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Vocabulary size and speed of word recognition in very young French-English bilinguals: A longitudinal study*

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Abstract

A longitudinal study of lexical development in very young French-English bilinguals is reported. The Computerized Comprehension Test (CCT) was used to directly assess receptive vocabulary and processing efficiency, and parental report (CDI) was used to measure expressive vocabulary in monolingual and bilingual infants at 16 months, and six months later, at 22 months. All infants increased their comprehension and production of words over the six-month period, and bilingual infants acquired approximately as many new words in each of their languages as the monolinguals did. Speed of online word processing was also equivalent in both groups at each wave of data collection, and increased significantly across waves. Importantly, significant relations emerged between language exposure, vocabulary size, and processing speed, with proportion of language exposure predicting vocabulary size at each time point. This study extends previous findings by utilizing a direct measure of receptive vocabulary development and online word processing.

Keywords

bilingualism; vocabulary development; word processing speed

Introduction

During the second year of life, children undergo a dramatic increase in vocabulary size (Bornstein, Putnick & De Houwer, 2006; Core, Hoff, Rumiche & Senor, 2013; Fernald & Marchman, 2012; Vagh, Pan & Mancilla-Martinez, 2009). Whereas this rapid increase in

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word knowledge is well established in monolingual children, the typical developmental trajectory of children learning more than one language from birth is not as well documented, especially with regard to receptive vocabulary. The present longitudinal study investigated the stability and continuity of vocabulary growth and speed of lexical access using the Computerized Comprehension Task (CCT; Friend & Keplinger, 2003; Friend, Schmitt & Simpson, 2012; Friend & Zesiger, 2011), a direct, laboratory based measure of receptive vocabulary, in monolingual and bilingual infants between 16 and 22 months of age.

The majority of recent research on early vocabulary development has been cross sectional in nature and has largely focused on vocabulary production in monolingual infants, with relatively fewer studies focusing on vocabulary comprehension and fewer still on bilingual vocabulary comprehension. Moreover, the bulk of the research on vocabulary comprehension in monolingual and bilingual infants has relied almost exclusively on parental report (De Houwer, Bornstein & DeCoster, 2006; De Houwer, Bornstein & Leach, 2005; Fernald, Perfors & Marchman, 2006; Pearson & Fernández, 1994; Stokes & Klee, 2009). Given these limitations in the extant literature, the current study was conducted with the aim of acquiring a better understanding of how bilingual children build their early receptive lexicons. Importantly, the CCT is the first tool of its kind to provide a direct measure of receptive vocabulary and processing speed during the second year of life. This is much earlier than traditional measures of receptive vocabulary development, such as the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997). The main goal of the present study was to use a longitudinal design to directly assess developmental change in word comprehension, in conjunction with parent report of vocabulary production, to gain a better understanding of how bilingual infants' receptive and expressive vocabularies change in relation to monolinguals at a critical period in lexical development.

Of those studies that have looked at the emerging receptive lexicons of bilingual infants, most suggest that receptive vocabulary development is largely on par with that of monolingual infants (Genesee & Nicoladis, 2007). In a landmark study, Pearson, Fernández and Oller (1993) showed that both the total and conceptual (total minus doublets) vocabularies of English-Spanish bilingual children from 8 to 30 months of age were on par with monolingual vocabulary scores over the same period. Whereas significant variability in receptive vocabulary was observed in each of the bilinguals' languages, average vocabulary size in the dominant language was largely equivalent to monolingual infants. This pattern of development in the receptive vocabulary of bilingual children has been corroborated by more recent work, suggesting that early bilingual receptive vocabulary develops at a rate that is similar to monolingual acquisition (Poulin-Dubois, Bialystok, Blaye, Polonia & Yott, 2012; Umbel, Pearson, Fernández & Oller, 1992). In contrast, recent work by Thordardottir (2011) suggests that individual vocabulary profiles in older bilingual children depend on children's language exposure history. Moreover, as bilingual children get older, comprehension in each language may begin to lag behind monolingual norms making measures of total and total conceptual vocabulary more appropriate when contrasting bilingual and monolingual vocabulary acquisition (Bialystok, Luk, Peets & Yang, 2010; Fernández, Pearson, Umbel, Oller & Molinet-Molina, 1992; Pearson et al., 1993).

Whereas studies on early word comprehension in bilingual infants are scarce, a large literature has focused on early vocabulary production. Several studies suggest that young bilingual children produce fewer words in each language compared to monolingual children (Core et al., 2013; Hoff, Core, Place, Rumiche, Señor & Parra, 2012; Hoff, Rumiche, Burridge, Ribot & Welsh, 2014; Pearson et al., 1993). Moreover, when exposure across languages is unbalanced, they also tend to produce more words in their dominant (L1) versus their non-dominant (L2) language (Hurtado, Grüter, Marchman & Fernald 2014; Pearson & Fernández, 1994; Pearson et al., 1993). However, when total and total conceptual vocabulary are taken into account, bilinguals typically produce as many words as their monolingual peers, although there is some debate as to which of these measures best captures processes of monolingual and bilingual acquisition (Core et al., 2013; Hoff et al., 2012; Junker & Stockman, 2002; Patterson & Pearson, 2012).

Several longitudinal studies on bilingual children 30 months of age and older have reported that, just like monolinguals, bilingual receptive and expressive vocabularies are largely stable, such that early vocabulary size predicts vocabulary size later in childhood (Bornstein, Hahn, Putnick & Suwalsky, 2014; Bornstein et al., 2006; Core et al., 2013; Hurtado et al., 2014; Mancilla-Martinez & Vagh, 2013; Scheffner Hammer, Lawrence & Miccio, 2008; Uchikoshi, 2006; Vagh et al., 2009). However, further research is required to determine whether this pattern also holds for receptive vocabulary in very young bilinguals.

