processing in Spanish compared to English, a Spanish-dominant pattern. The direct comparison of RT across Spanish and English was deemed appropriate given that the respective RTs were measured using the same experimental set-up and linguistic stimuli that were translation equivalents of each other. Relative receptive language skills of the children were also measured at 36 months using the English and Spanish versions of the *Peabody Picture Vocabulary Test* (Dunn & Dunn 1997; Dunn, Padilla, Lugo & Dunn 1986). For all measures, the ratio scores were log transformed to normalize the distributions.

Hurtado et al. (2014) reported significant first order correlations between all three measures – relative exposure, relative vocabulary size and relative RT – at both age points (30 and 36 months). First, 30-month-olds who were more skilled in real-time interpretation of words in Spanish as compared to English were also those who were more advanced in producing words in Spanish as compared to English, $r(36) = -.54$, $p < .001$. Similarly, relative mean RT was strongly associated with both relative expressive and relative receptive vocabulary at 36 months.

This significant relation between relative vocabulary size and relative RT observed by Hurtado et al. (2014) was consistent with the findings of Marchman et al. (2010), where *absolute* vocabulary size and RT were significantly related within each language. That is, those children who were faster to comprehend English words in real time also were reported to know more English words, and those children who were faster to comprehend Spanish words were reported to know more Spanish words. However, in contrast to Marchman et al.'s absolute-to-absolute comparisons, the relative-to-relative comparison of vocabulary and RT in Hurtado et al. captured how skilled these bilingual children were in processing words in one language in relation to the other, regardless of their overall skill in language processing. Those children who were relatively more skilled in one language also knew relatively more words in that language. This suggests that relative-to-relative comparisons can still provide a useful tool for investigating the relationship between vocabulary and processing skill in bilingual language development.

A central question in this research was to what extent within-child differences in relative vocabulary and processing skill in Spanish versus English could be predicted by differences in children's daily experiences in these two languages. Consistent with Pearson et al. (1997), Hurtado et al. reported strong relations between relative language exposure and S:E ratios in expressive vocabulary at both 30 and 36 months (rs .59 to .62, $p < .001$). Thus, results at two age points suggest that bilingual children who heard relatively more Spanish than English in their daily interactions with others were also relatively more successful at learning words in Spanish compared to English, and analogously, that children

who heard relatively more English were relatively more successful at learning English words.

Most relevant here is the significant relation observed between relative exposure and relative speed of online spoken language understanding, $r(37) = -.47$, $p < .001$, as shown in Figure 2. Those children who were relatively faster to process Spanish words in the LWL task were also those who were reported to spend relatively more of their daily lives in interaction with Spanish speakers. Hurtado et al. (2014) were the first to document this relation between early processing efficiency and exposure in a bilingual population, providing further evidence that children's early skill at accessing words during real-time comprehension is tied to their early experience with and practice in a particular language.

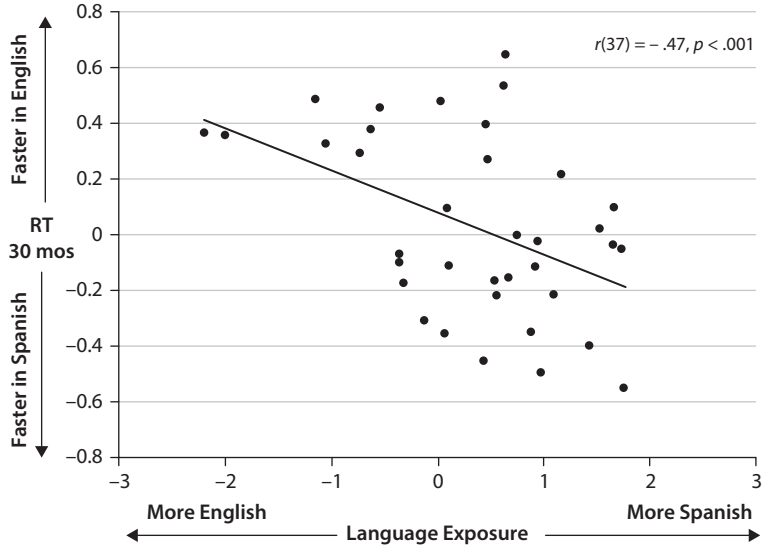


Figure 2. Relation between log-transformed S:E ratios in language exposure and S:E ratios in processing speed in response to Spanish vs. English words at 30 months (adapted from Hurtado et al. 2014)

