LANGUAGE DOMINANCE AND LEXICAL-SEMANTIC PROCESSING IN BILINGUAL TODDLERS

by

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Prior research suggests that language systems interact in bilingual individuals. The current study seeks to extend prior work by investigating whether or not bilingual toddlers exhibit cross-language priming effects and to what extent measures of proficiency versus exposure modulate lexical-semantic processing within and across languages. Here we present findings on a group of Spanish-English bilingual toddlers at 24 months of age (N = 20). Consistent with prior literature, toddlers demonstrated cross-language priming effects, suggesting that language systems interact in the second year of life. Additionally, our results indicate that lexical-semantic processing is related to language proficiency, such that vocabulary was a stronger predictor than cumulative exposure. Surprisingly, proficiency measured by vocabulary size and speed of word recognition either facilitated or inhibited lexical-semantic processing, dependent on language condition. Together these findings demonstrate that proficiency modulates lexical-semantic processing within and across languages.

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Introduction

A Growing Bilingual Population

More than half of the world's population is bilingual, with data indicating that the number of individuals who speak more than one language will continue to steadily increase (Grosjean, 2010; U.S. Census Bureau, 2011). In the U.S. alone, 12% of the total population identify as bilingual Spanish-English speakers (U.S. Census Bureau, 2011). Moreover, 28% of children ages 0 to 8 in Oregon are considered dual language learners (Park, O'Toole, & Katsiaficas, 2017). What these statistics indicate is that bilingualism is a common experience for many families in the U.S.

Despite this growing number of bilingual individuals, there remains a gap in the current literature surrounding bilingual language development and the mechanisms which govern the acquisition of two or more languages. Prior literature has shown that early language development in young English-speaking and Spanish-speaking monolingual children is predictive of later literacy skills (Fernald, Perfors, & Marchman 2006; Hurtado, Marchman, & Fernald, 2007; Marchman & Fernald, 2008). Specifically, speed of word recognition and vocabulary size in monolingual children two years of age predicted novel word learning and working memory in those same children at 8 years of age. Additionally, recent work posits that speed of word recognition in both monolingual and bilingual children is associated with overall language abilities (i.e., auditory processing, phonology, lexical-semantics), all of which are crucial components of emergent literacy skills (e.g., Marchman et al., 2010; De Anda et al., 2018). What this literature suggests is that early language skills (i.e., speed of word processing and vocabulary size) determine educational outcomes for both monolingual and bilingual children. This research highlights the importance of examining early language and vocabulary specifically in the growing population of dual language learners. However, the current body of research in this population is lacking. As such, practitioners, educators, and clinicians are less informed about how to support healthy language development at the earliest ages in diverse learners. Providing additional resources and literature to Speech-Language Pathologists and educational professionals on typical and atypical bilingual development will also help promote proper diagnosis and treatment of these children (Bedore & Peña, 2008). As the number of bilingual Spanish-English speakers in Oregon and throughout the U.S. continues to increase, it is important to consider how these dual language learners are exposed to and tasked with organizing words and concepts within and across languages. Understanding this formation of dual vocabulary systems is crucial in supporting early language development in children who grow up in bilingual homes and furthermore in promoting the preservation of the home language. Below we review research surrounding vocabulary acquisition in bilingual children. We will then present testable predictions about the development of lexical-semantic processing and cross-language interaction specifically in dual language learning toddlers.

Bilingual Language Experience

Broadly construed, bilingualism refers to the ability to use two or more languages and exists on a spectrum characterized in terms of proficiency and exposure (Byers-Heinlein & Lew-Williams, 2013). Typically, a dual language learner is defined as a child under 8 years of age who has at least one parent who speaks a language other than English in the home (Park, O'Toole, & Katsiaficas, 2017). In the present study, we use the terms dual language learner and bilingual interchangeably since both terms accurately describe the emerging state of two language systems in our participant population.

Prior research in monolingual children suggests that during the second year of life there is a dramatic increase in vocabulary size, or the lexicon (McMurray, 2007). It is well documented that this rapid increase of the lexicon is comparable in both monolingual and bilingual children (e.g., Pearson & Fernández, 1994.) During this rapid period of lexical development, two-year-old children begin to form connections between different vocabulary words. This process of associating words and their concepts results in the formation of lexical-semantic networks. Within these systems of networks are lexical items, or words (e.g., *dog*), and semantic relationships, or concepts (e.g., *pet*, *fur*, *woof*). Despite meeting similar language milestones as their monolingual peers, dual language learners are tasked with organizing words and concepts within *and* across two languages (Wojcik, 2017). Specifically, bilingual children are responsible for language discrimination, or differentiating between two different networks of speech sounds, lexicons, and word representations (Werker & Byers-Heinlein, 2008).

In addition to engaging in the language discrimination process, a bilingual child's language experience is split between two languages. This split language experience differs from monolingual individuals who only receive input in one language. That is, most often, bilingual individuals are not exposed to the same amount of input in one language compared to their other language which results in an unequal distribution in proficiency and exposure. Wojcik (2017) suggests that this research on lexical-semantic networks in bilingual children is important because it will reveal how early language environments in dual and single language contexts shape early language development. To this extent, the goal of the present study is to examine how lexical-semantic networks in bilingual toddlers emerge and interact during the second year of life since this period of development is characteristic of rapid vocabulary growth. Of importance is how language dominance, or the relative level of language exposure and proficiency, modulates lexical-semantic networks within and across languages.

Lexical-Semantic Priming Studies

Recall that bilingual individuals are responsible for organizing two language systems. These language systems build connections of words and concepts, or lexical-semantic networks. In a lexical-semantic network, words are organized based on their word meanings, such that words with similar meanings are categorized together. Prior literature has employed priming tasks in order to determine lexical-semantic processing abilities in both monolingual and bilingual adults and children. Priming is the process by which an individual is exposed to stimuli which elicits a response to a subsequent stimulus. In the context of lexical-semantics, researchers present priming words with different semantic relations to determine how people process words with related word meanings (McDonough & Trofimovich, 2009). Of importance to the present study is cross-language priming, or the relation between words across two languages (Kootstra & Muysken, 2017). The underlying assumption with cross-language priming tasks is that they provide evidence for cross-language activation.

Lexical-semantic priming in bilingual adults

The majority of work examining cross-language lexical-semantic associations has been conducted in adults. It is well understood that bilingual adults show lexical-semantic activation across languages. Kroll and Stewart (1994) showed that Dutch-English bilingual college students demonstrated asymmetric connections between lexical-semantic networks. That is, these bilingual adults switched more quickly from their non-dominant, or second, language (English) to their dominant, or first, language (Dutch) than the reverse. Evidence suggests that lexical associations from the non-dominant language to the dominant language are stronger than from the dominant to non-dominant language due to the directionality of second language acquisition in adults. What Kroll and Stewart (1994) propose is the Revised Hierarchical Model in which lexical and conceptual links are bidirectional yet differ in strength based on language dominance (see also Kroll, Van Hell, Tokowicz, & Green, 2010). The lexical links from the second language to the first language are stronger because the second language requires lexical mediation via the first language. Conceptual memory is stronger in the first language. What these results suggest is twofold: lexical spaces are shared across languages in bilingual adults, and the strength of lexical-semantic networks differs as a function of dominance.

Lexical-semantic priming in children

Although bilingual adults demonstrate cross-language priming effects, do bilingual children evince similar cross-language processing effects? De Anda, Poulin-Dubois, Zesiger, & Friend (2016) posit that simultaneous bilingual children do not have a robust, first language lexical network to map a second language onto. Thus, the associations and processes which underlie cross-language interaction in the developing dual language systems of children may differ. As reviewed by Paradis (2007), simultaneous bilingualism typically refers to children whose dual language learning experiences begin at birth or before the age of three. This early acquisition of two languages is referred to as bilingual first language acquisition. Conversely, sequential bilingualism typically denotes someone who is exposed to and acquires their second language after their first language system has been established. While the processes which underlie cross-language interaction in adults who are sequential bilinguals has been widely investigated, it remains unknown how young dual language learners build lexical-semantic networks within and across their dual language systems. To this extent, we review lexical-semantic priming studies conducted with monolingual and bilingual children to elucidate findings between adults and children.

Lexical-semantic priming in monolingual children

In monolingual studies, evidence shows that infants demonstrate emerging lexical-semantic priming effects as they enter the second year of life. Arias-Trejo and Plunkett (2009) proposed that prior exposure to a semantically related word *facilitates* target preference, or longer looking toward the primed target. In order to test this hypothesis, they employed the Intermodal Preferential Looking Task to evaluate semantic word relatedness. The Intermodal Preferential Looking Task (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987) has been used as a behavioral measure to assess the prime effect which is a measure of lexical-semantic processing. Children are presented with pairs of words that are either semantically related (e.g., *dog* and *bird*) or unrelated (e.g., *dog* and *flower*). The task utilizes an eye-tracking system which captures looking behavior during the presentation of spoken words and visual stimuli. To measure the prime effect, the difference in looking time between the related and unrelated trials is computed. This effect is believed to occur as a result of spreading activation which is thought to be stronger for semantically related words. Spreading activation is the process by which closely related words are connected by short links, whereas more distantly related words are separate by links farther apart (Collins & Loftus, 1975). This process was demonstrated by Arias-Trejo and Plunkett (2009) who found that 21-month-olds monolingual English toddlers demonstrated emerging priming effects as demonstrated by their longer looking times to the target when presented with a semantically related word as opposed to a semantically unrelated word. These findings suggest that monolingual children are sensitive to the semantic relation between word pairs by 21 months of age.

To follow up on these findings, 21-month-old and 24-month-old monolingual infants were presented with associatively (e.g., *dog* and *bone*) and/or semantically (e.g., *dog* and *cat*) related trials to investigate whether infants demonstrated an understanding of differing lexical-semantic relationships (Arias-Trejo & Plunkett, 2013). The present study only investigated lexical-semantic processing between semantically related words. Monolingual infants 21-months-of-age demonstrated priming between words that were both associatively and semantically related, whereas 24-month-olds evinced priming effects for either associatively or semantically related words. Overall, these findings suggest that lexical-semantic networks in monolingual infants emerge by 21-months-of-age and become stronger by 24-months-of-age. Of interest to the present study is whether bilingual infants demonstrate cross-language priming effects in the second year of life.