Vocabulary Growth Across Languages

Generally speaking, both monolingual and bilingual infants show fairly linear patterns of growth over time with respect to both comprehension and production, although during the second year many children experience a sharp acceleration in growth (Goldfield & Reznick, 1990; Kan & Kohnert, 2012; Pearson & Fernández, 1994; Vagh et al., 2009). While dramatic increases in total receptive and expressive vocabulary have been observed during this period, bilinguals experience this increase in one language at a time, typically in L1 followed by L2 (Pearson & Fernández, 1994).

Interestingly, previous cross-sectional studies examining cross-language relationships in early receptive and expressive vocabulary development in bilinguals have found weak or absent links across languages, suggesting that vocabulary growth in a child's L1 does not always directly predict vocabulary growth in L2 (Kan & Kohnert, 2008; Marchman, Fernald & Hurtado, 2010). However, a recent study conducted by Kan and Kohnert (2012) using a dynamic measure of receptive and expressive vocabulary development (a word learning task) suggests otherwise. Although the results from this study seem to contradict previous research by providing evidence of cross-language relationships in bilingual vocabulary development, Kan and Kohnert's use of a dynamic measure involving the rate of change in novel word learning, rather than static observations of vocabulary size or online speech processing, may have tapped more directly into the processes involved in early vocabulary development. Their study suggests that existing vocabulary size, as well as exposure to each language, has significant effects on word learning and later vocabulary comprehension and production in bilingual children. Importantly however, there is currently a lack of longitudinal studies in the literature aimed at gaining a better understanding of the relation between rates of vocabulary growth across languages in bilingual infants. In the present research, we used a longitudinal design and a multi-method approach (parent-reported vocabulary production on the MCDI and a touching-while-listening paradigm), to acquire a more comprehensive understanding of the stability at the individual level and continuity at the group level of both receptive and expressive vocabulary development in very young French-English bilingual children.

Speed of Online Word Processing

Numerous studies have now looked at speed of online word processing in both infants and young children, with most of these studies emphasizing the relation between language exposure, early vocabulary development, and processing speed. Recent work using the looking-while-listening paradigm (LWL), which involves tracking of infants' eye gaze as they are prompted to attend to a target image on a screen, has provided crucial information about early online processing of words. Two recent studies using the LWL procedure with samples of 18-month-old monolinguals have shown that both existing vocabulary and processing speed work in conjunction with one another to facilitate word learning, with efficiency in word recognition at 18 months of age being positively correlated with accelerated vocabulary growth over the following year (Fernald & Marchman, 2012; Fernald, Marchman & Weisleder, 2013). This finding was paralleled in a longitudinal study carried out by Fernald, Perfors and Marchman (2006) with English-speaking monolingual 15-, 18-, 21- and 25-month-olds, which showed increases in word processing speed over time. Moreover, they were able to show stability in speed and accuracy in spoken word recognition with performance at 15 months of age predicting the same measures at 25 months of age; children who were faster and more accurate at 25 months of age were also those who showed faster and more accelerated growth in parent-reported expressive vocabulary across the second year. These studies seem to suggest that vocabulary size and online processing abilities work in conjunction with one another to facilitate uptake of input in the environment, ultimately increasing rates of growth over time.

In bilinguals, similar patterns are observed. Marchman and colleagues (2010) reported that although Spanish-English bilinguals at 30 months of age had comparable expressive vocabulary sizes in L1 and L2, they fell below monolingual norms in each of their individual languages. A composite measure of expressive vocabulary however was on par with monolingual norms. Interestingly, no differences were observed between processing speed in L1 and processing speed in L2 on the LWL task. Moreover, whereas vocabulary size in L1 was predictive of processing speed in L1 and vocabulary size in L2 was predictive of processing speed in L2, no cross-language relationships were observed for these variables. Total vocabulary scores however were to some extent predictive of processing speed in both Spanish and English, suggesting that overall vocabulary knowledge influences speed of online word processing and vice versa. Similar relations were found between relative receptive and expressive vocabulary size and processing speed in a sample of Spanish-English bilinguals at both 30 and 36 months of age, with evidence suggesting that these relations are stable across the second year (Hurtado et al., 2014).

Although the research by Marchman et al. (2010) and Hurtado et al. (2014) clarifies the relation between vocabulary size and online processing in Spanish-English bilingual children in the third year of life, our knowledge remains limited regarding how processing efficiency influences stability across languages during the period of accelerated vocabulary growth in the second year (MacLeod, Fabiano-Smith, Boegner-Pagé & Fontolliet, 2013; Hoff et al., 2012; Schwartz, Moin & Leikin, 2012). The present study aimed to extend the findings of Marchman et al. and Hurtado et al. by using a direct measure of word comprehension to assess receptive vocabulary growth and processing speed in the second year (Friend & Keplinger, 2003; Hendrickson, Mitsven, Poulin-Dubois, Zesiger & Friend, 2014; Legacy, Zesiger, Friend & Poulin-Dubois, 2015). Our goal was to assess online processing much earlier in development, as well as to determine how speed of online word processing changes over time during the second year of life, a critical period for lexical growth. Assessing infants at 16 months of age, and again six months later, at 22 months of age, made it possible to examine both within- and cross-language relations.

Language Exposure

One of the most important factors related to early vocabulary development and speed of word processing is language exposure (Bosch & Ramon-Casas 2014; DeAnda, Arias-Trejo, Poulin-Dubois, Zesiger & Friend, 2016; Hurtado et al., 2014; Poulin-Dubois et al., 2012). Whereas presumably balanced exposure across languages should result in balanced rates of acquisition, most bilingual children are not equally exposed to the languages that they hear (Hoff, 2013). Recent research suggests that generally speaking, strategies such as the one-parent-one-language rule do not provide children with balanced exposure to each language (De Houwer, 2007). The language preference of the child, the relative majority status of the languages, and individual differences in the quality and amount of input each parent typically provides for the child all contribute to uneven patterns of exposure. These differences in language exposure typically result in children keeping pace with monolinguals in their L1, but over time experiencing slower vocabulary development in their L2 (MacLeod et al., 2013).