When Marchman et al. (2010) originally looked at the relation between exposure and processing efficiency, their findings suggested much weaker correlations. They observed that relative balance of exposure was only modestly related to children's RTs in English, and no significant correlations were found between balance of exposure and RTs in Spanish. The comparison in this earlier study was between relative amount of exposure and RTs measured in *absolute* terms. As we saw, this comparison fails to capture the variance associated with differences in the 'richness' of the input between the child's two languages, as well as the well-known

variation in the overall amount of speech different children hear in their daily lives. It is therefore possible that the weak relations between (relative) exposure and (absolute) processing efficiency originally observed by Marchman et al. (2010) were due to the fact that these two types of variation obscured a relation that was actually more solid. Another potential complicating factor is that estimates of exposure were based on parental interview, rather than direct observation. Little is known about the validity of caregiver reports of language exposure in estimating the "true" nature of the learning experiences of young bilingual children. Methods that allow naturalistic observations of bilingual children over an extended period of time in interactions with the multiple speakers of English and Spanish in their lives could provide critical new information in this regard.

5. From parent report to observational measures of language exposure

We next report preliminary data from two ongoing studies which seek to obtain a more comprehensive look at the early learning environments of young bilingual learners. These studies take advantage of new digital recording technology, the LENA™ (Language ENvironment Analysis) system, to obtain day-long naturalistic audio-records of children's interactions with caregivers. The LENA™ system consists of a small audio-recording device that is worn by the child in the front pocket of specially-designed clothing. Parents are asked to turn on the recorder at the beginning of the day, and the recorder automatically turns itself off after 16 hours of recording. This system enables more extensive, more representative, and less intrusive recordings of children's daily interactions than is possible using other methods. The LENA™ software uses speech-recognition algorithms to estimate total adult word counts (AWC) per 5-minute segment based on all clear adult speech in proximity to the target child. In our studies with monolingual Spanish-learning children (Weisleder & Fernald 2013), these recordings have revealed striking variability in total AWC in talk to children, ranging from ~29,000 to fewer than 2,000 adult words heard in a 10-hour day. Importantly, these differences in AWCs were significantly correlated with both vocabulary size and processing efficiency in the LWL task. Those children who heard more Spanish words in interactions with their caregivers also knew more Spanish words and displayed greater efficiency in processing Spanish words during real-time language comprehension.

As we have argued here, variability in the absolute amount of child-directed speech provided by different caregivers is an important factor to consider in studies of bilingual language development as well. Using LENA™ technology in our research on English-Spanish bilinguals allows us to derive *direct* estimates of the amount of talk that bilingual children hear from different speakers in their daily

lives, to address several important questions: What is the degree of concordance between the estimates of exposure to different languages that parents report and those based on these day-long recordings of naturalistic interactions? That is, when parents are asked to estimate how much exposure a child has to a particular language during a typical week, do those estimates reflect the number of English and Spanish words the child is actually hearing? And, importantly, which method of estimating exposure is more closely related to children's skill at processing language in real time?

In an ongoing study (Marchman, Martínez, Hurtado, Grüter & Fernald 2014), we explore this question in primarily-Spanish-speaking 36- to 40-month-olds whose home exposure was Spanish from their parents but who were hearing different amounts of English from other sources (e.g. siblings, television). Children's processing efficiency was assessed using parallel English and Spanish sessions of the LWL procedure, and parents provided reported estimates of how much English and Spanish their child regularly heard in a typical week based on a comprehensive interview. Parents were also asked to have their child wear the LENA recorders on a "typical day", providing 8–12 hour naturalistic audio-records of children's interactions with caregivers.

While the LENA™ automated system has been demonstrated to provide reliable estimates of caregiver word counts in monolingual environments (Weisleder & Fernald 2013), the LENA™ system cannot differentiate which of those adult words are in English vs. in Spanish. Therefore, we needed to develop a procedure for listening that would enable us to divide the child's interactions based on the language that was being used. For each LENA™ recording, trained coders listened to each 5-min segment and identified: (1) how much English versus Spanish (5-point scale) was heard, (2) from whom (e.g. parents, siblings) and (3) in what context (e.g. mealtime). In this first study, we measured the amount of *time* of the recording (i.e. sum of the 5-minute segments) in which the child heard English versus Spanish across the entire recording, deriving a proportion score to represent the relative amount of the child's typical day during which the child heard English versus Spanish. These analyses also controlled for differences across children in recording length. The measures based on in-home recordings were then compared to the estimates of the proportions of daily experiences of the child reported by the parent during the comprehensive language background interview.