Lexical-semantic priming in bilingual children

One of the first studies to investigate cross-language semantic priming in bilingual infants has demonstrated that semantic systems are highly interconnected across languages (Singh, 2014). Using the Intermodal Preferential Looking Paradigm, Singh (2014) reported that 30-month-old Mandarin-English bilingual toddlers demonstrated priming effects only when the prime word was presented in the dominant language. In the context of Singh's study, the dominant language referred to the language of most exposure. Prime words presented in the non-dominant language did not evince priming effects. In other words, only when the prime word was presented in the dominant language did children show longer looking times toward the target image. These results were evinced in both within- and cross-language trials, which suggests that lexical spaces interact across semantic networks despite evidence for reduced semantic activation between words within the bilingual toddler's non-dominant language.

To follow up on monolingual and bilingual work, De Anda and Friend (in review) explored the developmental organization of lexical-semantic networks in typically-developing Spanish-English bilingual toddlers. Participants were tested longitudinally at 18 and 24 months of age to compare their lexical-semantic processing skills using the Intermodal Preferential Looking Paradigm. Results showed that the 24-month-olds, but not 18-month-olds, evinced robust priming effects. That is, 24-month-old bilingual toddlers demonstrated a significant difference in looking time between semantically related and unrelated trials. In addition, lexical-semantic priming was strongest in the dominant language of exposure. In summary, results showed that the organization of lexical-semantic networks in Spanish-English bilingual toddlers emerges during 18-months of age and becomes well-established at 24-months of age. What these results suggest is that the emergence of lexical-semantic processing follows similar trajectories in both monolingual and bilingual children during the second year of life (e.g., Arias-Trejo & Plunkett, 2009, 2013; Singh, 2014).

Recently, Potter, Fourakis, Morin-Lessard, Byers-Heinlein, and Lew-Williams (2018) extended bilingual findings on cross-language interaction by examining the effects of language dominance and language mixing on real-time language processing. Eighteen- to 30-month-old Spanish-English bilingual toddlers were presented with single- and switched-language trials in a Looking-While-Listening procedure, which measures looking behavior, and thus word processing. However, rather than examining lexical-semantic priming, the task indexes speed of lexical retrieval for single words. Language dominance was defined as the toddlers' language of most exposure. As expected, toddlers demonstrated greater looking accuracy in single-language trials presented in their dominant language (DL) versus their non-dominant language (NDL). During switched-language trials, toddlers had more difficulty processing the subsequent target noun in their NDL when the preceding sentence frame was in their DL. Conversely, toddlers performed equally well in trials where the sentence frame was in the NDL and the subsequent target word was either the NDL or DL. Thus, there was no switch cost from the NDL to the DL in switched-language trials. In other words, processing switched-sentence frames in the NDL resulted in subsequent target word recognition in both the DL *and* NDL, whereas processing was disrupted when there was a switch from DL to NDL. These results suggest that robust lexical-semantic connections in the DL may inhibit subsequent target word processing across languages, whereas weaker connections in the NDL result in similar effects across languages since the NDL generates weaker predictions about subsequent word processing.

As we have reviewed above, there is sufficient evidence to suggest that bilingual children evince cross-language priming effects which suggests that lexical-semantic networks are shared across languages and emerge during the second year of life. Certainly, the current body of literature indicates that language dominance plays a role in within- and cross-language processing. However, there remains a gap in the discussion of how proficiency and exposure predict lexical-semantic processing. As we have reviewed, the large majority of previous studies use language *exposure* to describe language dominance. Exposure does not capture one's language abilities in full because it is difficult to determine the extent to which language is processed based on what an individual hears. It remains unknown how language *proficiency* plays a role given that it may be a stronger predictor since children's internal representations (i.e., proficiency) may be better at describing word processing than the amount of language input as we discuss below. Indeed, there appears to be conflicting evidence for the ways in which language dominance affects on-line lexical-semantic processing. Thus, the present study seeks to clarify the role of proficiency and exposure on cross-language lexical-semantic processing in bilingual toddlers. Below, we review how language dominance is measured and how it might predict lexical-semantic processing.

Language Dominance

As we have discussed in our review above, language dominance influences monolingual and bilingual children's language processing. But how might language dominance be measured? Is it by exposure from the input in their environment or from acquired proficiency and skills in each language? Bedore, Peña, Summers, Boerger, Resendiz, Greene, Bohman, and Gilliam (2012) state that research needs to consider the ways in which language dominance is defined and measured in bilingual children since they are emerging in their ability to process and produce language, and cannot provide adults with a comprehensive overview of their language skills. Thus, we provide a clear explanation of how language dominance is defined and measured in order to best characterize the dual language learning toddlers in the present study.

Exposure

With respect to exposure, Grüter, Hurtado, Marchman, and Fernald (2014) define relative language exposure in terms of the proportional input of each language. Whereas some bilingual children may receive relatively equal exposure across two languages (e.g., 50% Spanish and 50% English), other children might be exposed to Spanish 70% of the time and English 30% of the time. In contrast, absolute language exposure is defined as the overall amount of input a child receives, and is often measured during a laboratory-based play session, such that a brief interaction between child and caregiver is used to measure the child's total language exposure (Hurtado, Grüter, Marchman, & Fernald, 2014). To this extent, calculating absolute language exposure fails to capture daily variation in the child's overall amount of exposure in each language (Unsworth, Chondrogianni, & Skarabela, 2018).

Bilingual children acquire both languages relative to the amount of input in each language. Thus, because language exposure is divided between two languages, bilingual children are less likely to proportionately hear each language in comparison to their monolingual counterparts (Hoff, Core, Place, Rumiche, Señor, & Parra, 2012; Grosjean, 2010; Byers-Heinlein, 2015). While monolingual and bilingual children experience the same burst in vocabulary development, the rate at which bilingual children develop each language tends to lag behind that of their monolingual peers when compared in a single language (Hoff & Core, 2015). To be sure, this pattern is not in itself indicative of language delay but instead a typical pattern in multilingual learners.

Prior research has shown that shown that the amount and quality of exposure young children receive influences language development in the domain of vocabulary size (Place & Hoff, 2011). For example, monolingual children who hear a large proportion of English will likely acquire vocabulary words in English relative to that amount of exposure. What this suggests is that language exposure supports proficiency.

However, in the context of dual language environments where young children are exposed to two languages, their acquisition of vocabulary words may vary between languages. In other words, the relative amount of language exposure that a child hears may not mirror their productive word proficiency which may be moderating the relation between language input and lexical-semantic processing. Even when children frequently hear one language, they oftentimes choose to speak a different language due to the environment, interlocutors, or necessity (De Houwer, 2011; Hoff & Core, 2013). This means that exposure and proficiency as measures of dominance should be evaluated separately in order to best characterize the language experience of bilingual children. The present study uses measures of relative language exposure to explore the central research questions. In addition, prior studies have relied on a narrow range of second language exposure, such that children with less than 20% exposure to a second language are excluded. Here we propose to examine the full range of exposure to precisely characterize its role in promoting lexical-semantic processing.

Proficiency

A better measure of children's word processing may be language *proficiency* rather than only language *exposure*. Language proficiency in young infants and toddlers is often measured as a function of vocabulary size (Bialystok & Feng, 2011). Furthermore, proficiency is split into domains of expressive and receptive language skills. Expressive vocabulary skills, or word production, refers to the ability to *produce* words and sentences. Receptive vocabulary skills, or word comprehension, denotes the ability to *understand* language including words and sentences. Bilingual children's expressive and receptive vocabulary skills are split across two languages, and thus, their proficiency can be unequally distributed between their two languages (Byers-Heinlein, Esposito, Winsler, Marian, Castro, Luk, 2019). Whereas one child might possess strong expressive skills such that they are able to produce many words in one language (e.g., Spanish), they may have poorer receptive skills say in their other language, English (i.e., difficulty understanding what their parent is saying to them in English). Measuring proficiency presents a unique challenge in understanding young children's language skills because they are unable to explicitly report their word comprehension (Bialystok, 2001). As such, parent report has been widely used by researchers to characterize children's expressive vocabulary skills (e.g., MacArthur-Bates Communicative Development Inventories; Fenson, Dale, Reznick, Bates, Thal, Pethick, Tomasell, Mervis, & Stiles, 1994). However, parent report of vocabulary knowledge is not well correlated with measures of spoken word processing (Fernald, Perfors, & Marchman, 2006). Prior researchers who have examined the role of vocabulary knowledge on spoken word processing have shown mixed findings. In the present study, we used *both* parent report and a behavioral task (e.g., Computerized Comprehension Task; Friend & Keplinger, 2003) to index word knowledge as a measure of language proficiency. In this way we clarified and extended previous studies. In addition, prior studies have relied on typically developing children only, which limits the range of language proficiency being examined. In the present study we sought to examine the full range of vocabulary knowledge and lexical processing by including children with and without early language delays.

The Present Study

Although lexical-semantic priming effects have been examined in prior literature, it remains unclear whether this extends to toddlers with a range of proficiency and exposure. In other words, is lexical-semantic processing predicted by the language(s) that the toddler hears, or the language(s) that the toddler produces? The present study examined language exposure and proficiency, respectively, to understand the strongest sources of variability in lexical-semantic processing. Importantly, we sought to examine exposure and proficiency along the full continuum whereas prior research has excluded children at the extreme ranges (e.g., children with >80% to a language, or children with early language delays).

Study Aims and Hypotheses

The present study sought to understand the unique cross-language interactions in bilingual toddlers, 24-months of age, and how measures of exposure and proficiency influenced this propensity. First, we asked, do lexical-semantic networks, or vocabulary systems, interact across languages, or are they relatively separate? We hypothesized that bilingual toddlers 24-months-of-age would show evidence for cross-language interactions since previous findings have demonstrated non-selective lexical access across languages in bilingual toddlers. (Singh, 2014; Potter et al., 2018). That is, when hearing a word in one language, bilingual toddlers automatically activate related words and concepts in their other language.

Second we asked, to what extent does proficiency versus exposure predict lexical-semantic processing? We expected that proficiency would be a stronger predictor rather than exposure for cross-language lexical-semantic processing consistent with bilingual adult findings who found that proficiency as measured by vocabulary size is a predictor of lexical-semantic processing due to the greater amount of lexical-semantic networks that have been formed (e.g., Zhao et al., 2011).

