Title
Lexical-Semantic Development in Monolingual and Bilingual Children

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Publication Date
2017

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

SAN DIEGO STATE UNIVERSITY

Lexical-Semantic Development in Monolingual and Bilingual Children

A dissertation submitted in partial satisfaction of the requirements for the degree
Doctor of Philosophy

in

Language and Communicative Disorders

by

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2017

The Dissertation of Stephanie De Anda is approved and is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

San Diego State University

2017

DEDICATION

Para mis padres que con su apoyo pude lograrlo todo.

EPIGRAPH

Bonita la gente que es diferente.

Jarabe de Palo

The conventional wisdom of the Tower of Babel story is that the collapse was a misfortune. That it was the distraction, or the weight of many languages that precipitated the tower's failed architecture. That one monolithic language would have expedited the building and heaven would have been reached. Whose heaven, she wonders? And what kind? Perhaps the achievement of Paradise was premature, a little hasty if no one could take the time to understand other languages, other views, other narratives period. Had they, the heaven they imagined might have been found at their feet. Complicated, demanding, yes, but a view of heaven as life; not heaven as post-life.

Toni Morrison

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would first like to thank my family for the sacrifices they made to ensure that I had an opportunity to pursue doctoral study. Mami and Papi thank you for setting aside your dreams to allow me to achieve mine. Arantxa and Manny, thank you for reminding me that laughter truly is the best medicine, especially when the ailment is grad school!

Thank you to my incredible mentors: To Dr. Margaret Friend, my advisor, for providing a learning environment where I was able to discover my own independent thoughts and ideas and, most importantly, to allow me to test them! To my committee members, Drs. Sarah Creel, Vic Ferreira, Rachel Mayberry, and Henrike Blumenfeld for their insightful comments and guidance throughout my candidacy. To Drs. Diane Poulin-Dubois and Pascal Zesiger, for the opportunity to collaborate on a project that contributed immensely to my training. To Drs. Natalia Arias-Trejo, Barbara Conboy, and Gabriela Simon-Cereijido, for guiding a young Latina scholar in the world of academia. To Drs. Sonja Pruitt-Lord and Alyson Abel for invaluable career guidance and for reminding me how science can serve others.

I would also like to acknowledge current and former doctoral students: To Erin Smolak for making our office a supportive space where we can talk about science, politics, and dogs. To Dr. Kristi Hendrickson for providing unending support and friendship. To the incredible research assistants of the Infant and Child Development Lab, especially Kelly Kortright, Lauren Thayer, and Hanna Moon who made this dissertation possible.

I would also like to thank the National Institutes of Health for funding all of the studies presented in this dissertation. Thanks to the hundreds of families who participated in the studies that I helped carry out over the last several years. We are grateful for your many contributions and for the opportunity to see your children grow! Lastly, thanks to Chris for believing in me every step of the way, even when my goals seemed forever out of reach.

Chapter 2, in full, is a reprint of material as it appears in DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). Lexical Processing and Organization in Bilingual First Language Acquisition: Guiding Future Research. *Psychological Bulletin,* 142(6), 655-667. The dissertation author was the primary investigator and author of this paper.

Chapter 3, in full, is a reprint of material as it appears in DeAnda, S., Bosch, L., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). The Language Exposure Assessment Tool: Quantifying exposure for bilingual research in young infants and children. *Journal of Speech Language and Hearing Research* [Advance online publication], 1-11.

Chapter 4, in full, is a reprint of material as it appears in DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (in press). Lexical Access in the Second Year: a Study of Monolingual and Bilingual Vocabulary Development. *Bilingualism: Language and Cognition.* The dissertation author was the primary investigator and author of this paper.

Chapter 5, in full, is being prepared for submission for publication of the material. DeAnda, S., & Friend, M. (in preparation). A cross-linguistic investigation of

word knowledge and lexical-semantic development in toddlers. The dissertation author was the primary investigator and primary author of this paper.

Chapter 6, in full, is being prepared for submission for publication of the material. DeAnda, S., & Friend, M. (in preparation). Lexical-semantic processing in bilingual toddlers. The dissertation author was the primary investigator and primary author of this paper.

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NIH Diversity Supplement, 2012-2014, NICHD HD068458-02W1.
This diversity supplement supports 2 years of doctoral training and research under the R01 awarded to Dr. Margaret Friend. Role: Pre-doctoral Trainee **$81,960**

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Friend, M., **DeAnda, S.,** Arias-Trejo, N., Poulin-Dubois, D., & Zesiger, P., (in press). Changes in SES and Minimal L2 Exposure effects on vocabulary growth across the second year. *Journal of Experimental Child Psychology.*

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (in press). Lexical Access in the Second Year: a Study of Monolingual and Bilingual Vocabulary Development. *Bilingualism: Language and Cognition.*

DeAnda, S., Bosch, L., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). The Language Exposure Assessment Tool: Quantifying exposure for bilingual research in young infants and children. *Journal of Speech Language and Hearing Research* [Advance online publication], 1-11.

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DeAnda, S., Arias-Trejo, N., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). SES, Minimal L2 Exposure, and Early Word Comprehension: New Evidence from a Direct Assessment. *Bilingualism: Language and Cognition,* 19(1), 162-180.