As shown in Figure 3, preliminary analyses with 10 participants so far show that estimates of relative English exposure based on parental interview reveal a different picture than more direct measures of relative amount of English heard by the child based on LENA recordings of caregiver-child interaction over a typical day at home. In particular, it appears that for some children there is a large discrepancy between reported language exposure and the actual proportion of

English words accessible to the child in a typical day. This suggests that at least for some parents, a comprehensive interview of what languages their child hears on a daily basis may not provide an accurate picture of what these bilingual children are actually experiencing, glossing over important variation that may have a significant impact on children's learning.

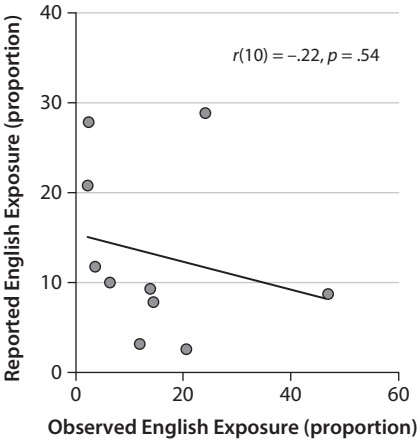
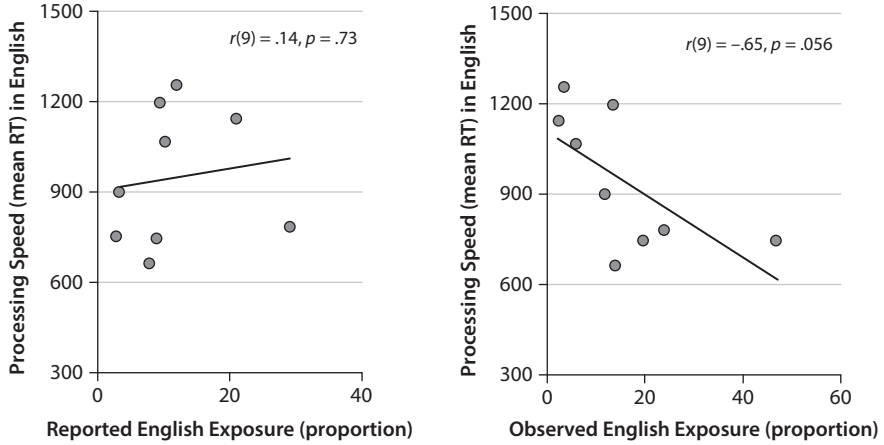


Figure 3. Relation between proportion language exposure estimates based on parental interview vs. naturalistic 8-12-hour recordings in the home using the LENA™ technology (adapted from Marchman et al. 2014)

Our next question was which of these estimates of exposure were more related to children's RT in the LWL task? As shown in Figure 4a, the reported estimates of children's exposure to English show no systematic relation to their skill at processing English words in real time. In contrast, Figure 4b shows stronger links between children's outcomes and exposure patterns based on the actual recordings. Thus, children's exposure proportions based on direct observation, rather than parent report, appear to offer considerable promise for clarifying the links between learning environments and language outcomes.

In a second set of analyses, we followed similar procedures but also derived estimates of the *absolute* number of words (AWC, 'absolute word count') that young bilingual children were hearing from caregivers, again with the goal of linking these estimates to children's efficiency at processing words in real time. As illustrated with the hypothetical children described earlier, we expected that we would find variation in the degree of engagement among caregivers, and that this variation would have important implications for the number of English and/or Spanish words the children would learn. This variation could be seen *between* speakers of English and speakers of Spanish in a given child's life, as we saw with



Figures 4a and b. Relation between English processing speed at 36 months and two estimates of relative English to Spanish exposure based on: (a) comprehensive parental report interview, and (b) naturalistic 8-12-hour recordings in the home, using the LENA™ technology (adapted from Marchman et al. 2014)

Alexa. It could also be that some children live in more language-rich environments more generally, and so there would be meaningful variation in caregiver engagement among children in a sample, as we saw in the differences between Kamila and the other three children in the total AWC they heard in a typical day.

The participants in this study so far are nine bilingual Spanish-English 36-month-olds, who were receiving a range of English to Spanish experiences in the home. LENA recordings were conducted over an 8 to 12 hour period in the home, and expert coders listened and identified English, Spanish and mixed child-directed segments. For the analyses reported here, we estimated the number of English words by summing the adult words in all of the 5-minute segments identified as English and dividing over the length of the recording, yielding mean AWC (per hour) in English. Spanish mean AWC was estimated by summing the word counts for segments identified as Spanish, divided by the recording length. For those segments identified as "mixed" (e.g. 75% English, 25% Spanish), the AWC estimates were added to the English versus Spanish totals depending on the scaled estimate (e.g. .75 English, .25 Spanish).