There are three possible hypotheses regarding the relation between proficiency and lexical-semantic processing. One hypothesis is that bilingual toddlers with larger vocabulary sizes would evince faciliatory processing, or a smaller prime effect, in within- and cross-language conditions. Recall that the prime effect is the difference between the proportion of looks (proportion looks = looks toward the target image divided by the sum of the target image and distractor image; T/T+D) in related trials and the proportion of looks in unrelated trials (related – unrelated proportion looks). In other words, toddlers with more words in their lexicon and more robust semantic connections between their lexicons would show a greater proportion of looks toward the target image in both within- and cross-language conditions. For toddlers with fewer words in their lexicon and weaker semantic networks in their dominant language, it was expected that they would show a smaller prime effect in within- and cross-language conditions. With respect to semanticity, it was expected that toddlers would evince a greater proportion of looks toward the target image given that the primed word and target word were semantically related. In trials where the prime and target word were semantically unrelated, we expected that toddlers would demonstrate a smaller proportion of looks toward the target image. In summary, it was hypothesized that proficiency would facilitate language processing both within and across language conditions, and that semantically related words rather than semantically unrelated words would facilitate lexical-semantic processing.

A second possibility is that vocabulary does not facilitate but instead inhibits lexical-semantic priming. For example, recent work with 18-month-old monolingual children points to the possibility that larger vocabulary size inhibits the prime effect (Borovsky and Peters, 2019). That is, monolingual toddlers with larger lexicons and more dense and clustered semantic spaces exhibit inhibitory word recognition because they have to suppress lexical links between their semantic networks in order to process words more efficiently. As an example, when hearing the word *dog* nearby semantic neighbors (e.g., competitors) such as *bird* need to be quickly suppressed to support efficient comprehension. Conversely, monolingual children with smaller productive vocabularies demonstrated facilitation in word recognition possibly because they have weaker semantic representations and underspecified categories. Thus, what these monolingual findings suggest is that larger vocabulary size may *inhibit* lexical-semantic processing whereas smaller vocabulary size may *facilitate* lexical-semantic priming effects. If these findings extend to bilingual toddlers, we hypothesized that larger vocabulary sizes within and across languages would demonstrate inhibitory priming effects in both within- and cross-language conditions, whereas those with smaller vocabularies would demonstrate faciliatory effects.

The third possible hypothesis is that language proficiency might not influence priming effects, regardless of vocabulary size. This hypothesis aligns with recent work published by Floccia, Delle Luche, Lepadatu, Chow, Ratnage, and Plunkett (2020) that investigated the role of translation equivalents in cross-language semantic priming. Bilingual toddlers 27-months of age demonstrated priming effects, regardless of the prime word language condition. Results indicated that neither language dominance as a function of exposure nor vocabulary size (determined by parent report) influenced cross-language priming. While Floccia et al. (2020) provide evidence for cross-language interaction, they suggest that lexical-semantic processing in bilingual toddlers occurs irrespective of contextual factors such as proficiency and exposure. Extending this to the current study, we too may find null language dominance effects in bilingual toddlers at 24- and 27- months of age. However, recall that parent report is limited in its ability to predict lexical-semantic processing abilities. As such, we will test language proficiency using both parent report and behavioral methods.

Methods

Participant Population

Participants in the current study were recruited as part of a larger longitudinal investigation which sought to examine Latina mothers and their children in dual language contexts. The present sample consisted of 20 participants, 8 of whom were female (Table 1). The mean age of the participants was 24.65 months (*SD* = 1.5). There was a relatively balanced range of participants across total family incomes ranging from $10,000 to $80,000 per year. Two families abstained from reporting their income. Of the 20 families, 7 fell below the national poverty line (https://aspe.hhs.gov/2019-poverty-guidelines). All participant's mothers identified as Latina, per the study's eligibility criteria, and most identified as Mexican, Mexican-American, or Chicana (*n* = 16). Toddlers were primarily exposed to Spanish and English from birth, thus they were considered simultaneous bilingual toddlers, or young dual language learners. Three participants were exposed to a third language (Japanese, Zapotec, and Catalan), however this accounted for less than 2% of their overall language exposure. Eighteen out of 20 participants were primarily exposed to Spanish with an average of 84% (*SD* = 16%) exposure to Spanish (Table 2). For toddlers whose dominant language was English, they received an average of 71% (*SD* = 11%) exposure to English. Early child language delay was not an exclusionary criterion. In the present sample, 8 toddlers had language delay based on study criteria which defined language delay as producing fewer than a sum of 50 words in one or both languages and not combining 2-word utterances. Because we did not have enough power to split analyses as a function of language delay, we treated proficiency as a continuum, and thus as one of the independent variables of interest in the present study. One participant did not contribute language exposure information because of experimenter error, and two participants' eye-tracking data was not included in final analyses due to fussiness.

Measures

Recall that we were interested in the organization of the vocabulary system in dual language learners as a function of their relative language dominance in Spanish and English. We asked, (a) do lexical-semantic networks interact across languages? and (b) to what extent does exposure versus proficiency predict lexical-semantic processing? Four measures were employed in the present study to investigate the relationship between the prime effect as the dependent variable of interest and language exposure and proficiency (i.e., expressive and receptive vocabulary comprehension) as the independent variables of interest.

Language Exposure Assessment Tool

The Language Exposure Assessment Tool (LEAT; De Anda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016) assessed the amount of relative language exposure a child received in both Spanish and English. Parents answered quantitative and qualitative interview-style questions on the number of speakers who interacted with their child, the languages that they spoke, and the amount of time a child interacted with each speaker in each language. Parent responses were recorded and analyzed in Microsoft Excel. Together this information provided a measure of cumulative language exposure since birth to both Spanish and English. The LEAT has high internal consistency and criterion validity (De Anda et al., 2016).

Computerized Comprehension Task

The Computerized Comprehension Task (CCT; Friend & Keplinger, 2003, 2008) determined receptive vocabulary size and haptic response time for correct target touches (i.e., a measure of lexical-semantic processing) in both Spanish and English. The CCT was used to assess language dominance. A semantically related target and distractor image (e.g., *dog* and *bird*) were presented simultaneously on the right and left side of a touch-sensitive tablet. An experimenter prompted the toddler to touch the target item (e.g., “Where’s the *dog*? Touch *dog*!) for each pair of words. The toddler’s receptive vocabulary comprehension in both Spanish and English was measured based on the number of correctly identified target words. Additionally, the toddler’s reaction time of correct target touches was measured in Spanish and English. Both Spanish and English versions of the CCT have good test-retest reliability and internal consistency (Friend & Keplinger, 2008; Friend, Schmitt, & Simpson, 2012).

We expected that toddlers with stronger dominance in one language (e.g., Spanish) would demonstrate larger receptive vocabulary scores in that language relative to the other (e.g., English). Furthermore, we expected that toddlers with stronger dominance and larger receptive vocabulary scores in one language would demonstrate faster haptic response times in that language as well.

English-Spanish Vocabulary Inventories

Expressive vocabulary was measured using the English-Spanish Vocabulary Inventories (ESVI; De Anda, Cycyk, Moore & Huerta, in prep.) which is a bilingual adaptation of the widely used MacArthur-Bates Communicative Development Inventories: Words and Sentences (MCDI; Fenson, Marchman, Thal, Dale, Reznick, &

Bates, 2007) and its Spanish adaptation, Inventarios del Desarrollo de Habilidades Comunicativas: Palabras y Enunciados (IDHC; Jackson-Maldonado, Thal, Fenson, Marchman, Newton, & Conboy, 2003). A checklist of 1755 words was provided to the parent to report the vocabulary words their toddler understands and says in both languages, including translation equivalents (words across languages with the same meaning, such as *banana* and *plátano*) and total conceptual vocabulary (two different words such as *dog* and *perro* as one concept represented in both languages). The ESVI complemented the CCT in order to determine the toddler's proficiency in both languages and measure language dominance. The MCDI and IDHC, from which the ESVI was adapted, have good test-retest reliability and validity (Fenson et al., 2007; Thal, Jackson-Maldonado, & Acosta, 2000)

We expected that toddlers with higher levels of exposure in Spanish would be reported to have higher expressive vocabulary sizes in Spanish. Likewise, it was expected that toddlers with higher levels of exposure to English would have higher expressive vocabulary sizes in English. Additionally, we expected that parent report of expressive vocabulary would converge with the behavioral measure of receptive vocabulary in both languages (Friend, Schmitt, & Simpson, 2012).

Lexical-semantic Processing Task: Eye-tracking

To assess the organization of vocabulary within and across languages, we employed the Intermodal Preferential Looking (IPL) paradigm using a noninvasive eye-tracking system (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; EyeLink1000, SR Research Ltd.). Previous studies have utilized the IPL task to investigate lexical-semantic priming in monolingual and bilingual children (Arias-Trejo & Plunkett, 2009, 2013; Singh, 2014; De Anda & Friend, in review). This recent body of literature has shown that both young monolingual and bilingual children are sensitive to semantic relationships between words by measuring the speed at which children are able to assess a pair of target and distractor images. It is believed that semantically related and unrelated words will elicit different looking patterns which is an indicator of lexical-semantic processing, or an individual's ability to access and perceive words, their meanings, and their relatedness—all of which form a system of lexical-semantic networks. The IPL task has been shown to converge with haptic behavioral measures of lexical-semantic processing in young children (Frank et al., 2016).

In the present study, toddlers were primed to assess pairs of images (a target and distractor) presented on a display computer monitor. Imageable nouns which appeared on the IPL task were selected to be known by 60% or more of 18-month-olds based on MCDI and IDHC norms (Fenson et al., 2000). The dependent variable of interest was the toddlers' looking time to the target object following the presentation of a semantically related or unrelated prime word. Experimental design was adapted from De Anda and Friend (in review). The presentation of spoken word stimuli and visual stimuli was as follows (see Figure 1). Each trial began with an attention-getter which appeared for a total of 1000 ms during the presentation of the carrier phrase ("I saw a…") and prime word (e.g., "*jacket*"). The target word (e.g., "*coat*") was presented in isolation 200 ms after the offset of the prime word. Then, 200 ms after the onset of the target word, the target and distractor images were presented for a total of 2500 ms. The location of the target and distractor images was counterbalanced, such that they appeared equally on the left and ride side of the screen.