Working Papers

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). Lexical Access in Monolingual and Bilingual Vocabulary Development. *Proceedings of the 41st Boston University Conference on Language Development.*

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Scholarly Awards

Society for Language Development, Student Award, 2016, $150
Boston University Conference on Language Development, Student Travel Fund, 2016, $350
San Diego State University Center for Cognitive Neuroscience, Travel Fund, 2016, $750
International Congress for the Study of Child Language, Travel Fund, 2015: $1600; 2017: $1200
International Congress for Infant Studies, Travel Funds, 2014, $1000
Speech Language and Hearing Sciences Graduate Student Travel Fund, 2012, $300

Invited Addresses

DeAnda, S. & Friend, M. (May 2017). "How Two Languages Interact in Early Bilingual Language Acquisition." Invited address given at the Annual Speech-Language Awareness and Information Day, SDSU, San Diego, CA.

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (September 2016). "Early Language Interaction in Bilingual Toddlers." Invited address given at the Collaborative Conference on Language, Literature & Linguistics, Barcelona, Spain.

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (September 2016). Exploring Cross-Language Links in Young Bilinguals." Invited address given at the Department of Basic Psychology, University of Barcelona, Barcelona, Spain.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (Aril 2016). "Separating Fact and Fiction about Bilingualism in Young Children." Invited address given at the San Diego Women, Infants, & Children (WIC) program, San Diego, CA.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (December 2013). "Dual Language Acquisition: The effect of minimal exposure, maternal input, and SES on emerging language." Invited address given at the Developmental Science Forum, SDSU, San Diego, CA.

DeAnda, S. & Friend, M. (October 2012). "Language Exposure, Maternal Education, and Vocabulary Comprehension in Young Children." Invited address given at the Laboratorio de Psicolinguistica, UNAM, Mexico.

Oral Presentations

DeAnda, S., Enriquez, B.*, Zesiger, P., Poulin-Dubois, & Friend, M. (July 2017). "Code- Switching in Young Spanish-English Bilingual Toddlers and Their Parents." In M. Friend (Chair), Expressive Language in Dual Language Learners. Paper accepted at the International Association for the Study of Child Language, Lyon, France.

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (January 2017). "Cross-Language links in Young Bilinguals." Paper presented at the Conference on Bilinguals in the Hispanic and Lusophone world, Tallahassee, FA.

Friend, M., **DeAnda, S.,** Poulin-Dubois, D., & Zesiger, P. (May 2015). "Vocabulary Growth, in Spanish and English Monolingual and Dual Language Toddlers." Paper presented at the International Symposium on Bilingualism, Rutgers University, NJ.

DeAnda, S., Friend, M., Arias-Trejo, N., Poulin-Dubois, D., & Zesiger, P. (July 2014). "The Influence of Environmental Variables on Early Vocabulary: Evidence from English and Spanish." In M. Friend (Chair), The Emerging Lexical-Semantic System: Findings from a Cross-Language, Direct Assessment of Word Comprehension**.** Paper presented at the International Association for the Study of Child Language, Amsterdam, NL.

DeAnda, S. (March 2013). "Variability in Early Language: Assessing Effects of Socioeconomic Status and Language Exposure." Paper presented at the SDSU Student Research Symposium, San Diego, CA.

Poster Presentations

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (April 2017). "Word Knowledge and Lexical Processing in Bilingual Toddlers." Poster accepted at the Society for Research in Child Development, Austin, TX.

Campos, A.*, **DeAnda, S**., & Friend, M. (March 2017). "Translation Equivalents and Code-Switching in Bilingual Preschoolers." Poster presented at the SDSU Student Research Symposium, San Diego, CA.

Thayer, L.*, **DeAnda, S**., & Friend, M. (March 2017). "How Vocabulary Supports Lexical Processing in Young Bilinguals." Poster presented at the SDSU Student Research Symposium, San Diego, CA.

Kortright, K.*, Moon, H.*, **DeAnda, S.,** & Friend, M. (March2017). "Understanding Variability in Executive Function Skill in Toddlers." Poster presented at the SDSU Student Research Symposium, San Diego, CA.

DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (November 2016). "Lexical Access in the Second Year: a Cross-linguistic Investigation of Mono- and Bilingual Vocabulary Development." Poster presented at the Boston University Conference on Language Development, Boston, MA.

Enriquez, B.*, **DeAnda, S**., & Friend, M. (March 2016). "Code-Switching in Young Spanish-English Bilingual Toddlers and Their Parents." Poster presented at the Student Research Symposium at San Diego State University, San Diego, CA.

DeAnda, S., Blossom, M., & Abel, A. (August 2015). "A Complexity Approach to Treatment of Tense and Agreement Deficits in Children with SLI." Poster presented at the American Speech Language & Hearing Science Annual Conference, Denver, CO.

Lopez, L.,* Alba, L.,* **DeAnda, S.,** Poulin-Dubois, D., Zesiger, P., & Friend, M. (March 2015). "Predicting Language Production at 30 months from Comprehension at 16 and 22 months." Poster presented at the Society for Research in Child Development Biennial Meeting, Philadelphia, PA.