Importantly, it has recently been suggested that discrepancies between studies regarding the relations between language exposure, vocabulary size, and processing speed, may in part be due to variations in the use of absolute and relative measures of input, both within and across studies. This discussion has centered on the fact that comparing a relative measure, such as proportion of language exposure, with an absolute measure, such as raw scores on the CDI or PPVT, may distort developmental patterns in the data (Grüter, Hurtado, Marchman & Fernald, 2014; Hurtado et al., 2014), Because relative measures such as proportion of language exposure do not account for variations in the quality of input that children hear in each language, it is often the case that correlations between language exposure and raw scores on vocabulary tasks are weak at best. However, accounting for some of this additional variance (by comparing ratios of language exposure to ratios of vocabulary size across languages) is more accurate and can strengthen correlations between these variables. Therefore the present study used this approach to examine relations between language exposure, vocabulary size, and processing speed.

The Present Study

The goals of the present study were twofold: 1) to extend previous research by investigating the continuity and stability of early receptive and expressive vocabulary development in a sample of French-English bilingual toddlers using a longitudinal design, and 2) to examine the relation between language exposure, vocabulary size, and processing speed using a direct measure of receptive vocabulary development and reaction time. By addressing these questions, this study will fill gaps in the extant literature on early bilingual vocabulary development as well as extend previous findings by utilizing an objective measure of receptive vocabulary development and online word processing in the second year of life.

Method

Participants

Bilingual participants were recruited through birth lists provided by a governmental health agency, and were from a large city in eastern Canada, whereas the monolingual participants were recruited through birth lists provided by the Canton of Geneva, Switzerland. In order to be eligible for the study, infants must have had no visual or hearing impairments. Monolingual participants were required to have 90% exposure to their first language (French). Bilingual participants were required to be French-English bilinguals from birth, and needed to have at least 20% exposure to their second language (Wave 1: $M = 37\%$, $SD = 9\%$, Range = 20% – 49%; Wave 2: $M = 35\%$, $SD = 9\%$, Range = 21% – 50%). Exposure to a third language, if any, was below 10%. Seventy-one percent of mothers held a University degree in the monolingual sample, and 78% in the bilingual sample. Participants from Wave 1 were invited six months later for Wave 2 data collection.

The final sample at Wave 1 consisted of 104 participants (45 bilinguals and 59 monolinguals), with bilinguals ranging from 15.30 to 19.07 months of age ($M = 17.31$), and monolinguals ranging from 15.63 to 17.07 months of age ($M = 16.28$). In total, 117 participants were tested. However, 13 of these participants were excluded at Wave 1 due to fussiness ($n = 7$), incomplete data ($n = 4$), having a large gap between appointments ($n = 1$), and experimental error ($n = 1$). The final sample at Wave 2 consisted of 90 participants (38 bilinguals and 52 monolinguals), with bilinguals ranging from 20.77 to 26.27 months of age ($M = 23.67$), and monolinguals ranging from 21.19 to 22.21 months of age ($M = 21.98$). The same children were re-tested, however twenty-two participants were excluded at Wave 2 for the following reasons: did not meet the language requirements ($n = 9$), fussiness ($n = 5$), and incomplete data ($n = 8$). In addition, there was a 4% attrition rate (5/117 children) from Wave 1 to Wave 2. Due to significant group differences in age at each wave of data collection, all statistical analyses controlled for this variable. No significant differences in maternal education level were observed.

For cross-wave analyses, only infants who were included in the final samples at both Wave 1 and 2 were included. The final longitudinal sample consisted of 34 bilinguals (20 males, 14 females) and 52 monolinguals (27 males, 25 females). In Wave 1, bilinguals were between 15.13 and 19.07 months of age ($M = 17.25$), and monolinguals were between 15.63 and 17.07 months of age ($M = 16.28$). In Wave 2, bilinguals were between 21.77 and 26.27

months of age ($M = 23.78$) and monolinguals were between 21.19 and 22.21 months of age ($M = 21.98$).

Materials

Language Exposure Assessment Tool (LEAT)—This questionnaire yields strong internal consistency and accounts for unique variance in children's vocabulary over and above the variance accounted for by global parent estimates of exposure (DeAnda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016*)*. The experimenter conducted an interview with a parent at each wave of data collection, to ask who communicates with the child on a weekly basis (e.g., parents, educator, grandparents, etc.), what language they speak to the child, and for how long. An estimate of the proportion of time that the child was exposed to each language from birth was then calculated at 16 and 22 months respectively.

CDI: Words and Gestures—The CDI: WG is a parent report vocabulary checklist that measures infants' receptive and expressive vocabulary, from 8 to 16 months of age. The European French adaptation (Kern, 1999) was used to measure vocabulary in the monolingual group in Geneva, and the American English (Fenson et al., 1993) and Canadian French (Trudeau, Frank & Poulin-Dubois, 1999) adaptations were used to measure vocabulary in the bilingual group. The English, Canadian French, and European French adaptations contain 396, 408 and 414 words, respectively. This CDI form was selected at the first wave of data collection (as opposed to the CDI: Words and Sentences) so that a direct comparison could be made between the receptive vocabulary component of the CDI: Words and Gestures and the CCT (please see Legacy et al., 2015 for a discussion of these receptive vocabulary comparisons).