The prime and target word pairings were organized across a 2 x 2 design and varied as a function of (a) language and (b) semanticity (Table 3). With respect to language, prime-target pairs were within the same language, or across Spanish and English. Specifically, within-language trials primed a target sentence ("I saw a *jacket*…") with a subsequent target noun ("*coat*") and accompanying target-distractor image pair (*bottle* and *coat*). In cross-language trials, the primed target sentence ("I saw a *hat*…") was followed by the target noun in the other language ("*suéter*" – sweater) and target-distractor image pair (*trash* and *suéter*). With respect to semanticity, two trial types were presented in both within- and cross-language blocks: semantically related and semantically unrelated word pairs. For example, in a within-language block, a related trial primed the word "cereal" with "toast" ("I saw *cereal*…*toast*!"). Likewise, in a cross-language block, a semantically unrelated trial primed "*árbol*" (tree) with "*fork*" ("Yo vi un *árbol…fork*!" – "I saw a *tree*…*fork*!"). Each toddler was presented a total of 36 experimental trials, with 20 related trials and 16 unrelated trials distributed across 2 within-language and 2 cross-language block conditions: English prime to English target, Spanish prime to Spanish target, English prime to Spanish target, and Spanish prime to English target. The presentation order of the blocks was determined based on the child's dominant language of exposure, and trials were pseudo-randomized such that no two participants received the same order of trials.

Procedure

Data collected for the present study took place in the Early Dual Language Development Lab at the University of Oregon. This study was approved by the University of Oregon's Institutional Review Board. Before visiting the lab, research assistants fluent in Spanish and English conducted a pre-visit screening phone call with the toddler's mother to determine participant eligibility and administer the LEAT. If the toddler was eligible to participate in the study, a time was scheduled for the toddler and their mother to visit the lab. During the lab visit, a research assistant fluent in Spanish and English administered the tasks outlined here. Following the informed consent process and completion of a demographic questionnaire, the CCT was administered in an observation room with video cameras capturing the task. Second, the toddler and their mother moved to a sound-attenuated booth in which the eye-tracking system was housed. The toddler was seated on the mother's lap in front of the computer monitor and eye-tracker and adjusted according to the eye-tracker's recording range. Following a three-point calibration sequence, a series of four trial blocks were presented to the toddler while the eye-tracker monitored total looking time to the target object relative to the distractor object on the screen following the auditory stimuli. Lastly, the ESVI was administered to the toddler's mother to report on the child's expressive vocabulary skills. In total, four measures were used to assess the organization of the vocabulary system in dual-language learners as a function of their relative language dominance: the LEAT, the CCT, the ESVI, and a lexical-semantic processing task using an eye-tracking system.

Coding

ESVI

Toddlers' total number of words produced in Spanish and English, as well as the number of translation equivalents, total vocabulary in both languages, and total conceptual vocabulary were tallied and entered into Microsoft Excel. Inter-rater reliability was calculated for 25% of the final sample and was above 95% (*M* = .998).

CCT

CCT coding procedures were adapted from Hendrickson, Mitsven, Poulin-Dubois, Zesiger, and Friend (2015). Correct touches to the prompted target word were coded and included in analyses for both Spanish and English administrations of the task. A correct target touch was defined as a non-ambiguous point or touch to the prompted target image. Responses less than 400 ms likely reflected an anticipatory haptic response prior to hearing the target word (Bailey & Plunkett, 2002; Poulin-Dubois et al., 2013; Hendrickson et al., 2015), and were thus removed from final analyses. Additionally, trials where toddlers responded after 7 s had passed were removed from final analyses consistent with CCT procedures and prior literature (e.g., Hendrickson et al., 2015). Haptic response time (speed of word processing) was analyzed using Eudico Linguistic Annotator software (ELAN; https://tla.mpi.nl/tools/tla-tools/elan; Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands). Only trials which were previously coded as correct target touches were included in haptic response time analyses. Inter-rater reliability was calculated for 25% of the final sample and established within .2 ms of the onset of the target word and the onset of the touch (*M* = .92).

Lexical-semantic Processing Task

Data were processed using EyeLink® Data Viewer software (SR Research Ltd). An area of interest (AOI) template which corresponded to the locations of the target and distractor images was assigned to each trial for the 2500 ms presentation of the target and distractor image pairs. AOIs for each target and distractor image were determined based on their distant from the midline (960 pixels). Images which appeared on the left-hand side of the display monitor were drawn an AOI which corresponded with 480 x 1080 pixels from the right-most portion of the image. Images on the right-hand side were drawn an AOI at 480 x 1080 pixels from the left-most portion of the image. Trials in which toddlers fixated only on the target image or only on the distractor image were omitted from final analyses as fixating on one image does not indicate that the toddler assessed both images in order to achieve correct target identification (Mani & Plunkett, 2010). In addition, trials in which toddlers only fixated on the target and distractor less than 25% of the 2500 ms (625 ms) image presentation were removed since trials less than 625 ms likely reflected looking behavior below chance (De Anda & Friend, in review). Microsoft Excel was used to calculate the difference between the proportion of total looks (PTL = target/target+distractor) in related trials and the proportion of total looks in unrelated trials (the prime effect). RStudio (RStudio Team, 2015) was used to calculate correlations between measures of language proficiency and exposure and the prime effect and all other statistical analyses outlined below.

Results

Vocabulary Size by Language Across Measures

Receptive vocabulary data measured by accuracy on the CCT did not mirror language exposure data and showed relatively balanced skills across Spanish (*M* = 18.60; *SD* = 8.83; *range* = 6 – 33) and English (*M* = 18.20; *SD* = 9.25; *range* = 3 – 35; see Tables 2 and 4). This highlights once again the fact that exposure and proficiency are not always aligned in language development. T-tests confirmed that there was no significant difference between Spanish and English CCT accuracy scores ($t(79) = -.47$, $p = .64$). Conversely, expressive vocabulary data demonstrated Spanish dominance patterns. Parents reported that their toddlers produced a larger number of Spanish words (*M* = 84.40; *SD* = 123.74; *range* = 3 – 505) than English words (*M* = 64.70; *SD* = 111.49; *range* = 0 – 444). Together this shows that expressive vocabulary may be more closely aligned with exposure than receptive skills, consistent with prior research (Thordardottir, 2011). Translation equivalents, or words across languages with the same meaning such as *apple* and *manzana*, (*M* = 36.10; *SD* = 90.70; *range* = 0 – 408) accounted for approximately 12% of total expressive vocabulary (the sum of words produced across both Spanish and English; *M* = 149.20; *SD* = 228.87; *range* = 7 – 949). Toddlers demonstrated a wide range in their total expressive conceptual vocabulary, which counts two different words such as *dog* and *perro* as one concept represented in both languages (*M* = 113.10; *SD* = 148.87; *range* = 6 – 541). As a group, toddlers were relatively balanced in their speed of word recognition in Spanish and English consistent with vocabulary findings. T-tests revealed that toddlers showed slightly faster reaction times in English ($t(79) = -3.35$, $p = .001$; English: *M* = 2.88; *SD* = .71) in contrast to

Spanish (*M* = 3.12; *SD* = .67). Notably, there was a slightly wider range of response times in English (*range* = 2.0 – 4.96) than Spanish (*range* = 2.27 – 4.51; see Table 4).

Lexical-Semantic Processing by Language

We analyzed the lexical-semantic processing data by calculating the proportion of total looks to the primed target image by semantic relatedness and language condition (within-language and cross-language). Visual inspection (Table 5; Figure 2) shows the prime effect (the proportion of total looks to the target in related trials minus the proportion of total looks to the target in unrelated trials) in each of the four conditions: Spanish prime to Spanish target, Spanish prime to English target, English prime to English target, and English prime to Spanish target (see Table 3). Recall that the prime effect is a measure of lexical-semantic processing. Specifically, in the within-Spanish condition, toddlers demonstrated a greater proportion of total looks to the target image during the related trials (*M* = .54; *SD* = .11; *range* = .35 – .88) than unrelated trials (*M* = .47; *SD* = .14; *range* = .17 – .67), but this was not significantly different as measured via t-test ($t(16) = 1.36$, $p = .19$). Likewise, in the cross-language Spanish to English condition, toddlers exhibited similar looking behavior, such that related trials (*M* = .53; *SD* = .12; *range* = .39 - .81) had a greater proportion of looks to the target than unrelated trials (*M* = .51; *SD* = .17; *range* = .15 – .87) but, again, this was not significantly different ($t(14) = -0.19$, $p = .85$). Conversely, in the within-English condition, toddlers had a significantly greater proportion of total looks to the target image when the trials were unrelated (*M* = .61; *SD* = .13; *range* = .38 – .86) versus related trials (*M* = .49; *SD* = .16; *range* = .1 – .71; ($t(13) = -2.51$, $p = .03$). Toddlers' looking behavior in the cross-language English to Spanish condition also revealed a greater proportion of total looks to the target image then the trials were unrelated (*M* = .57; *SD* = .13; *range* = .31 - .78) compared to related trials (*M* = .55; *SD* = .18; *range* = .34 - .93) though this was marginally significant ($t(13) = -2.01$, $p = .07$) .

Vocabulary and Lexical-Semantic Processing

Next, we compared exposure and proficiency to see which variable was the better predictor of the prime effect across language conditions to answer the second research question. We ran correlation tests evaluating the association between each measure in each language condition (Spanish to Spanish, Spanish to English, English to English, and English to Spanish) against the prime effect (Tables 6-9) for all participants. In the within-Spanish condition, the prime effect was positively correlated with speed of word processing (i.e., haptic response time) in Spanish ($r(15) = .54$, $p = .03$), but not with Spanish vocabulary or Spanish or English exposure (Figure 3). In the cross Spanish to English language condition, the prime effect was negatively correlated with Spanish receptive vocabulary ($r(13) = -.57$, $p = .03$) and positively correlated with Spanish speed of word processing ($r(13) = .53$, $p = .04$), but not with Spanish exposure or English vocabulary or exposure (Figures 4 and 5). In the within-English condition, the prime effect was negatively correlated with speed of word processing in English ($r(12) = -.77$, $p = .001$), but not with English vocabulary or English or Spanish exposure (Figure 6). The prime effect was not correlated with any measure of proficiency or exposure in the English to Spanish cross language condition (all *p*s > .23).

Discussion

The aim of the present study was to examine the role of exposure versus proficiency on lexical-semantic processing in 24-month-old Spanish-English bilingual toddlers. We explored two central questions in order to clarify how dual language systems interact with one another and are organized: do lexical-semantic networks (e.g., vocabulary systems) interact across languages, or are they relatively separate in 24-month-old bilingual toddlers? Further, to what extent does exposure and proficiency modulate the organization of lexical-semantic networks? Our overall findings reveal that lexical-semantic networks in 24-month-old dual language learners do interact across languages and are modulated by measures of proficiency, specifically vocabulary size and lexical access. In what follows we elaborate on the contributions and interpretations of these findings.