Alba, L.,* Lopez, L.,* **DeAnda, S.,** Poulin-Dubois, D., Zesiger, P., & Friend, M. (March 2015). "Does early receptive vocabulary predict expressive vocabulary at 30 months in Spanish-speaking children?" Poster presented at the Society for Research in Child Development Biennial Meeting, Philadelphia, PA.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (September 2014). "The Language Exposure Questionnaire: Quantifying exposure for research on

young infants and children." Poster presented at the Society for Research in Child Development Special Topics Meeting on Developmental Methodology, San Diego, CA.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (November 2014). "Maternal input and children's vocabulary: A direct comparison between English and Spanish monolingual preschoolers in the US." Poster presented at the Society for Research in Child Development Special Topics Meeting on Parenting At Risk, San Diego, CA.

DeAnda, S., Abreu-Mendoza, R., Arias-Trejo, N. & Friend, M. (July 2014). "Vocabulary size and SES effects in Mexican Spanish infant learners." Poster presented at the International Conference on Infant Studies, Berlin.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (July 2014). "Factors Affecting Lexical Growth in Spanish Speaking Infants." Poster presented at the International Conference on Infant Studies, Berlin.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (August 2013). "Assessing the Continuum of L2 Exposure: Effects on Early Vocabulary Comprehension." Poster presented at the NIH Summer Scholars Workshop, Bethesda, MD.

DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (July 2013). "Effects of SES and Maternal Input on Early Language: New Evidence from a Direct Assessment of Vocabulary Comprehension." Poster presented at the Workshop on Infant Language Development, San Sebastian, Spain.

Friend, M., Zesiger, P., Deak, G., **DeAnda, S.,** Conboy, B., & Poulin-Dubois, D. (April 2013). "Bilingual Language Assessment: Why Direct Assessment Matters." Poster presented at the Society for Research in Child Development, Seattle, WA.

DeAnda, S., & Friend, M. (April 2013). "Assessing the Effects of SES and Language Exposure on Early Comprehension." Poster presented at the Society for Research in Child Development Biennial Meeting, Seattle, WA.

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ABSTRACT OF THE DISSERTATION

Lexical-Semantic Development in Monolingual and Bilingual Children

by

Stephanie De Anda

Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2017
San Diego State University, 2017

Professor Margaret Friend, Chair

The studies included in this dissertation explore lexical-semantic development within early toddlerhood across monolingual and bilingual language learners. That is, when and how do children map words with their respective meanings when they are learning one or two languages? Chapter 1 presents a brief overview of the seminal questions that guided this dissertation research. Chapter 2 presents a comprehensive review of the empirical literature examining lexical-semantic development in young monolingual and bilingual children followed by a discussion of theoretical models and their ability to account for the available evidence. Importantly, the chapter ends drawing attention to several gaps in our understanding of bilingual lexical development that are the foci of Chapters 3 through 5. Specifically, Chapter 3 presents a methodological tool for operationalizing language exposure in dual language learning contexts. Chapter 4 examines the influence of vocabulary size on speed of auditory word recognition using haptic responses in 16 to 22 month old monolingual and bilingual toddlers. The final set of studies (Chapters 5 and 6) report on monolinguals and bilinguals, respectively, and extend the previous work on word learning to the development of connections between words using gaze responses to assess lexical-semantic networks in the second year of life. Here we investigate how single or dual language exposure and vocabulary size influence the emergence of lexical-semantic priming. Throughout this dissertation, we consistently examine how theoretical models can guide predictions and be revised to account for early development. Together these investigations advance our understanding of bilingual language representation in the semantic domain.

Chapter 1: Introduction

Children begin building a lexicon quite early, with some recent research suggesting that infants as young as 6 months can understand the meanings of common nouns (Bergelson & Swingley, 2012). By 12 months, children produce their first word and by 24 months begin combining words to form two-word utterances. Further, between first words and the onset of word combinations, the learning of new words occurs at an accelerated rate (McMurray, 2007; McMurray, Horst, & Samuelson, 2012). Given that children learn words so early and at such a remarkable rate, an important new direction in research on early language examines how young children organize lexical information. This dissertation sets out to examine the development of children's lexical-semantic organization over the second year.

One candidate model for children's early lexical organization is the emergence of lexical-semantic networks. According to this model, young children are sensitive to the semantic relatedness between words and use this information to "cluster" words together. These lexical islands of clustered words are thought to resemble categories, such that children link words that overlap in meaning. For example, banana, apple, and orange may all cluster together roughly representing a food category. Indeed, as we review below, there is evidence from a variety of previous studies that supports the notion that young children are sensitive to the semantic relatedness between words.

One important source of evidence comes from electrophysiological studies. For example, adult signatures of lexical-semantic processing, such as the N400, have been replicated in young children from 12 to 18 months of age (Travis et al., 2011; 2014). Travis et al. used Magnetoencephalography (MEG) responses to spoken words

to assess one-year-olds' lexical-semantic processing. They found that the same neural signature that reflects semantic processing in adults is evinced as early as the second year. Similarly, they demonstrated that young children use the same brain areas as adults, namely the left frontemporal regions, when processing semantic information. Together this work suggests that children's brain responses reflect sensitivity to semantics in language processing.