CDI: Words and Sentences—The CDI: WS is a parent report vocabulary checklist that measures toddlers' expressive vocabulary from 16 to 30 months of age, and was used at Time 2 of data collection. The English (Fenson et al., 1993), Canadian French (Trudeau et al., 1999), and European French adaptations (Kern, 1999) contain 680, 624 and 691 words, respectively. *Computerized Comprehension Task.* The computerized comprehension task (CCT; Friend and Keplinger, 2003; available at http://childes.psy.cmu.edu/cct/) directly assesses receptive vocabulary in infants. The program is administered on a touch screen, on which two images appear simultaneously, and the infant is asked to touch a target image. The infant has 7 seconds to respond, as the trial times out after that. There is an auditory reinforcement for every correct touch, which consists of an automated voice labeling the noun, verb, or adjective (e.g,. *bubbles*, *jumping*, or *wet*) and a subsequent sound associated with the noun, verb, or adjective (i.e. bubbles popping, children giggling, or water splashing). There are two forms of the CCT (Form A and B) such that the target images on one form serve as the distractor images on the other. For each form, there are four practice trials, administered to make sure that the child understands the task, and 41 test trials. The test trials consist of 41 pairs of images; 23 noun pairs, 11 verb pairs, and 7 adjective pairs, which are balanced for size, colour, brightness, difficulty level, and word category. The target appears equally as often on the left and right sides of the screen, and there are similar numbers of easy, medium, and difficult words. A word was classified as easy if more than 66% of 16-month-olds comprehended the word, moderate if 33%–66% of 16-month-olds comprehended the word, and difficult if less than 33% of 16-month-olds comprehended the word (Dale & Fenson, 1996). In order to determine the difficulty level of each word for the English CCT, normative data from the CDI: WG was used (Dale & Fenson, 1996). A French adaptation of the CCT was developed in the same way using the French adaptation of the CDI (Friend & Zesiger, 2011). The French adaptation included many of the same items as the English CCT and included a few modifications to reflect cultural differences. Stimuli were presented in the same pseudo-randomized fashion across participants following Hirsh-Pasek and Golinkoff (1996) such that the target does not appear in the same left-right orientation more than twice in a row. Administration of the CCT followed the procedure described by Friend, Schmitt, and Simpson (2012). Importantly, the CCT exhibits good test-retest reliability and convergence with parent report (Friend & Keplinger, 2008).

Procedure

At each Wave, monolinguals came for one visit in French, and bilinguals came for two visits, one in French and one in English, approximately two weeks apart. Parents were first interviewed using the LEAT to obtain an estimate of each child's language exposure. Following this, parents of monolingual children filled out the European French CDI: WG and parents of bilingual children filled out the Canadian French and English CDIs. The CCT was then administered in an adjoining room, where language and form were counterbalanced across visits. Infants were seated on their parent's lap at a distance where they could easily touch the screen. Parents wore opaque glasses and noise-cancelling headphones to prevent interference.

Prior to beginning the test trials, the experimenter presented the child with 4 practice trials in order to familiarize them with the touch screen. Once the child showed an understanding of the task, the experimenter presented the child with two images and prompted them to touch a target image by saying: "Where's the __________? Touch __________." for nouns; "Who is _______? Touch __________." for verbs; and "Which one is __________? Touch __________." for adjectives.

Participants returned to the laboratory six months after Wave 1, and followed the same procedure. Thus, the LEQ and CCT were re-administered, and parents filled out the CDI: WS. At the end of each session in Wave 1 and 2, parents received 25$ in compensation, and children received a small gift and a certificate of merit.

Results

One goal of the present study was to assess vocabulary comprehension and production longitudinally in monolingual and bilingual infants at 16 and 22 months of age, to obtain a better understanding of how children acquiring more than one language from birth build their emerging lexicons during a period of rapid vocabulary acquisition. Previous findings (Removed for blinding, 2015) suggest that parent report may overestimate vocabulary comprehension in young bilinguals. As such, vocabulary comprehension was assessed in both groups of infants using the CCT, and vocabulary production was assessed using the CDI. Given the significant difference in age between the monolingual and bilingual samples, ANCOVAs were performed for each variable with age entered as a covariate. Table 1 presents the scores on each measure at each wave of data collection for the monolinguals and bilinguals, and Table 2 presents the difference scores across testing occasions on each measure.

Receptive Vocabulary

At both 16 and 22 months of age, the bilinguals were able to comprehend more words in their L1 compared to their L2 on the CCT, Wave 1: $F(1, 43) = 4.30$, $p = .044$, partial $\eta^2 = .091$; Wave 2: $F(1, 37) = 12.83$, $p = .001$, partial $\eta^2 = .257$. They were also significantly less accurate than the monolinguals on this task in both their dominant and non-dominant languages at both waves of data collection (see Table 1 for between-group comparisons). However, although both L1 and L2 accuracy lagged behind that of the monolinguals at each wave, the bilinguals comprehended more words than the monolinguals when total vocabulary (L1 plus L2) was used.

When considering growth across waves (Wave 2 – Wave 1), the results indicate that, as expected, both bilinguals and monolinguals improved their performance on the CCT over this 6-month period, suggesting a steady progression in lexical development (see Table 2). The bilinguals appeared to accumulate approximately as many new words in their L2 ($M = 14.44$, $SD = 6.89$) as they did in their L1 ($M = 16.59$, $SD = 7.22$), $F(1,33) = 2.04$, $p = .163$, $\eta^2 = .058$, and no differences in growth were observed when comparing the monolinguals to bilinguals in each of their languages. Importantly, although accuracy on the CCT at Wave 1 was correlated with accuracy on the CCT at Wave 2 for the bilinguals in L1, $r(32) = .45$ $p = .009$, it was not correlated across waves for the bilinguals in L2, $r(32) = .27$ $p = .124$. A positive correlation was also observed for the monolinguals, $r(50) = .37$, $p = .006$. This suggests that whereas stability across waves exists for the monolingual infants and the bilinguals in their dominant language, there is a lack of stability in vocabulary acquisition for the bilinguals in their second language. Moreover, the larger bilingual children's vocabularies were on the CCT at 16 months of age, the fewer new words they accumulated across this 6-month period (L1: $r(32) = -.74$ $p < .001$; L2: $r(32) = -.51$ $p = .002$). This was also the case for the monolingual infants, $r(50) = -.63$ $p < .001$. Importantly however, neither sample of infants reached ceiling on this task, which suggests that this result is not simply due to children with larger vocabularies having fewer words to learn across waves.