Evidence of Lexical-Semantic Priming

To answer our first question, we examined toddlers' lexical-semantic priming effects in related and unrelated word conditions within and across languages. We showed that toddlers with a variety of linguistic abilities (e.g., with and without early language delays) demonstrate priming effects. This is consistent with a recent but growing body of literature that shows that bilingual infants and toddlers are forming a semantic system that is shared across their languages. For example, we previously reviewed that Singh (2014) found evidence for asymmetric semantic priming effects in 30-month-old Mandarin-English bilingual toddlers. Only when the prime word was presented in the dominant language did toddlers show a greater proportion of looks toward the target image. Singh (2014) proposed that lexical spaces interact across semantic networks given that these priming effects were observed in both within- and cross-language conditions, and therefore dual language systems form an interconnected system. Consistent with Singh's (2014) findings, we indeed showed that Spanish-English bilingual toddlers demonstrated priming effects across languages. However, toddlers in the present study were more likely to evince priming effects in their weaker language which contradicts Singh's (2014) findings that priming effects were only observed with a dominant language prime.

Although Potter et al. (2018) utilized a different paradigm (Looking-While-Listening task) than Singh (2014) and the present study (Intermodal Preferential Looking Paradigm), they nevertheless showed evidence for cross-language semantic priming in 30-month-old Spanish English bilingual toddlers. As we have reviewed, toddlers had longer looking times when the subsequent target noun was in their weaker language (non-dominant language) than when it was preceded by a sentence frame in their stronger language (dominant language). Interestingly, toddlers performed comparably in trials where the sentence frame was in their weaker language and the target words were either in the weaker or stronger language. What Potter et al. (2018) suggest is that independent of the prime word language condition, toddlers demonstrated better target recognition in their stronger language. Indeed, these results suggest that lexical-semantic connections in the stronger language may inhibit subsequent target word processing, whereas less robust semantic networks in the weaker language may result in faciliatory effects.

Relatedly, De Anda and Friend (in review) demonstrated that 24-month-old Spanish-English bilingual toddlers demonstrated a significant difference in looking time between semantically related and unrelated trials. These toddlers showed a greater proportion of looks in related trials which was consistent across language conditions. In other words, these bilingual toddlers evinced robust priming effects in within and cross-language conditions, again showing evidence for cross-language interaction of lexical-semantic networks. Here we demonstrate that we have replicated findings of within- and cross-language lexical-semantic priming across bilingual populations.

In the present study, toddlers demonstrated the expected lexical-semantic priming behavior in their stronger language (Spanish)—they evinced a larger proportion of looks toward the primed target image in semantically related trials in both within- and cross-Spanish language conditions (see Figure 2). For example, when toddlers were primed with *zapato* (shoe), they subsequently had longer looking times toward the target *calcetines* (socks). These priming effects are consistent with both monolingual and bilingual work which suggests that consecutively processing two words with meanings that are closely related leads to a longer proportion of looks to the target image (Arias-Trejo and Plunkett; 2009, 2013; Singh, 2014; De Anda & Friend, in review). The idea is that spreading activation across the semantic space leads children to look towards the related image for longer than if it were preceded with an unrelated word (Collins & Loftus, 1975). Likewise, toddlers in the present study evinced similar looking behavior in trials where the prime word was in Spanish though this did not reach significance.

However, our findings differ from previous studies because we saw that toddlers in the present study were more likely to evince priming effects in their weaker language (English). As a group, toddlers' exposure to English and their vocabulary size in

English was smaller relative to Spanish. While we found evidence of shared lexical-semantic networks across languages, toddlers showed priming effects only when the prime word was in English. This effect may seem, on the surface, counterintuitive. One possibility for the difference in findings may be due to the language group included in each study. Across prior studies, children's language exposure was much more balanced, and children with less than 20% exposure to a second language were typically excluded. In the present study, toddlers' exposure as a group was around 78% exposure to Spanish. Further, unlike prior studies, we represented the full range of language proficiency by including toddlers with language delays. Another possibility is that these young bilingual children are demonstrating lexical-semantic organization similar to bilingual adults where the second, or weaker, language is semantically mediated by the stronger language (Kroll et al., 1994, 2010). It may be that toddlers in the present study with weaker English exposure and proficiency skills are using their robust semantic networks in Spanish to drive processing in English. For example, a toddler who has weaker exposure and proficiency in English could map onto their semantic space in Spanish in order to facilitate cross-language processing in their English lexicon. As such, it is possible that the processes of lexical-semantic priming are different for toddlers with less balanced exposure and with weaker language proficiency.

Taken together, what these findings suggest is that during semantically related trials in the stronger language, Spanish, children show a facilitative effect in that priming spreads to both Spanish and English consistent with prior research (Singh, 2014). Conversely, in the weaker language (English) an inhibitory process is seen, such that the semantically unrelated words evinced longer looks to the target than the related trials. We believe that this pattern of results may be best explained by differences in proficiency as we will discuss below.

Proficiency vs. Exposure

The second question of interest in the present study asked whether measures of language proficiency or exposure were stronger predictors of lexical-semantic priming effects. Here we showed that lexical-semantic priming effects were more likely to be correlated with measures of proficiency than exposure. In fact, relative language exposure was not associated with priming in within- and cross-language conditions. Instead, reaction time (indexing speed of word recognition) was correlated with the prime effect in the within-language conditions (Spanish prime to Spanish target and English prime to English target), whereas receptive vocabulary size was associated with the prime effect only in the cross Spanish to English condition but not in the reverse cross English to Spanish condition. Together this suggests that the breadth and efficiency of toddlers' vocabulary is generally a better predictor of lexical-semantic organization than exposure as we predicted.

Despite the predicted association between proficiency and the priming effect, we were surprised that the direction of the effect was such that larger priming effects in Spanish prime conditions (Spanish prime to Spanish target and Spanish prime to Spanish target) were correlated with a smaller vocabulary size and slower reaction time. That is, toddlers with smaller vocabularies and slower speeds of word recognition evinced the largest prime effects. Yet, in the within-English condition, larger prime effects were associated with faster reaction times. How can we make sense of these seemingly anomalous findings?

First, no other studies have used direct behavioral measures of vocabulary (i.e., CCT) in determining the association between proficiency and priming effects. Previous studies have relied on parent report (such as the ESVI) and have not found effects, likely due to the differences inherent in the tasks (parent report and behavioral measures) being compared in the present study (e.g., Floccia et al., 2020). Nevertheless, the negative association observed in the stronger language (Spanish) is, on the surface, surprising. For example, we predicted that toddlers with larger vocabularies would be much more sensitive to the semantic relations between words. However, it is possible that toddlers with large vocabularies are more likely to have stronger semantic competition between related words. For example, Chen and Mirman (2012) propose that near semantic neighbors exert a net inhibitory effect, whereas distant semantic neighbors exert a net facilitative effect. In other words, it might be more efficient to suppress processing of semantic competitors to ultimately achieve correct word identification. Toddlers with larger vocabulary sizes are more likely to have dense networks with more semantic competitors, and it is in their interest to quickly discard these semantic competitors. This, in turn, would lead to smaller priming effects for those toddlers with larger vocabulary sizes. In fact, these were the same toddlers that showed the fastest speed of word recognition, such that the smallest priming effects were shown in toddlers with the fastest speed of processing. Again, it is possible that toddlers with large vocabularies are capable of quickly matching words to their referents and discarding unrelated words (i.e., inhibiting competitors). Conversely, toddlers with sparse lexicons may benefit from hearing a semantically related word since they are less likely to have semantic competitors. In this way, they are less likely to exert inhibition. A possibility is that having faster speed of word recognition (which corresponds with vocabulary size) may yield greater inhibition, or interference (Mirman & Magnuson, 2008). It has been demonstrated that monolingual toddlers show evidence for semantic inhibition in priming tasks. Chow, Aimola Davies, Fuentes, and Plunkett (2019) and Borovsky and Peters (2019) showed that 18-month-old monolingual infants with larger vocabulary sizes are more likely to have numerous overlapping semantic networks, whereas toddlers with smaller vocabularies will possess fewer semantic links between words in their lexicon.

We extend these findings to the present study given that 24-month-olds have more robust lexical-semantic networks, and bilingual toddlers have dual language systems that are competing. Semantic inhibition may be more efficient for these bilingual toddlers with larger vocabularies in their stronger language given that they have multiple competing networks within *and* across both language systems. Similarly, Borovsky and Peters (2019) posit that lexical connectivity interferes with word recognition in 18-month-old monolingual toddlers with relatively large vocabularies. We believe that these findings extend to the current group of bilingual toddlers who also show an inhibition effect in their strongest language.

Turning to the weaker language (English) toddlers showed an association in the opposite direction compared to Spanish between the prime effect and speed of word recognition. When processing words in English only, toddlers with the fastest speed of word recognition in English were also more likely to have the largest priming effects in English. In this case, vocabulary size was not a predictor. Taken together, this suggests that when processing semantic information in the weaker language (English), young children make use of their speed of word recognition to leverage their sparse vocabulary knowledge (Fernald, et al., 2006). It is possible that these toddlers are engaging in semantic facilitation in their weaker language because they have sparse semantic networks and therefore must access all available lexical information of distant words and concepts.

Collectively, our findings suggest that these bilingual toddlers are engaging in inhibition and facilitation effects depending on the nature of their lexical knowledge in Spanish and English. Further, in the English-to-Spanish cross-language condition, no measure of proficiency (i.e., vocabulary size or speed of word recognition) was correlated with priming effects. These findings align with recent work by Floccia et al. (2020) who suggest that language dominance as measured by exposure and parent report of expressive vocabulary does not influence cross-language semantic priming in 27-month-old bilingual toddlers. While the present study differs in terms of language group and participant age, our findings in conjunction with Potter et al. (2018) and Floccia et al. (2020) seem to suggest that when the prime word is in the dominant language, it does not support processing of the subsequent cross-language word that is weakly represented in their lexicon. Given that English was the weaker language for the majority of the bilingual toddlers in the present study, our findings support the notion that sparse semantic networks and small lexicons in the non-dominant does not support cross-language processing. Overall, we have provided evidence that 24-month-old dual language learning toddlers exhibit cross-language lexical-semantic processing that is modulated by vocabulary size.

Limitations and Future Directions

Although the present study is one of the first to clarify how measures of exposure and proficiency modulate lexical-semantic processing in bilingual toddlers, this study contains a few limitations that are to be addressed. These limitations include the small sample size, the wide variability of language exposure, and a lack of English dominant participants.