To illustrate the emerging findings in this ongoing research, Table 2 presents a summary of the results for two children in this study, whom we will call Clarissa and Yasel. Both of these children had about 60% of their daily interactions in Spanish, according to parent report. However, the LENA recordings revealed that Clarissa is hearing much denser talk, nearly 1,500 words per hour, compared

with only 600 words/hour for Yasel. And consistent with our previous findings (Hurtado et al. 2014; Weisleder & Fernald 2013), differences in the density of Spanish that these children heard were reflected in differences in their skill at processing Spanish words in real time. Clarissa was more than 300 ms faster than Yasel to recognize the referent of a spoken word during real-time comprehension, a skill that we predict will have long term consequences for her language learning more generally.

Table 2. Descriptive statistics based on 8-hour recordings for two Spanish/English bilingual children. Mean RT in Spanish reflects the speed with which these children recognize familiar Spanish words in the LWL task at 36 months

Participant	Reported Spanish Proportion	Total recording (mins)	Adult Spanish words/hr	Mean RT in Spanish (ms)
Clarissa	62%	480	1500	566
Yasel	57%	510	600	887

6. Conclusion

Our goal in this chapter was to present a summary and overview of what we know so far about the development of real-time language processing skill in young bilinguals in relation to individual differences in language exposure. The findings that have emerged from a set of studies with Spanish-English bilingual children growing up in California show consistent relations between early processing efficiency and vocabulary size *within* each of a child's languages. These within-language links suggest that early processing skill and vocabulary learning are intimately related. For example, when a child quickly and consistently orients to an object in the world in response to speech, that child is demonstrating skill in understanding, a skill that may be linked to a variety of perceptual, cognitive, and motor processes that support further language learning. This child may have more resources available for attending to subsequent words or for processing information in the visual scene that would facilitate comprehension, as compared to a child who is less skilled. Such increased capacity could offer an advantage when that child later encounters an unfamiliar word or could facilitate the encoding of the distributional relations across words that form the basis for morphology and grammar. More efficient processing could also enable the child to process more of the input they hear in everyday speech – parsing it better and forming more complete phonological representations, which in turn

could facilitate word learning, as well as subsequent development in morphology and syntax.

While individual differences in these early skills likely derive from multiple sources, there is growing evidence that quantitative and qualitative features of children's early learning environments are critical contributors. In this chapter, we showed that differences in exposure patterns are related not only to differences in vocabulary size, but also to differences in online processing skill. The inclusion of additional experiential factors not addressed here, such as the proportion of children's actual *use* of the language (Bedore et al. 2012), are expected to further strengthen this relation, and will be important to consider in future work.

We also observed that the strength of the contingency between language exposure and outcome measures is critically dependent on how the constructs on both sides of the equation are operationalized. Using hypothetical data from four bilingual children, we demonstrated that a scenario where 'exposure' is measured in *relative* terms and outcomes in *absolute* terms may fail to capture two important sources of variation: (1) variation between children in the overall amount of speech they hear from caregivers combined over the two languages, and (2) variation between caregivers who provide exposure to one language versus the other. When appropriate, the first type of variability is controlled for by keeping both measures – exposure and outcomes – in relative terms. Consistent with this observation, our previous work demonstrates that correlations are strengthened when both exposure and processing efficiency are measured in relative terms, that is, Spanish-to-English ratios, than when *relative* exposure is paired with *absolute* measures of processing speed in each language (Hurtado et al. 2014).

To capture both kinds of variation, an ideal scenario would be one where an absolute measure of exposure, such as the number of words in each language addressed to the child during a typical day, could be related to an absolute outcome measure, such as number of words produced, or average processing speed. Estimates of a child's absolute exposure are generally more difficult to obtain, and this difficulty is exacerbated in the case of bilingual children, for whom input measures based on caregiver speech during a play session in the laboratory are not necessarily indicative of the child's more general language experiences. Yet moving out of the laboratory and embracing new digital recording and analysis technology may bring us a step closer to finding a valid way to operationalize 'exposure' in absolute terms, even for bilingual children.

While there is clearly much left to be done, several important tendencies are beginning to emerge from the results described here: (1) there is substantial variability among bilingual children in the actual number of words they hear over the course of a day, in each language and in both languages combined, (2) this

variability does not always align well with the proportion of time children are reported by parents to be exposed to each language, and (3) absolute exposure measures appear to be more closely related to absolute measures of child outcomes, for example, processing speed and vocabulary size, than are measures of exposure derived from parent report. With further refinement in the techniques for capturing important variation in bilingual children's language experience, we expect that future work will lead to greater understanding of the intricate relations between language exposure, vocabulary learning, and language processing efficiency, relations that are of critical importance in early language development in all contexts, regardless of whether a child is learning one language or two.

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