Expressive Vocabulary

At 16 months of age, both the bilinguals and the monolinguals had only begun to build their productive vocabularies, as measured by the CDI. Interestingly, whereas the bilinguals were able to produce more words in their L1 compared to their L2, $F(1,44) = 6.80$, $p = .012$, partial $\eta^2 = .134$, they did not significantly differ from the monolinguals with respect to production in either of their individual languages (See Table 1). When L1 and L2 were combined to create a measure of total vocabulary, it appeared that the bilinguals were able to produce significantly more words than the monolinguals. At 22 months of age, this difference between bilingual composite measures of vocabulary and monolingual scores on the CDI disappeared. Moreover, whereas the gap between L1 and L2 was maintained for the bilinguals, $F(1,37) = 19.05$, $p < .001$, partial $\eta^2 = .340$, the monolinguals surpassed the bilinguals with regard to production in L2. Looking across waves, both groups increased their production, with bilinguals acquiring significantly more new words in their L1 compared to their L2, $F(1,33) = 16.14$, $p < .001$, partial $\eta^2 = .328$. Bilinguals also showed similar rates of growth in L1 and L2 relative to the monolinguals (See Table 2), with production scores at Wave 1 correlated with production scores at Wave 2 for both the monolinguals, $r(50) = .55$, $p < .001$, and bilinguals, L1: $r(32) = .69$, $p < .001$; L2: $r(32) = .50$, $p < .001$, suggesting stability in vocabulary size across waves. Further, there was no indication that differences in growth across languages could be attributed to changes in exposure over time: mean exposure to L2 was consistent over time at the group level (*Ms* = 37% and 35% at Waves 1 and 2, respectively). However it is important to note that, although growth in vocabulary over time was expected in both groups, the extent of this growth might be inflated due to the use of different forms of the CDI at 16 and 22 months of age since the CDI: WG administered at 16 months assesses children on fewer items than the CDI: WS administered at 22 months.

Reporter Effects

Whereas no significant differences existed between our monolingual and bilingual samples in either L1 or L2 on the CDI at Wave 1 of data collection, by Wave 2 the gap between bilinguals' expressive vocabulary in L1 and L2 had widened such that a significant difference emerged between the monolinguals and the bilinguals in L2. This suggests that whereas bilinguals seem to be able to keep pace with monolinguals when it comes to producing words in their dominant language, their expressive vocabulary in L2 appears to develop more slowly over time. This difference in expressive ability across languages may in part be due to a rapid increase in vocabulary acquisition occurring in the bilinguals' dominant language. As discussed earlier, expressive vocabulary growth in L2 appears to slow down as new words are rapidly acquired in L1. Alternatively, an imbalance in either the quantity or quality of language exposure could be affecting vocabulary development in the bilinguals' non-dominant language, ultimately leading to a discrepancy in vocabulary growth across languages. Although both of these explanations are plausible, it is also possible that reporter effects on the CDI could have resulted in the observed findings. However, post-hoc analyses revealed that differences in L1/L2 expressive vocabulary measured by parent report on the CDI were mirrored, at the individual level, in differences in L1/L2 receptive vocabulary measured directly on the CCT. That is, when the bilingual sample was divided into two groups based on the number of expert reporters that filled out the CDI, children who exhibited differences in L1 and L2 vocabulary size on the CDI also exhibited such differences on the CCT (Children with 2 expert reporters: Wave 1 CDI: $t(22) = 3.11$, $p = .005$, $d = .652$; Wave 1 CCT: $t(22) = 2.09$, $p = .048$, $d = .435$; Wave 2 CDI: $t(30) = 4.00$, $p < .001$, $d = .743$; Wave 2 CCT: $t(30) = 2.96$, $p = .006$, $d = .614$; Children with one expert reporter: no statistically significant differences).

Speed of Online Word Processing

Another important goal of the current study was to investigate the relationship between early vocabulary development and speed of online word processing as measured by latency to touch the target image. In order to address this goal, group differences in reaction time on the CCT were examined. Five bilingual participants were excluded from the RT analyses at

Wave 1 due to technical difficulties resulting in missing RT data. This resulted in a longitudinal RT sample of 31 bilingual participants.

At 16 months of age, bilinguals were as fast to respond to correct trials on the CCT in L2 as they were in L1, $F(1,39) = .025$, $p = .875$, partial $\eta^2 = .001$. Moreover, these young bilinguals responded as quickly as the monolinguals on this task (see Table 1). This result was also observed at 22 months of age, $F(1,37) = 1.76$, $p = .193$, partial $\eta^2 = .045$, with no differences between the groups. Although both groups significantly decreased reaction times (RT) across waves (see Table 2), there were no significant differences between groups or languages with respect to this reduction in RT, $F(1,30) = .164$, $p = .688$, partial $\eta^2 = .005$.