First, the present study included a small sample size of 20 participants of Spanish-English dual language learning toddlers. Although our sample size achieved adequate power based on prior work (De Anda & Friend, in review), the inclusion of children with language delay necessitates a larger sample so that this group effect can be examined. Including these toddlers is important because they allow us to look at proficiency skills across the full range of language proficiency. However, it has been shown that children with language delay have more sparse semantic networks, which could potentially inflate our conflicting findings that semantic inhibition and facilitation occur within the same language condition (Beckage, Hills, & Smith, 2010). Thus, future work should seek to include a large sample size of both typically developing bilingual toddlers and bilingual toddlers with language delay in order to individually examine their lexical-semantic processing within and across languages. Additionally, while this particular Spanish-English language group is a growing population in the U.S., we must not assume that these findings can be generalized across all Spanish-English bilingual toddlers. Furthermore, our findings of cross-language interaction should not be generalized across different language groups (e.g., French-English).

Second, toddlers with more than 80% exposure to their dominant language, and thus less than 20% exposure to their non-dominant language, were included in the present study in order to examine exposure across a wide range. These criteria differ from prior studies who have defined bilingual individuals as falling within the 20-80% range (Bedore et al., 2012). However, toddlers with exposure percentages greater than 80% and less than 20% were included in the present study because they still had regular exposure (i.e., at least once a week) to their second language as reported by their parent. Relatedly, as a group, the toddlers included in the present study were Spanish dominant. Therefore, results from the lexical-semantic priming task are likely skewed toward exhibiting more robust lexical-semantic priming effects in Spanish. Therefore, future research should attempt to include a relatively equal balance of Spanish dominant and English dominant participants in order to provide a more comprehensive overview of how language dominance patterns modulate lexical-semantic processing in both languages.

Conclusion

The present study investigated whether Spanish-English bilingual toddlers exhibit cross-language priming effects, whether exposure or proficiency was a stronger predictor of lexical-semantic processing, and how this measure influenced within- and cross-language processing. Results reveal that bilingual toddlers do evince cross-language priming effects, which provides evidence that dual language systems interact with one another. Overall, we show that language dominance does indeed modulate lexical-semantic processing, in that effects in the strongest language (Spanish) differed in comparison the weaker language (English). Here, we propose that children's vocabulary influences their ability to organize and connect meaning to words within and across languages in both inhibitory and faciliatory processes. Importantly, the current study is one of the first to use a behavioral assessment of vocabulary given that prior parent-report tools have been inconclusive.

Our findings seek to inform clinicians such as Speech-Language Pathologists on using assessments that account for both languages, since we have shown that bilingual individuals have dual language systems which interact. Our study presents a novel bilingual assessment tool, the ESVI, which is designed to capture the unique dual language experience of bilingual toddlers. Specifically, the ESVI can be used to determine children's overall expressive vocabulary size in both languages. Emergent expressive vocabulary has been linked to later language and literacy skills. Thus, it is important for clinicians to assess both languages using a tool such as the ESVI in order to best support dual language learners as they acquire both of their languages (e.g., Lee, 2011; Hoff et al., 2014). Because recent findings suggest that one's stronger language supports processing of their weaker language, and bilingual children may have different linguistic strengths (e.g., vocabulary size, syntax, pragmatics) in each language, it is necessary to address both languages in assessment and treatment. Additionally, it is crucial that clinicians support families who speak a minority language (e.g., Spanish in the context of the U.S.) in order to preserve the home language as this has been shown to promote early dual language development (Hoff & Core, 2015). Ultimately, our findings contribute to the current understanding of bilingual first language acquisition and emerging bilingual theoretical models which aim to explain the young bilingual mind.

Figures

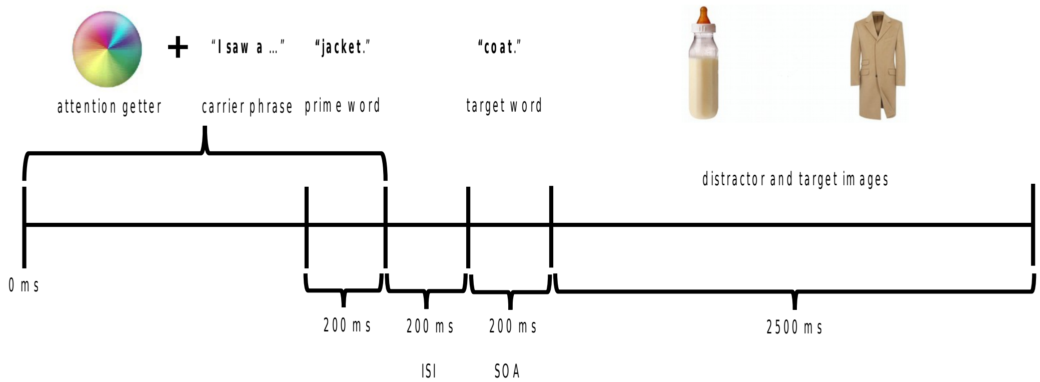

Figure 1. Example trial sequence of a within-English block.

Note. ISI: interstimulus interval; SOA: stimulus onset asynchrony

The ISI is the time between the offset of the prime word and the onset of the target word. The SOA is the time between the onset of the target word and the onset of the target and distractor image pairs.

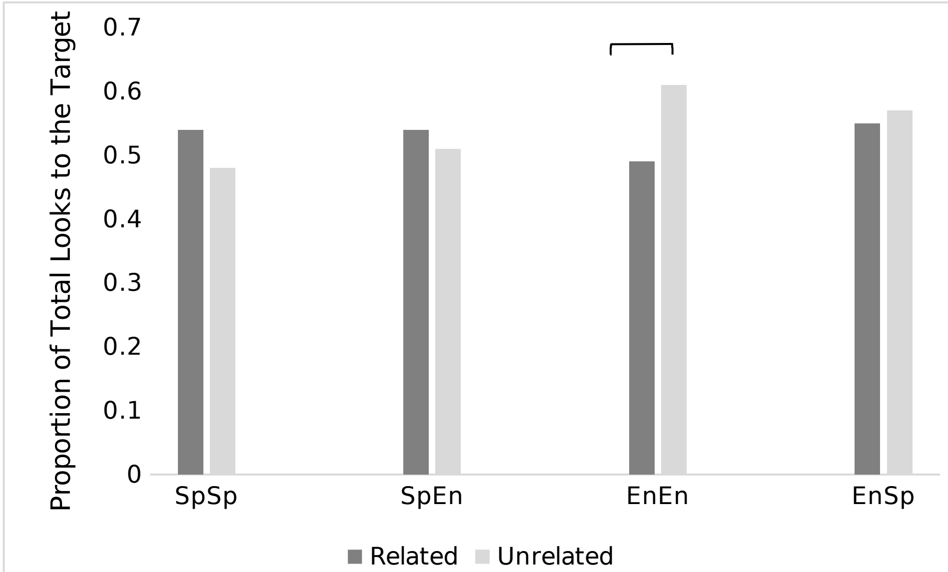

Figure 2. Proportion of total looks to the target by language condition and trial relatedness.

Notes. Error bars represent the standard error of the mean. SpSp: Spanish prime to Spanish target; SpEn: Spanish prime to English target; EnEn: English prime to English target; and EnSp: English prime to Spanish target.

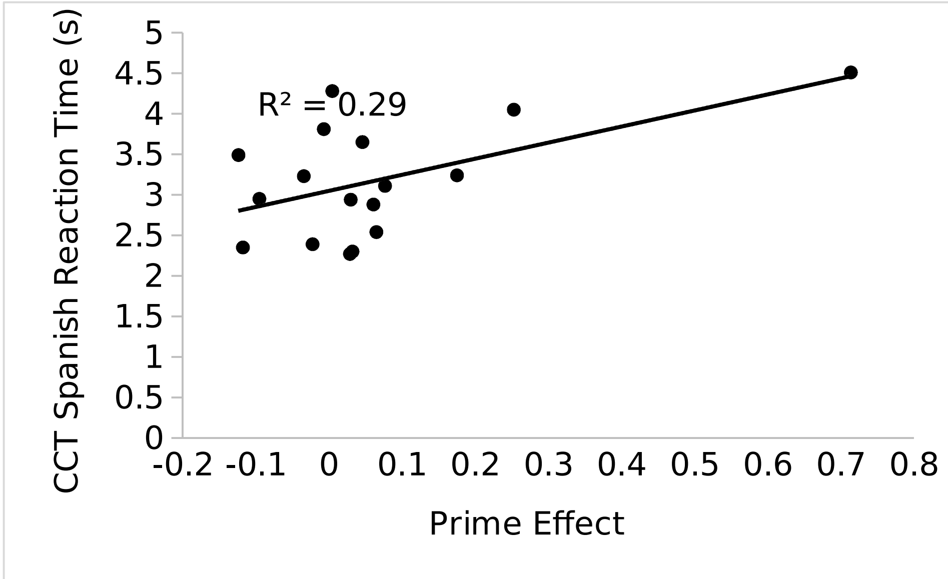

Figure 3. Correlations between prime effect and CCT Spanish reaction time in within-Spanish condition.

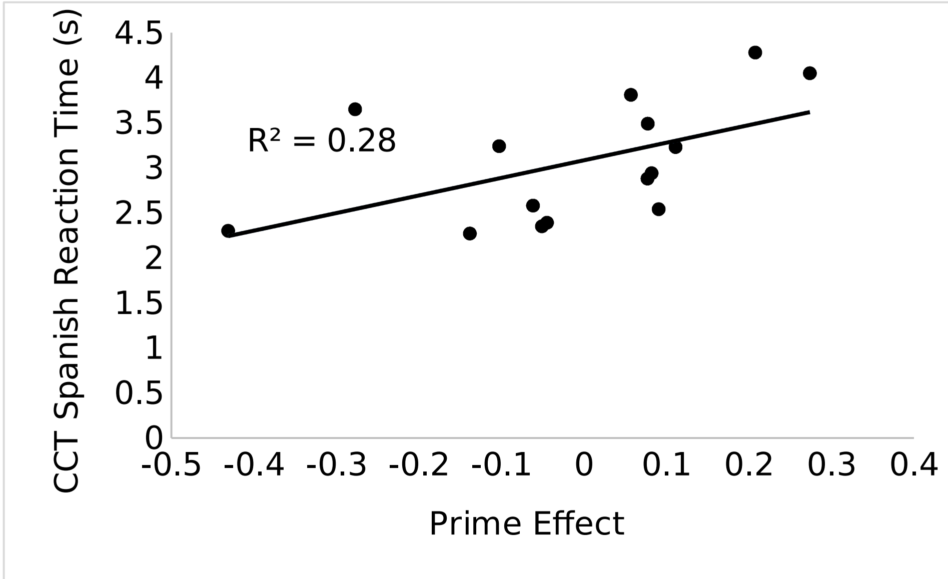

Figure 4. Correlations between prime effect and CCT Spanish reaction time in cross-Spanish to English condition.