Behavioral evidence also corroborates the notion that children use semantics to guide lexical organization by the beginning of the second year. In head-turn preference studies, children exhibit semantic facilitation effects in response to purely auditory cues. To illustrate, researchers presented children with semantically related and unrelated word lists, respectively (Delle Luche, Durrant, Floccia & Plunkett, 2014). The related word list contained a series of words that were semantically similar (e.g., animals). The unrelated list contained lexical items that were semantically unrelated. Toddlers at 18 months of age preferred to listen to the related word list relative to the unrelated word list. Similarly, Willits et al. (2013) presented children with semantically related (e.g., dog and cat) vs. unrelated (juice and cat) word pairs. Results showed that children evince semantic priming effects given auditory information in the absence of visual stimuli by the end of the second year. Semantic priming is the process by which children use semantic information to facilitate processing of subsequent and semantically related words. The idea is that words prime other words based on the amount of featural overlap between them through spreading activation at the semantic level leading to a facilitative effect.

A more common method employed to assess semantic priming effects is an adaption of the Preferential Looking Paradigm. In this task, children also listen to related versus unrelated word pairs but, in this task, visual stimuli are presented to measure gaze behavior to a lexical referent. In a series of studies, researchers have shown that semantic priming effects emerge by 24 but not 18 months of age (Arias-Trejo & Plunkett, 2009; 2013). That is, children look significantly longer to the target object when preceded by a semantically related word relative to an unrelated word by the end of the second year. Together this body of work shows that young children are sensitive to semantic information and use it to guide language processing by the end of the second year of life.

Dissertation Aims

This dissertation aims to examine two areas of inquiry related to lexical-semantic processing: development and variability. Specifically, this dissertation explores developmental changes in children's lexical-semantic processing during the second year of life. With respect to development, the present studies seek to inform our understanding of changes that occur in children's speed of word recognition and lexical-semantic organization over the second year. In addition, these studies examine the sources of variability that influence the rate and shape of development from 16 to 24 months of age. Of particular interest are the role of vocabulary size and single versus dual language exposure in lexical-semantic organization.

Importantly, these questions regarding the development and variability of lexical-semantic organization are examined longitudinally within monolinguals and bilinguals. I begin by asking whether there are differences in spoken word processing

efficiency as a function of single versus dual language exposure and whether this changes over the period from 16 to 22 months of age. This informs us about development and variability in the speed of processing for individual words. Next, I explore changes in lexical-semantic priming over the period from 18 to 24 months of age. That is, when do young children begin to link words such as *apple* and *orange,* and how quickly are children able to identify the meaning of *banana*? This is different from the previous study in that here we assess when in development children begin to connect the meanings of different words and how this varies with age, vocabulary size, and language exposure.

I explore the role of bilingualism on speed of word processing and lexical-semantic associations within and across two languages. That is, when do young bilinguals come to understand that *dog* and *gato* are related? Further, are children faster at processing words in the dominant relative to the non-dominant language? Are bilinguals faster overall than their monolingual peers? A second source of variability concerns the role of vocabulary breadth on lexical processing. For example, does vocabulary size predict the facility of word recognition and children's lexical-semantic processing? Further, within bilinguals, we ask whether within- or cross-language word knowledge supports lexical processing. In this way, the present dissertation examines how vocabulary size and single and dual language exposure influence both the speed of lexical access and the emergence of lexical-semantic networks.

Outline of the Dissertation

We begin the dissertation in Chapter 2 by providing a comprehensive review of the literature examining extant research on lexical-semantic development in

monolinguals and bilinguals, respectively. This review is followed by a discussion of computational models of bilingual language processing and their ability to account for the available empirical evidence (DeAnda, Poulin-Dubois, Zesiger & Friend, 2016). This chapter ends with a discussion of questions for future research, some of which I hope to answer in this very dissertation.

Chapter 3 precedes the behavioral studies by first presenting a published methodological tool that aids in assessing language exposure in young children. Specifically, the Language Exposure Assessment Tool (LEAT, DeAnda, Bosch, Poulin-Dubois, Zesiger & Friend, 2016) is an electronic interview-based questionnaire that queries parents on children's early language exposure. This published manuscript further evaluates the psychometric properties of the questionnaire by examining the internal consistency, construct validity, and utility of the LEAT. In this way, we present a tool that enables us to quantify language experience to one or two languages and classify children into monolingual and bilingual groups for the subsequent studies included in the dissertation.

Chapter 4 presents a published longitudinal study of speed of word recognition at 16 and 22 months of age in Spanish and English monolingual and bilingual children (DeAnda, Hendrickson, Poulin-Dubois, Zesiger & Friend, 2016). To examine development, the study examines changes in word recognition over time. To explore variability, we ask whether there exist differences in children's word recognition as a function of single or dual language exposure. Similarly, the study asks whether there exist within or cross-language associations between word knowledge and speed of word recognition. That is, does vocabulary size in one language support word retrieval

in the other language? We end the chapter by discussing the implications of the findings for models of early bilingual language processing and representation.

Chapter 5 investigates lexical-semantic priming effects in Spanish and English monolinguals longitudinally at 18 and 24 months of age. To examine sources of variability, the study employs a behavioral measure of vocabulary size to evaluate the role of word knowledge in supporting the emergence of lexical-semantic organization. That is, are there individual differences in the efficiency of lexical-semantic processing as a function of vocabulary size? Further, given that previous studies have examined lexical-semantic priming in British English monolinguals, the study sought to extend these findings in a new group of language learners: Spanish monolinguals in the U.S.