Interestingly, at the first wave of data collection, vocabulary size on the CCT was negatively correlated with RT for monolinguals, $r(57) = -.66$, $p < .001$, with a trend toward the same result for vocabulary size and RT in L2 for bilinguals, L2: $r(38) = -.30$, $p = .060$. The correlation between vocabulary size and RT in L1 for bilinguals was in the expected direction (L1: $r(38) = -.25$, $p = .118$) but not significant. Whereas vocabulary size in L1 and L2 were positively correlated, $r(43) = .39$, $p = .008$, this relation did not hold for RT. At the second wave of data collection, these within-language correlations remained for monolinguals, $r(50) = -.63$, $p < .001$, and for bilinguals in L1, $r(36) = -.35$, $p = .031$, and L2, $r(36) = -.39$, $p = .016$. Vocabulary size in L1 and L2 on the CCT was also correlated at Wave 2, $r(36) = .46$, $p = .004$, as was RT in L1 and L2, $r(36) = .64$, $p < .001$. Lastly, unlike the stability observed for receptive vocabulary on the CCT and expressive vocabulary on the CDI, RT on the CCT was not correlated across waves for either bilinguals or monolinguals.

Language Exposure, Vocabulary Size & Processing Speed

In order to investigate the relation between language exposure, relative vocabulary size, and relative processing speed, ratios were calculated for each child by dividing their score in English by their score in French. Log transformations were then applied to these ratios, and bivariate correlations were run using these relative measures (Hurtado et al., 2014). At 16 months of age, language exposure was positively related to expressive vocabulary size on the CDI, $r(43) = .68$, $p < .001$, with the correlation being in the expected direction but not significant for receptive vocabulary on the CCT, $r(43) = .23$, $p = .126$. Language exposure at 22 months of age was positively correlated with concurrent receptive, $r(36) = .34$, $p = .036$, and expressive, $r(36) = .70$, $p < .001$, vocabulary size, with language exposure correlated across waves, $r(32) = .64$, $p < .001$. Interestingly, neither language exposure nor vocabulary size was correlated with processing speed at either wave of data collection.

Developmental Trends in Language Exposure, Vocabulary Size & Processing Speed

Importantly, language exposure at Wave 1 was a significant predictor of both receptive vocabulary on the CCT (See Table 3; $r^2 = .22$, $F(1, 29) = 8.14$, $p = .008$; $\beta = .47$, $p = .008$), and expressive vocabulary on the CDI ($r^2 = .24$, $F(1, 29) = 8.92$, $p = .006$; $\beta = .49$, $p = .006$) at 22 months of age, accounting for 22% and 24% of the variance, respectively in the bilingual sample. Similarly, vocabulary size at Wave 1 significantly predicted vocabulary size at Wave 2 in the monolingual sample, as expected (CCT: $r^2 = .14$, $F(1, 50) = 8.15$, $p = .006$; $\beta = .44$, $p = .018$; CDI: $r^2 = .30$, $F(1, 50) = 21.08$, $p < .001$; $\beta = .55$, $p < .001$).

Importantly, processing speed at 16 months was a significant predictor of vocabulary size on the CCT, but not on the CDI, at 22 months of age for the bilinguals (see Table 3; $r^2 = .11$, $F(1, 28) = 4.72$, $p = .038$; $\beta = .34$, $p = .008$). Interestingly, processing speed at 16 months did not predict receptive or expressive vocabulary at 22 months of age in the monolingual sample.

Discussion

The goals of the present study were twofold: 1) to investigate the continuity and stability of early receptive and expressive vocabulary development in a sample of French-English bilingual toddlers using a longitudinal design, and 2) to examine the relation between language exposure, vocabulary size, and processing speed using a direct, laboratory-based measure of receptive vocabulary and reaction time. Our findings provide new evidence about lexical development during the second year in French-English bilingual children.

Vocabulary Growth

At both 16 and 22 months of age, bilingual toddlers comprehended more words in their L1, as measured directly with the CCT, than they did in their L2. However, over the 6-month testing interval, bilingual infants accumulated as many new words in their L2 as they did in their L1 suggesting a balanced rate of acquisition. The first finding, that vocabulary size was larger in L1 than in L2 at each wave, parallels our findings on parent reported expressive vocabulary on the CDI, which showed that the gap between bilingual infants' dominant and non-dominant languages emerges early and is maintained over time. However, the fact that children acquired approximately as many new words in L2 as they did in L1 across waves, despite uneven levels of exposure to each language, suggests accelerated rates of vocabulary growth in their L2 during this period of development. Previous findings suggest that as toddlers' vocabularies become more balanced, they are more likely to integrate translation equivalents (TEs; words in each language for the same concept, such as *dog* in English and *chien* in French) into their vocabularies (*blinded for review*). This process may help to account for a higher rate of acquisition in L2 relative to L1. That relative language exposure predicted relative vocabulary growth across waves suggests that relative language exposure plays a strong role in the construction of bilingual children's early lexicons.

Stability of Vocabulary Size & Processing Speed

Results from the CCT and CDI suggest both acceleration and stability in receptive and expressive vocabulary size across waves for the monolinguals and bilinguals. However, whereas the CDI suggests stability in expressive vocabulary development for the bilinguals in both of their languages, the CCT evinced stability only in the dominant language, such that receptive vocabulary scores in L1 were positively correlated across waves. One possibility for this discrepancy is a true lack of stability in bilingual infants' L2 receptive vocabulary that is not reflected in parent reported expressive vocabulary. Our behavioural findings are consistent with Bornstein and colleagues' (2014) recent study on the stability of language development in monolingual children. They report that receptive and expressive core language skills are less stable from 20 months to 4 years of age than they are from 4 years of age to 10 years of age. Bilinguals' L2 CCT accuracy scores might be particularly susceptible to this lower stability, particularly given the increased variability in input that is often experienced by bilingual infants. Moreover, although there is data to suggest that performance on the CCT is stable from 16 to 20 months of age for monolingual infants (Friend & Keplinger, 2008), this is the first study to examine the stability of the CCT in a bilingual sample of infants. Thus, direct assessment of receptive vocabulary in the second year suggests differential stability across dominant and non-dominant languages.