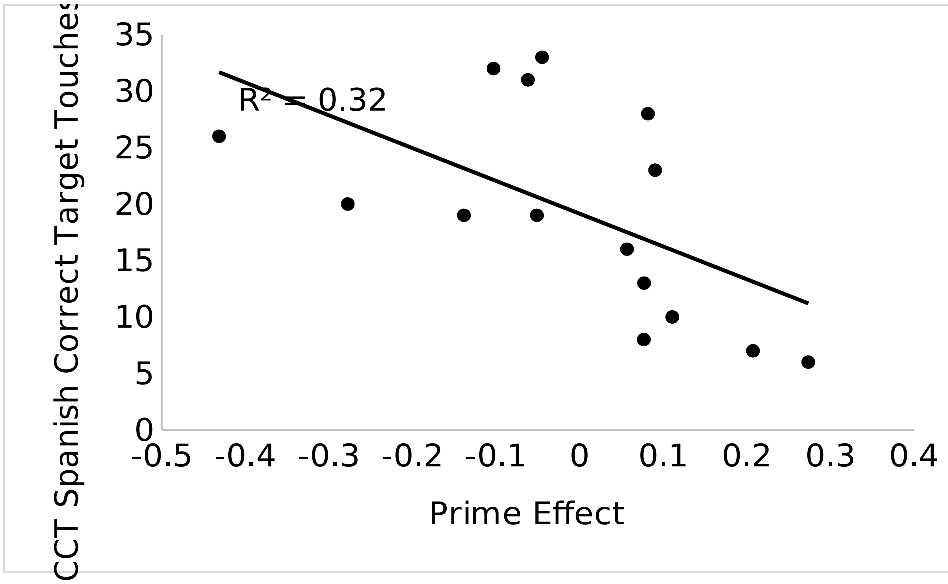

Figure 5. Correlations between prime effect and CCT Spanish correct target touches in cross-Spanish to English condition.

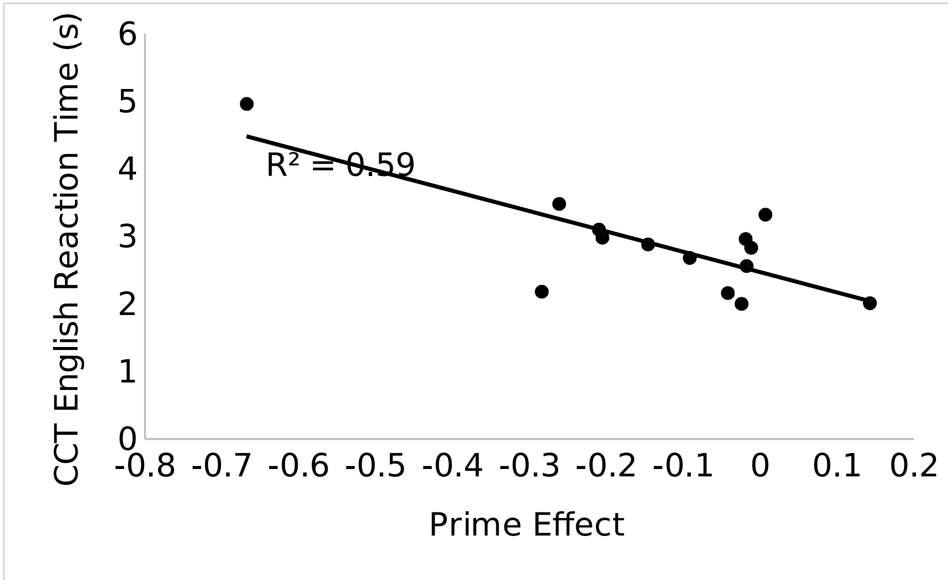

Figure 6. Correlations between prime effect and CCT English reaction time in within-English condition.

Tables

Table 1. Demographic Information for Dual Language Learning Toddlers.

Characteristic	Age: *M* = 24.65; *SD* = 1.5; *Range* = 22 – 26 N = 20
	Number (Proportion) of Participants
Sex	
Female	8 (.4)
Male	12 (.6)
Approximate Parental Income	
$10,000 or less	1 (.05)
$10,001 - $20,000	4 (.2)
$20,001 - $30,000	2 (.1)
$30,001 - $40,000	3 (.15)
$40,001 - $50,000	1 (.05)
$50,001 - $60,000	4 (.2)
$60,001 - $70,000	0 (0)
$70,001 - $80,000	3 (.15)
More than $80,001	0 (0)
Unknown	2 (.1)
Maternal Ethnicity	
Latina	20 (1)
White/not Latina	0 (0)
Maternal Nationality	
Mexican, Mexican American, Chicana	16 (.8)
Salvadoran	1 (.05)
Nicaraguan	1 (.05)
Argentinean	1 (.05)
Chilean	1 (.05)
Dominant Language of Exposure	
Spanish	18 (.9)
English	2 (.1)

Note. The dominant language of exposure refers to cumulative language input as measured by the LEAT (Language Exposure Assessment Tool; De Anda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016).

Table 2. Language Exposure Characteristics Determined by the LEAT.

n = 19	*M* (*SD*)	*Range*
Language Exposure		
Spanish	.78 (.23)	.21 – 1
English	.22 (.23)	0 – .79
Other	.002 (.01)	0 – .02
Number of Languages	2.11 (.46)	1 – 3
Number of Speakers	5.0 (1.7)	3 – 10
Dominant Language of Exposure	.84 (.16)	.53 – 1
Spanish (*n* = 17)	.71 (.11)	.63 – .79
English (*n* = 2)		

Note. The dominant language of exposure refers to cumulative language input as measured by the LEAT (Language Exposure Assessment Tool; De Anda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016).

Table 3. Example of Prime-Target Pairings for Spanish Dominant Trial Sequence.

Condition	Prime Word	Target Word and Image	Distractor Image	Trial Type
Sp-Sp	mesa (table)	silla (chair)	cookie	related
	zapato (shoe)	calcetines (socks)	phone	related
	vaso (cup)	gato (cat)	brush	unrelated
	jugo (juice)	naranja (orange)	clock	related
	zapato (shoe)	comida (food)	hands	unrelated
	baño (bathroom)	plato (plate)	teddy bear	unrelated
	jabón (soap)	tina (bathtub)	broom	related
	sol (sun)	luna (moon)	carrots	related
	casa (house)	cara (face)	noodles	unrelated
Sp-En	plátano (banana)	apple	feet	related
	pantalón (pants)	shirt	money	related
	árbol (tree)	fork	couch	unrelated
	pan (bread)	cheese	toothbrush	related
	dedo (finger)	towel	button	unrelated
	globo (balloon)	door	cracker	unrelated
	juguete (toy)	doll	bubbles	related
	casa (house)	store	pen	related
	pájaro (bird)	flower	window	unrelated
En-En	jacket	coat	bottle	related
	cereal	toast	frog	related
	spoon	leg	rock	unrelated
	cow	horse	television	related
	cereal	monkey	paper	unrelated
	key	bunny	swing	unrelated
	truck	bicycle	picture	related
	kitchen	tummy	highchair	related
	pillow	toe	bowl	unrelated
En-Sp	hat	suéter (sweater)	trash	related
	pillow	cama (bed)	diaper	related
	arm	pollo (chicken)	box	unrelated
	blanket	cuna (crib)	bag	related
	pants	carro (car)	milk	unrelated
	pig	avión (airplane)	sink	unrelated
	pajamas	cuarto (bedroom)	bib	related
	rain	cielo (sky)	medicine	related
	duck	pelota (ball)	stroller	unrelated

Measure	*M* (*SD*)	*Range*
CCT Correct Target Touches		
Spanish	18.60 (8.83)	6 – 33
English	18.20 (9.25)	3 – 35
CCT Speed of Word Processing (Haptic Response Time of Target Touch)		
Spanish	3.12 (.67)	2.27 – 4.51
English	2.88 (.71)	2.00 – 4.96
ESVI Expressive Vocabulary Size		
Spanish	84.50 (123.74)	3 – 505
English	64.70 (111.49)	0 – 444
ESVI TE's	36.10 (90.70)	0 – 408
Total Expressive Vocabulary Size	149.20 (228.87)	7 – 949
Total Expressive Conceptual Vocabulary Size	113.10 (148.87)	6 – 541

Table 4. Vocabulary Size by Language Across Measures.

Notes. CCT: Computerized Comprehension Task (Friend & Keplinger, 2003, 2008); ESVI: English Spanish Vocabulary Inventories (De Anda, Cycyk, Moore & Huerta, in prep.); TE's: translation equivalents; Total expressive conceptual vocabulary size was calculated by subtracting translation equivalents from total expressive vocabulary size.

Table 5. Lexical-Semantic Processing by Language.

Measure	*M* (*SD*)	*Range*
Prime Effect		
Spanish to Spanish		
Related	.54 (.11)	.35 – .88
Unrelated	.47 (.14)	.17 – .67
Spanish to English		
Related	.53 (.12)	.39 – .81
Unrelated	.51 (.17)	.15 – .87
English to English		
Related	.49 (.16)	.10 – .71
Unrelated	.61 (.13)	.38 – .86
English to Spanish		
Related	.55 (.18)	.34 – .93
Unrelated	.57 (.13)	.31 – .78

Note. Prime effect is the proportion of total looks to the target in related trials minus the proportion of total looks to the target in unrelated trials.