Chapter 6 extends Chapter 5 by employing the same methodological approach to examine development and variability within Spanish/English bilinguals. Indeed, within bilinguals, there are a series of unique questions. With respect to development, it is presently unknown whether bilinguals evince lexical-semantic priming on a timetable similar to their monolingual peers. That is, do bilinguals evince priming at 24 but not 18 months, as in monolingual development? As we review in Chapter 2, it is possible that bilinguals evince priming effects earlier, later, or at the same time as monolinguals given the dearth of empirical evidence on the topic. Further, it is unclear whether bilinguals evince lexical-semantic priming from one language to another in a way that supports cross-language processing. Similarly, Chapter 6 examines whether within- or cross-language word knowledge supports the emergence of lexical-semantic priming in the second year. The dissertation ends with a discussion (Chapter 7) that

explores the implications of these studies for models of early lexical-semantic development.

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Chapter 2: Lexical Processing and Organization in Bilingual First Language Acquisition: Guiding Future Research

Psychological Bulletin
2016, Vol. 142, No. 6, 655–667

0033-2909/16/$12.00 http://dx.doi.org/10.1037/bul0000042

Lexical Processing and Organization in Bilingual First Language Acquisition: Guiding Future Research

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A rich body of work in adult bilinguals documents an interconnected lexical network across languages, such that early word retrieval is language independent. This literature has yielded a number of influential models of bilingual semantic memory. However, extant models provide limited predictions about the *emergence* of lexical organization in bilingual first language acquisition (BFLA). Empirical evidence from monolingual infants suggests that lexical networks emerge early in development as children integrate phonological and semantic information. These findings tell us little about the interaction between 2 languages in early bilingual memory. To date, an understanding of *when* and *how* languages interact in early bilingual development is lacking. In this literature review, we present research documenting lexical-semantic development across monolingual and bilingual infants. This is followed by a discussion of current models of bilingual language representation and organization and their ability to account for the available empirical evidence. Together, these theoretical and empirical accounts inform and highlight unexplored areas of research and guide future work on early bilingual memory.

Keywords: bilingualism, lexical networks, semantics, vocabulary, language acquisition

The period of early language acquisition provides a window into the developing cognitive system. One of the earliest developing components of language is vocabulary comprehension. Central questions in this area are concerned with the network between lexemes (i.e., single lexical units) and their respective meanings. An especially productive avenue of research investigates this question in bilinguals, providing insight into language exposure factors that contribute to the organization of meaning in two separate languages. Indeed, bilingualism is an invaluable model for exploring normative language development, as many children around the world are exposed to more than one language. In particular, the period of *early* bilingual first language acquisition informs our understanding of the development of the complex and interconnected linguistic system of the bilingual.

Extant research on the question of bilingual lexical processing has primarily focused on adults. Perhaps most important, work on adult bilinguals has generated some of the most influential models of language representation. Currently, however, a gap exists between the infant and adult literatures with regard to both theory and empirical evidence. It has been noted that a developmental perspective is lacking in our current understanding of bilingual lexical processing (e.g., Grainger, Midgley, & Holcomb, 2010). A developmental perspective that includes the early preschool period can clarify a number of existing issues in the current bilingual language processing literature. We discuss three primary questions in bilingual language processing that can be informed by a developmental approach.

First, a developmental model answers the questions of *when* and *how*. For example, *when* and *how* do the lexicons of bilinguals begin to separate? Are they ever integrated? Historically, researchers debated language-selective versus language-nonselective semantic activation in bilingual language processing. Although previous findings demonstrate that language-nonselective access takes place in adulthood (e.g., Dijkstra, 2005; Kroll, Bobb, & Wodniecka, 2006; Marian & Spivey, 2003), there is insufficient evidence to determine when early parallel processing begins and whether it is universal in bilingual acquisition.

Second, a developmental perspective offers insight into the factors that influence language processing. Unlike many of the existing

This article was published Online First February 11, 2016.

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This research was supported by NIH awards 5R01HD068458 and HD068458-02S1 to the senior author and 1F31HD081933 to the first author, and does not necessarily represent the views of the National Institutes of Health. We gratefully acknowledge the contributions of Drs. Henrike Blumenfeld and Gabriela Simon-Cereijido for their feedback on previous versions of this article.

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models that describe the late L2 adult learner, the young child does not have a strong preexisting L1 lexical network onto which it is possible to map a second language. Indeed, in bilingual first language acquisition (BFLA), the networks for the two languages arise in concert and dependencies between languages influence processing in important ways. Relatedly, understanding how the young bilingual solves the problem of language might help us understand why and how early and late L2 learners differ. Indeed, adult bilinguals differ as a function of the age of first second language exposure, such that the brain's gray matter and functional organization is modulated by age of acquisition and second language proficiency (Fabbro, 2001; Perani et al., 1996; Klein, Mok, Chen, & Watkins, 2014; Mechelli et al., 2004; Vaid & Hull, 2002).

Third, a model of bilingualism that extends from infancy through adulthood would allow us to address relations between simultaneous and sequential acquisition and their implications for lexical-semantic structure. Such model would of necessity be based on auditory language processing. Models that explain visual word recognition in adulthood are limited in their ability to explain auditory comprehension early in the process of language acquisition. This illustrates the importance of a developmental model of acquisition that takes into account the early origins of lexical-semantic structure in audition and, ultimately, how this becomes realized in reading and writing. The focus of the present review is on the literature on early auditory language processing with the goal of synthesizing extant research and recommending directions for future research to flesh out the early stages of a comprehensive developmental model.