Although L1 receptive vocabulary size on the CCT and L1 and L2 expressive vocabulary size on the CDI were fairly stable during the second year, RT on the CCT was not correlated across waves for neither monolingual nor bilingual toddlers. Importantly, previous research with monolingual infants has shown that RTs are variable early in development and become more stable over time. For example, Fernald et al. (2006) investigated the stability of RTs using the LWL procedure in a sample of English-speaking infants at 15, 18, 21, and 25 months of age. They found that although RTs were correlated across 18 and 21 months, and marginally correlated across 21 and 25 months, RTs were not correlated across 15 and 18 months of age. That RT was not correlated across waves for both the monolingual and bilingual samples in the present study is consistent with previous research documenting limited stability in processing speed early in development.

Cross-Language Relations in Bilinguals' Vocabulary Size & Word Processing Speed

Importantly, cross-language relationships were observed for receptive vocabulary on the CCT and expressive vocabulary on the CDI at both waves of data collection. This is in contrast to previous research finding an absence of cross-language relationships in vocabulary size in 30-month-old Spanish-English bilinguals (Marchman et al., 2010). Expressive vocabulary in L1 at Wave 1 significantly predicted expressive vocabulary in L2 at Wave 2, with a trend observed for a relation between L2 vocabulary at Wave 1 and L1 vocabulary at Wave 2. The presence of cross-language relationships across measures at each wave suggests some transfer between languages. This transfer appears to be bidirectional, with vocabulary development in L1 impacting vocabulary development in L2 and vocabulary development in L2 impacting vocabulary development in L1, both within and across waves. Within-language relations between vocabulary scores on the CCT and RT emerged at 16 months of age for monolinguals and for bilinguals in L2. These within-language relations were maintained at 22 months in both groups and extended to L1 in bilinguals. Also by 22 months of age, RTs in L1 and L2 were positively correlated reflecting the impact of general working memory and processing skills required for online language processing.

Consistent with Hurtado et al. (2014) and Marchman et al. (2010), the present findings show that monolingual and bilingual children with larger vocabularies are faster at online processing of words, and that language exposure predicts vocabulary size. However, although these studies found significant relations between language exposure and RT using both raw scores and relative ratios, these relations were not replicated in the present study. One possible reason for these discrepancies is the age of the children, with both prior studies investigating these relations in 30-month-old children. Importantly, these older samples exhibited much larger, and possibly more decontextualized vocabularies, than children in the present study. Recall that one goal of this present research was to extend previous findings to younger children in a period of rapid acceleration of vocabulary growth. Thus, it is possible that the relation between exposure and RT emerges after this period. This may follow from the finding that RT is unstable early in development. Alternatively, differences in procedure may have contributed to the discrepancy between our findings and previous research. Both Hurtado et al. and Marchman et al. used the LWL procedure to measure receptive vocabulary, which differs in many respects from the CCT. One key difference across the two measures is the degree to which target words vary according to difficulty. Whereas the LWL only includes words that are "highly familiar" to children based on lexical norms for the target age range and parent report of the child's word knowledge, the CCT incorporates easy, medium, and difficult words based on lexical norms, and children may not be familiar with all of the words included on the CCT. To test whether this difference contributed to the discrepancy in findings, we analyzed easy word trials on the CCT separately (words that are normatively familiar). However, the same pattern of results was observed with no strengthening of the relation between exposure and RT. Another procedural difference is that LWL and the CCT differ in the degree of volition required to execute a response. Whereas LWL measures an automatic visual response, the CCT requires much more effort on the part of the child in order to produce a response. This volitional component might in turn lead to variations in RT from those observed using a more automated response. It is possible that differences in response modality contributed to the absence of a relation between exposure and RT in the present study. More interesting however, is the possibility that the relation between exposure and RT emerges once vocabulary growth and processing speed stabilize in the third year.

Language Exposure, Vocabulary Size, & Processing Speed

Our findings replicate Hurtado et al. (2014) showing that language exposure predicts relative vocabulary size over the course of development. However, whereas Hurtado et al. found this relation in a sample of 30-month-old Spanish-English bilinguals using the PPVT/TVIP and CDI, we have replicated and extended this finding to a younger sample of 16-month-old French-English bilinguals, using the CCT and CDI as measures of receptive and expressive vocabulary respectively. In addition, Hurtado et al. found that relative processing speed, as measured using the LWL procedure, was a significant predictor of receptive and expressive vocabulary size in children from 30 to 36 months of age. This result was observed for bilinguals in the present study using the CCT as a measure of receptive vocabulary size and RT. Importantly, however, language exposure was not related to RT within or across waves, which diverges from Hurtado et al.'s findings. In addition, the relation between vocabulary size and processing speed was observed for receptive vocabulary but did not extend to expressive vocabulary on the CDI at 22 months. The present study examined these relations in a much younger sample, with key differences present across RT modalities. The instability of RT early in development (e.g., Fernald et al., 2006) may also have contributed to the lack of relation between processing speed, language exposure, and expressive vocabulary. Nevertheless, the fact that processing speed was observed to predict receptive vocabulary outcomes across a 6-month period for a sample of very young bilinguals emphasizes the bidirectional nature of the relation between online word processing and vocabulary growth.

Interestingly, in the monolingual sample, RT at 16 months did not predict vocabulary size at 22 months, above and beyond initial vocabulary size. Previous studies reporting links between vocabulary size and processing speed in monolinguals have done so at a single point in time rather than longitudinally, or have looked at the link between processing speed and vocabulary retrospectively, finding that children with faster processing speeds at 24 months also had larger vocabularies and acquired more words across the second year (Fernald et al., 2006; Fernald et al., 2013). Our prospective, longitudinal findings suggest that speed of processing is a stronger predictor of language outcomes in bilinguals whereas vocabulary size is a stronger predictor in monolinguals. This may reflect differential processing demands in early bilingual, as contrasted with monolingual, acquisition.