Table 6. Correlations for Within-Spanish Language Condition.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Prime Effect											
2. CCT Spanish Correct Target Touches	-.31 [-.69, .20]										
3. CCT Spanish RT	.54* [.08, .81]	-.61** [-.83, -.24]									
4. ESVI Spanish	-.16 [-.59, .35]	.33 [-.13, .68]	-.26 [-.63, .21]								
5. Spanish Exposure	.30 [-.23, .69]	-.10 [-.53, .38]	.25 [-.23, .63]	.19 [-.29, .59]							
6. CCT English Correct Target Touches	-.33 [-.70, .18]	.64** [.27, .84]	-.45* [-.74, -.01]	.17 [-.30, .57]	-.52* [-.79, -.09]						
7. CCT English RT	-.18 [-.61, .33]	-.18 [-.58, .28]	.52* [.10, .78]	-.06 [-.49, .39]	-.15 [-.57, .33]	-.07 [-.50, .39]					
8. ESVI English	-.13 [-.57, .38]	.34 [-.12, .68]	-.29 [-.65, .18]	.89** [.74, .96]	-.10 [-.53, .37]	.41 [-.04, .72]	.03 [-.42, .47]				
9. English Exposure	-.29 [-.69, .24]	.09 [-.38, .52]	-.25 [-.63, .23]	-.18 [-.59, .30]	-1.00** [-1.00, -1.00]	.52* [.09, .79]	.15 [-.33, .56]	.11 [-.36, .54]			
10. ESVI TE's	-.13 [-.57, .38]	.36 [-.09, .69]	-.26 [-.63, .20]	.88** [.73, .95]	.13 [-.34, .55]	.31 [-.15, .66]	-.00 [-.44, .44]	.92** [.80, .97]	-.12 [-.55, .35]		
11. ESVI Total Expressive Vocabulary Size	-.15 [-.59, .36]	.35 [-.11, .68]	-.28 [-.64, .18]	.98** [.94, .99]	.05 [-.41, .50]	.29 [-.17, .65]	-.02 [-.46, .43]	.97** [.92, .99]	-.04 [-.49, .42]	.93** [.82, .97]	
12. ESVI TCV	-.15 [-.59, .36]	.31 [-.15, .66]	-.27 [-.64, .19]	.96** [.90, .98]	.00 [-.45, .46]	.26 [-.21, .63]	-.03 [-.46, .42]	.93** [.83, .97]	.01 [-.45, .46]	.81** [.58, .92]	.97** [.93, .99]

Notes. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

CCT: Computerized Comprehension Task (Friend & Keplinger, 2003, 2008); ESVI: English Spanish Vocabulary Inventories (De Anda, Cycyk, Moore & Huerta, in prep.); RT: reaction time; TE's: translation equivalents; TCV: total conceptual vocabulary

Table 7. Correlations for Within-English Language Condition.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Prime Effect											
2. CCT Spanish Correct Target Touches	.07 [-.48, .58]										
3. CCT Spanish RT	-.31 [-.72, .26]	-.61** [-.83, -.24]									
4. ESVI Spanish	.31 [-.27, .72]	.33 [-.13, .68]	-.26 [-.63, .21]								
5. Spanish Exposure	.22 [-.38, .69]	-.10 [-.53, .38]	.25 [-.23, .63]	.19 [-.29, .59]							
6. CCT English Correct Target Touches	.05 [-.49, .57]	.64** [.27, .84]	-.45* [-.74, -.01]	.17 [-.30, .57]	-.52* [-.79, -.09]						
7. CCT English RT	-.77** [-.92, -.40]	-.18 [-.58, .28]	.52* [.10, .78]	-.06 [-.49, .39]	-.15 [-.57, .33]	-.07 [-.50, .39]					
8. ESVI English	.25 [-.32, .69]	.34 [-.12, .68]	-.29 [-.65, .18]	.89** [.74, .96]	-.10 [-.53, .37]	.41 [-.04, .72]	.03 [-.42, .47]				
9. English Exposure	-.22 [-.69, .38]	.09 [-.38, .52]	-.25 [-.63, .23]	-.18 [-.59, .30]	-1.00** [-1.00, -1.00]	.52* [.09, .79]	.15 [-.33, .56]	.11 [-.36, .54]			
10. ESVI TE’s	.23 [-.35, .68]	.36 [-.09, .69]	-.26 [-.63, .20]	.88** [.73, .95]	.13 [-.34, .55]	.31 [-.15, .66]	-.00 [-.44, .44]	.92** [.80, .97]	-.12 [-.55, .35]		
11. ESVI Total Expressive Vocabulary Size	.28 [-.29, .71]	.35 [-.11, .68]	-.28 [-.64, .18]	.98** [.94, .99]	.05 [-.41, .50]	.29 [-.17, .65]	-.02 [-.46, .43]	.97** [.92, .99]	-.04 [-.49, .42]	.93** [.82, .97]	
12. ESVI TCV	.30 [-.27, .72]	.31 [-.15, .66]	-.27 [-.64, .19]	.96** [.90, .98]	.00 [-.45, .46]	.26 [-.21, .63]	-.03 [-.46, .42]	.93** [.83, .97]	.01 [-.45, .46]	.81** [.58, .92]	.97** [.93, .99]

Notes. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

CCT: Computerized Comprehension Task (Friend & Keplinger, 2003, 2008); ESVI: English Spanish Vocabulary Inventories (De Anda, Cycyk, Moore & Huerta, in prep.); RT: reaction time; TE’s: translation equivalents; TCV: total conceptual vocabulary

Table 8. Correlations for Cross Spanish to English Language Condition.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Prime Effect											
2. CCT Spanish Correct Target Touches	-.57* [-.84, -.08]										
3. CCT Spanish RT	.53* [.02, .82]	-.61** [-.83, -.24]									
4. ESVI Spanish	.17 [-.37, .63]	.33 [-.13, .68]	-.26 [-.63, .21]								
5. Spanish Exposure	.21 [-.36, .67]	-.10 [-.53, .38]	.25 [-.23, .63]	.19 [-.29, .59]							
6. CCT English Correct Target Touches	-.41 [-.76, .12]	.64** [.27, .84]	-.45* [-.74, -.01]	.17 [-.30, .57]	-.52* [-.79, -.09]						
7. CCT English RT	.39 [-.16, .75]	-.18 [-.58, .28]	.52* [.10, .78]	-.06 [-.49, .39]	-.15 [-.57, .33]	-.07 [-.50, .39]					
8. ESVI English	.14 [-.40, .61]	.34 [-.12, .68]	-.29 [-.65, .18]	.89** [.74, .96]	-.10 [-.53, .37]	.41 [-.04, .72]	.03 [-.42, .47]				
9. English Exposure	-.22 [-.67, .35]	.09 [-.38, .52]	-.25 [-.63, .23]	-.18 [-.59, .30]	-1.00** [-1.00, -1.00]	.52* [.09, .79]	.15 [-.33, .56]	.11 [-.36, .54]			
10. ESVI TE’s	.04 [-.48, .54]	.36 [-.09, .69]	-.26 [-.63, .20]	.88** [.73, .95]	.13 [-.34, .55]	.31 [-.15, .66]	-.00 [-.44, .44]	.92** [.80, .97]	-.12 [-.55, .35]		
11. ESVI Total Expressive Vocabulary Size	.16 [-.38, .62]	.35 [-.11, .68]	-.28 [-.64, .18]	.98** [.94, .99]	.05 [-.41, .50]	.29 [-.17, .65]	-.02 [-.46, .43]	.97** [.92, .99]	-.04 [-.49, .42]	.93** [.82, .97]	
12. ESVI TCV	.22 [-.33, .66]	.31 [-.15, .66]	-.27 [-.64, .19]	.96** [.90, .98]	.00 [-.45, .46]	.26 [-.21, .63]	-.03 [-.46, .42]	.93** [.83, .97]	.01 [-.45, .46]	.81** [.58, .92]	.97** [.93, .99]

Notes. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

CCT: Computerized Comprehension Task (Friend & Keplinger, 2003, 2008); ESVI: English Spanish Vocabulary Inventories (De Anda, Cycyk, Moore & Huerta, in prep.); RT: reaction time; TE’s: translation equivalents; TCV: total conceptual vocabulary

Table 9. Correlations for Cross English to Spanish Language Condition.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Prime Effect											
2. CCT Spanish Correct Target Touches	.20 [-.37, .66]										
3. CCT Spanish RT	.02 [-.52, .54]	-.61** [-.83, -.24]									
4. ESVI Spanish	.01 [-.52, .54]	.33 [-.13, .68]	-.26 [-.63, .21]								
5. Spanish Exposure	-.27 [-.72, .33]	-.10 [-.53, .38]	.25 [-.23, .63]	.19 [-.29, .59]							
6. CCT English Correct Target Touches	.11 [-.45, .60]	.64** [.27, .84]	-.45* [-.74, -.01]	.17 [-.30, .57]	-.52* [-.79, -.09]						
7. CCT English RT	.34 [-.23, .74]	-.18 [-.58, .28]	.52* [.10, .78]	-.06 [-.49, .39]	-.15 [-.57, .33]	-.07 [-.50, .39]					
8. ESVI English	.11 [-.45, .61]	.34 [-.12, .68]	-.29 [-.65, .18]	.89** [.74, .96]	-.10 [-.53, .37]	.41 [-.04, .72]	.03 [-.42, .47]				
9. English Exposure	.27 [-.33, .71]	.09 [-.38, .52]	-.25 [-.63, .23]	-.18 [-.59, .30]	-1.00** [-1.00, -1.00]	.52* [.09, .79]	.15 [-.33, .56]	.11 [-.36, .54]			
10. ESVI TE’s	.17 [-.40, .64]	.36 [-.09, .69]	-.26 [-.63, .20]	.88** [.73, .95]	.13 [-.34, .55]	.31 [-.15, .66]	-.00 [-.44, .44]	.92** [.80, .97]	-.12 [-.55, .35]		
11. ESVI Total Expressive Vocabulary Size	.06 [-.49, .57]	.35 [-.11, .68]	-.28 [-.64, .18]	.98** [.94, .99]	.05 [-.41, .50]	.29 [-.17, .65]	-.02 [-.46, .43]	.97** [.92, .99]	-.04 [-.49, .42]	.93** [.82, .97]	
12. ESVI TCV	-.01 [-.54, .52]	.31 [-.15, .66]	-.27 [-.64, .19]	.96** [.90, .98]	.00 [-.45, .46]	.26 [-.21, .63]	-.03 [-.46, .42]	.93** [.83, .97]	.01 [-.45, .46]	.81** [.58, .92]	.97** [.93, .99]

Notes. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

CCT: Computerized Comprehension Task (Friend & Keplinger, 2003, 2008); ESVI: English Spanish Vocabulary Inventories (De Anda, Cycyk, Moore & Huerta, in prep.); RT: reaction time; TE’s: translation equivalents; TCV: total conceptual vocabulary

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