The goal of the present review is twofold. The first aim is to outline our current understanding of lexical-semantic processing in the early preschool period, before children have begun to read, across monolingual and bilingual first language acquisition. The focus is on auditory comprehension of spoken language rather than production, as comprehension generally precedes production and provides an earlier window into the emerging lexical system. In addition, we focus on lexical-semantic processing as a means of exploring language coactivation in early bilingual development. That is, how and when do children connect words across lexicons based on meaning?

The second aim of this review is to discuss how this literature might inform existing models of bilingual lexical acquisition, and to suggest gaps in our understanding to guide future research. Throughout this review, we evaluate extant bilingual models in light of the available evidence with regard to lexical-semantic processing in monolingual and bilingual children. This review helps to address each of our motivating questions by covering the extant literature on the early, auditory, stages of lexical-semantic processing in BFLA. First, when and how do bilinguals build a lexical-semantic system? Second, what are the lexical-semantic learning mechanisms involved in BFLA and how do these differ from monolingual acquisition? As we discuss, there is a dearth of evidence to fully answer each of these questions. As such, we end with a discussion of gaps in our current understanding of the development of lexical-semantic processing and suggestions for future research.

Literature Search

To review lexical-semantic processing in early development, we first began the literature search with a small set of papers that explicitly addressed the issue of early lexical-semantic organization: Mani and Plunkett (2010); Mani, Durrant, and Floccia (2012); Arias-Trejo and Plunkett (2009, 2013); Willits, Wojcik, Seidenberg, and Saffran (2013); Wojcik and Saffran (2013); Von Holzen and Mani (2012), and Singh (2014). This guided the choice of selection criteria for a more systematic electronic search. We were particularly interested in evaluating models of bilingual auditory language acquisition. It is important for the purposes of this search that the models that we review are revisions of previous models within the last 5 years (e.g., the Self-Organizing Model of Bilingual Processing, SOMBIP, was revised in 2010 into DevLex-II; Processing Rich Information from Multidimensional Interactive Representations, PRIMIR, was revised to include bilinguals in 2011). These revisions modeled the behavioral evidence up to 2008 and 2010, respectively. Thus, the aim in the present article was to review research that has emerged since 2008 to evaluate the validity of these models against new findings and to guide future work.

The electronic search included English language, peer-reviewed, empirical manuscripts in PsycNET and PubMed for the period of infancy and toddlerhood. We sought empirical research that assessed lexical processing in spoken language with the following selection criteria: (a) assessed auditory language; (b) language comprehension rather than production; (c) included infants and/or toddlers; (d) included monolinguals and/or bilinguals; and (e) studied normative populations. The search included the following keywords: (lexico-semantic OR lexical OR semantic OR networks OR language processing OR comprehension OR bilingual OR monolingual OR priming OR activation OR recognition OR implicit naming OR auditory OR lexicon OR vocabulary) AND ages 0 to 5 years. A total of 56 publications met these criteria.

Lexical-Semantic Development in Early Language Acquisition

There is a dearth of research on language coactivation in bilinguals to parallel that in monolinguals, and even less has been conducted in children prior to school entry. In what follows, we present evidence from two separate lines of research that have investigated how the early lexical-semantic system develops in monolinguals and bilinguals, respectively. We review the earliest stages of development, namely infancy and toddlerhood. Although the present discussion is mainly concerned with lexical-semantic organization, we include some findings on the interaction of phonology and grammar with semantics in language acquisition to highlight what appears to be the early development of a highly interconnected lexical-semantic network. However, it is important to note that, in the interest of characterizing the development of this network, the majority of the research reviewed focuses on word-level learning and organization. We take a chronological approach and begin with the period of early infancy, characterized by word learning in the early stages of building a lexical-semantic system. This is followed by the literature on toddlers, where we find more direct evidence of the existence of a lexical network as early as the second year of life.

Early Word Learning Mechanisms in Monolinguals and Bilinguals

Before children can begin forming lexical networks and thereby connect words based on meaning, they must first acquire the

lexical items themselves. Early in infancy, children are tasked with the problem of forming the object representations onto which words are mapped. A rich word learning literature that documents the complex task of linking words onto referents over the first few months of life emerged beginning in the late 1950s (e.g., Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Brown, 1958; Nelson, 1973; Nelson, 1974; Werner & Kaplan, 1963). Rather than review this impressive literature in its entirety, we focus here on studies that provide a comparison between monolinguals and bilinguals and the word learning mechanisms they employ before age 2 to reveal the putative beginnings of lexical-semantic networks. As we discuss, the literature demonstrates similarities in the mechanisms that support early word learning and differences in relative timing across monolingual and bilingual first language acquisition.