Conclusion

In sum, our findings suggest that bilingual toddlers develop their receptive and expressive vocabularies at approximately the same rate as monolingual toddlers. Whereas both receptive and expressive vocabulary development may begin slowly in bilinguals with learning divided across languages, over time toddlers acquire approximately as many new words as their monolingual peers in their dominant language. In L1 vocabulary growth, bilingual toddlers keep pace with monolingual peers whereas L2 vocabulary growth is slower with regard to both comprehension and production. However, when total vocabulary is considered, bilinguals comprehend and produce as many, if not more, words than their monolingual peers.

No major differences in processing efficiency were observed across groups or languages at either wave of data collection and both groups significantly decreased their RTs across a six-month period. Nevertheless, interesting relations between vocabulary size and processing efficiency emerged. Children with larger vocabularies were faster at processing words and processing efficiency was predictive of receptive vocabulary acquisition across languages at 22 months of age. Finally, significant cross-language relations were observed for receptive and expressive vocabulary size at 16 and 22 months.

In conclusion, this study is the first to investigate vocabulary growth in a sample of French-English bilingual toddlers using a longitudinal design in conjunction with a direct measure of vocabulary development. By examining both expressive and receptive vocabulary growth from 16 to 22 months of age, we have been able to show that bilingual toddlers largely keep pace with their monolingual peers when their dominant language or total vocabulary is considered. Moreover, learning more than one language from birth does not appear to hinder the online processing of words, and may be facilitative of total vocabulary acquisition in young bilinguals. Our findings suggest a complex interplay between language exposure, processing efficiency, and word learning across the first two years of life. Receptive and expressive vocabulary growth across languages provided evidence of both acceleration and stability across waves in both monolingual and bilingual toddlers, however further research is required in order to fully understand the long-term developmental trajectory bilingual infants take in acquiring each of their languages.

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Table 1

Monolingual and bilingual comprehension and production scores within each wave.

	Monolinguals (n = 59)			Bilinguals (n = 45)					
Wave 1	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**F-test**	**Significance**	η^2
CCT total vocabulary (R)	16.36	6.93	2.00–32.00	21.56	9.51	4.00–41.00	4.87	$p = .030$	.093
CCT L1 (R)				11.69	6.55	1.00–27.00	4.67	$p = .033$	.109
CCT L2(R)				10.16	5.62	2.00–26.00	15.33	$p < .001$	.193
CDI total vocabulary (E)	24.02	26.22	0–115.00	85.76	75.44	4.00–355.00	14.33	$p < .001$	.254
CDI L1 (E)				49.98	39.13	4.00–138.00	3.48	$p = .065$	.239
CDI L2 (E)				37.22	42.11	0–238.00	1.73	$p = .192$	.037
Reaction Time L1	4165.12	944.31	2282.00–6023.00	3656.00	924.50	2141.00–6027.00	2.14	$p = .147$	.072
Reaction Time L2				3619.00	949.90	1285.00–5445.00	2.87	$p = .093$	.078
Wave 2	**Monolinguals (n = 52)**			**Bilinguals (n = 38)**					
CCT total vocabulary (R)	29.31	6.12	12.00–40.00	49.97	11.07	17.00–66.00	29.14	$p < .001$	.622
CCT L1 (R)				27.76	6.23	12.00–37.00	6.78	$p = .011$	.076
CCT L2 (R)				23.66	7.19	2.00–35.00	13.83	$p < .001$	.176
CDI total vocabulary (E)	208.14	137.21	28.00–523.00	363.00	236.31	67.00–1027.00	.727	$p = .332$	.186
CDI L1 (E)				225.90	153.43	57.00–643.00	1.60	$p = .210$	.052
CDI L2 (E)				137.11	110.65	3.00–446.00	6.27	$p = .014$	.085
Reaction Time L1	3406.19	899.57	1901.82–5163.54	3155.87	707.20	1856.50–5239.74	.103	$p = .749$	.050
Reaction Time L2				3031.80	642.94	2026.58–5087.75	.209	$p = .649$	.067

E = expressive

R = receptive

Table 2

Monolingual and bilingual cross-waves difference scores.

	Monolinguals (n = 52)			Bilinguals (CCT & CDI n = 34; RT n = 31)					
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**F-test**	**Significance**	η^2
CCT total vocabulary (R)	12.56	7.29	−3.00–28.00	29.82	10.77	6.00–54.00	35.65	p = .000	.489
CCT L1 (R)				16.59	7.22	−5.00–30.00	1.24	p = .268	.084
CCT L2 (R)				14.44	6.89	−4.00–30.00	.806	p = .372	.017
CDI total vocabulary (E)	184.19	125.68	19.00–514.00	287.40	189.10	55.00–825.00	5.07	p = .027	.099
CDI L1 (E)				189.20	129.00	19.00–532.00	.004	p = .953	.001
CDI L2 (E)				103.40	97.62	−74.00–344.00	3.81	p = .054	.111
Reaction Time L1	720.89	1278.94	−3212.50–1996.88	−686.00	952.50	−3087.50–753.25	.053	p = .819	.001
Reaction Time L2				−583.00	1071.00	−2688.86–1844.66	.010	p = .920	.010

E = expressive

R = receptive

Table 3

Multiple regression models (standardized Betas) with English:French ratios of language exposure and processing speed at 16-months as predictors of English:French ratios of receptive (CCT) and expressive (CDI) vocabulary size at 22-months (n = 31).

	22 months			
	Relative receptive vocabulary		Relative expressive vocabulary	
16-month predictor	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Relative language exposure	.47**	.41*	.49**	.50**
Relative processing speed (RT)	—	.34*	—	−.07
Total R^2	.22	.33	.24	.24

*p < .05;

**p < .01