We begin by considering evidence of differential developmental timing of word learning mechanisms. For example, 14- and 19-month-old bilingual children are able to learn syllables that differ only in their pitch contour (rising vs. falling intonation) as distinct labels for objects in a habituation paradigm, even when their native language does not use pitch contour as a cue for meaning. By 22 months, however, they no longer distinguish syllables based on pitch (Graf Estes & Hay, 2015). Monolinguals, in contrast, fail to distinguish syllables based on pitch as early as 17 months when their language does not use pitch as a cue to meaning (Hay, Graf Estes, Wang, & Saffran, 2015). However, evidence from a preferential looking paradigm suggests that the extended sensitivity for pitch as a cue to meaning applies only to those bilinguals learning a language that uses pitch as a phonemic contrast (Singh, Hui, Chan, & Golinkoff, 2014). Specifically, bilinguals and monolinguals learning languages where pitch is nonphonemic showed similar developmental trajectories. These disparate findings across studies may be explained by differences in task demands (e.g., habituation vs. preferential looking). Nevertheless, findings demonstrating a prolonged period of flexibility in bilinguals are consistent with the *resource limitation hypothesis* in phonetics that suggests that bilinguals face more challenges in word learning relative to monolinguals (Costa & Sebastián-Gallés, 2014; Fennell, Byers-Heinlein, & Werker, 2007; Fennell & Werker, 2003; Stager & Werker, 1997; Werker & Fennell, 2004; Werker, Fennell, Corcoran, & Stager, 2002). Despite being exposed to greater linguistic breadth than monolinguals, bilinguals may have reduced exposure to the unique characteristics of their languages (since exposure is split across languages) resulting in a protracted trajectory with regard to the application of early word learning mechanisms.

This unique bilingual challenge has implications for the rate and order of word learning. By comparing the vocabularies of bilinguals and monolinguals as early as 6 months of age Bilson, Yoshida, Tran, Woods, and Hills (2015) assessed vocabulary development in bilinguals and monolinguals beginning at 6 months of age and demonstrated that a similar word learning model fit both the monolingual and bilingual data. However, in bilinguals there was an interaction between the first and second language such that word learning was facilitated by knowledge of the translation equivalent in the nontarget language. This facilitation effect influenced the order of word learning in bilinguals. In a separate study, Bosch and Ramon-Casas (2014) investigated the nature of translation equivalent facilitation effects. Their findings demonstrated that the extent of facilitation is limited by the phonological similarity of the two languages that the child is learning, such that greater phonological overlap leads to a greater facilitation effect. These findings have implications for lexical-semantic structure across monolingual and bilingual development. When word knowledge in one language facilitates word learning in a second language, this suggests early developing links across lexicons in the young bilingual that foster word learning within and across languages. Indeed, as we review in the following section, there is evidence from toddlers that there may be significant differences in the lexical-semantic networks of monolingual and bilingual children.

As children enter the period of toddlerhood, they begin to use more sophisticated approaches to word learning, and the interaction between acquired word knowledge and continuing word learning becomes more apparent. Sixteen- to 22-month-old monolingual children become increasingly skilled in using the presence of a known referent to guide the mapping of novel labels and referents (i.e., disambiguation), and this ability correlates with expressive vocabulary size (Graham, Poulin-Dubois, & Baker, 1998). However, it is not until 30 months of age that this learning strategy results in the retention of word meaning over a short delay (Bion, Borovsky, & Fernald, 2013). Thus, prior word knowledge exerts an effect on subsequent word learning in the second year of life and into the third.

This interaction of lexical knowledge with word learning is also evident in bilingual development. Recent findings suggest that the propensity to use disambiguation in word learning is related to the complexity of lexical-semantic structure. Here, complexity refers to the extent that there exist many-to-one mappings between words and referents, in addition to one-to-one mappings. This is true in bilingualism to the extent that children possess unique words specific to a single referent across their two languages as in the case of translation equivalents (e.g., *dog* and *perro*). Bilinguals who know more translation equivalents are less likely to apply disambiguation in a word learning task than bilinguals who know fewer translation equivalents (Byers-Heinlein & Werker, 2009, 2013). That is, those children that more often map two words onto a single referent across languages are likely to apply a novel label equally to a novel and known referent as opposed to using disambiguation as a strategy.

In contrast to the previous mechanisms discussed, associative learning is one way that monolingual and bilingual child may approach the task of word learning similarly. Although the extent to which associative learning is used in early language acquisition is debated, there is evidence that children can achieve word referent mappings using associative learning strategies prior to significant vocabulary growth. As early as 2 months of age, young monolingual infants map simple syllable sequences to novel objects via associative links. However, this word learning mechanism is relatively weak, as they form these syllable-object pairings only if auditory and visual information are synchronized (Gogate, Prince, & Matatyaho, 2009). By 6 months, monolinguals are able to form word-object pairings for highly frequent words in their environment (Tincoff & Jusczyk, 1999). Word-object association continues to develop, such that by approximately 14 months, infants link referents and objects after only a few minutes of exposure to the arbitrary mapping (Curtin, 2011; MacKenzie, Graham, & Curtin, 2011; Schafer & Plunkett, 1998; Werker, Cohen, Lloyd, Casasola, & Stager, 1998). A bit later, between 18

and 24 months of age, toddlers similarly map words to motion events (Friend & Pace, 2011; Katerelos, Poulin-Dubois, & Oshima-Takane, 2011).

The question remains, however, whether a similar developmental trajectory characterizes associative word learning in bilinguals. Using the Switch procedure (Werker, Cohen, Lloyd, Casasola, & Stager, 1998), Byers-Heinlein, Fennell, and Werker (2013) compared associative word learning in monolingual and bilingual 12- and 14-month-olds. After habituating to a word-object pair both monolingual and bilingual 14-month-olds (but not 12-month-olds) demonstrated longer looking to the named object during switch trials (when an untrained label was presented) relative to when the trained word was presented. Notably, no differences were observed between bilingual and monolingual children in their ability to detect a change in the word-object pairing.

Although the previous findings provide evidence that bilingual and monolingual children apply associative learning strategies similarly, it remains unclear whether these strategies suffice under conditions of dual language exposure. Specifically, in experimental conditions like those we have reviewed, both monolingual and bilingual toddlers receive similar exposure to a particular word-object pairing. However, as has been suggested previously, bilinguals experience fewer exposures to any single word-object mapping relative to monolinguals because these mappings occur across languages.

Important for the present discussion, differences in the frequency of word-object associations have implications for lexical-semantic processing. Even before the first birthday, at 10 months, young infants draw category boundaries based on whether objects receive consistently distinct labels, or a single label across all objects (Plunkett, Hu, & Cohen, 2008). Vouloumanos and Werker (2009) investigated 18-month-olds' word learning given reliable versus random word-object mappings. Eighteen-month-olds were sensitive to statistical regularities in word-object mappings, even in low-frequency conditions. However, the statistical strength of the word-object associations modulated auditory processing of newly learned words, such that children were faster at shifting their gaze to the referent for strong (or frequent), relative to weak (or infrequent), word-object associations. This is early evidence that the frequency of word-object mappings modulates lexical processing. One prediction that follows from these findings is that bilinguals may be slower to develop strong word-object associations by virtue of more limited exposure in any one language and, consequently, may evince slower lexical processing. However, no study to date has directly compared differences in lexical access across bilingual and monolingual infants as a function of associative frequency. Preliminary evidence, however, suggests that speed of lexical access is equivalent in monolingual and bilingual toddlers at 16 and 22 months of age, such that both groups do not differ in speed of online word processing (Legacy, Zesiger, Friend, & Poulin-Dubois, 2015). These findings suggest that early simultaneous dual language experience might not, in fact, modulate the speed of word processing.

The findings on word learning mechanisms in bilingual and monolingual children highlight two important implications for the present discussion: first, although bilinguals learn words at approximately the same rate as monolinguals (Pearson, Fernandez, & Oller, 1993), and can (and do) apply similar word learning heuristics, they often differ from monolinguals in the frequency and timing of their use. Second, these findings on disambiguation provide suggestive evidence of an interconnected system across languages as early as the second year of life for young bilinguals, such that this cross-linguistic network has implications for the application of word learning strategies.

Evidence for Lexical-Semantic Organization

Monolinguals. In addition to learning individual words, bilingual and monolingual children begin organizing their existing vocabularies even before entering the period of significant vocabulary growth. In the previous section, we focused on the organization of single words. In addition to indirect evidence in the word learning literature of a lexical-semantic system developing early in the second year, neural and behavioral methods provide converging direct evidence for early lexical-semantic organization. For example, evidence from magnetoencephalography and structural Magnetic Resonance Imaging (MRI) suggests that the brain areas recruited for semantic processing between 12 and 18 months of age in the earliest stages of language acquisition continue to develop with age (Travis et al., 2014) and parallel those recruited in adults (Travis et al., 2011).

Behavioral evidence corroborates these findings. Delle Luche, Durrant, Floccia, and Plunkett (2014) presented 18-month-old monolinguals with lists of related (e.g., animals) and unrelated words (e.g., clothes and food) using a head-turn preference procedure. Infants listened longer to the related versus the unrelated word list suggesting that, indeed, children are sensitive to the semantic relatedness of known words as early as the second year of life. In addition, 24-month-olds prioritize semanticity over visual information (such as color). Specifically, children are faster to orient to semantically related referents for a target word rather than referents that share the same color (Mani, Johnson, McQueen, & Huettig, 2013).

In an earlier study, Mani, Durrant, and Floccia (2012) examined children's sensitivity to both phonological and semantic relatedness between words. In this study, related trials consisted of primes that contained a phonological subprime that related semantically to the target image. For example the prime *boat* is phonologically related to *bowl,* which is semantically related to the target, *cup.* At age 2, monolinguals showed increased looking times to targets for phono-semantically related primes relative to the unrelated trials. There are two possible accounts of this finding. First, the phonological prime may recruit looking to a phono-semantically related target (i.e., boat primes bowl which is related to cup) through subprime semantic *activation* of the target (i.e., bowl primes cup) resulting in an increment in looking time to the target in the related condition relative to the unrelated condition. Alternatively, this increment in looking time could be caused by subprime *inhibition* of semantically unrelated words (i.e., bowl inhibits shirt). In either case, the findings highlight the interaction between phonological and semantic information.

Similarly, there is evidence that grammar influences lexical activation. At age 2, monolinguals encode grammatical gender information for known nouns (Bobb & Mani, 2013). German toddlers were presented with pairs of visual objects that were grammatically and semantically congruous, grammatically congruous and semantically incongruous, semantically congruous and grammatically incongruous, or did not match grammatically or

semantically. When targets and distractors were semantically and grammatically congruous, children showed fewer overall looks to the target, suggesting impaired activation of the target relative to the distractor. In contrast, children were able to identify the target when it differed from the distractor either semantically or grammatically. In sum, by age 2, monolinguals exhibit lexical networks that interact at phonological, grammatical, and semantic levels to produce coactivation of related known words within their single language system.

In the following section, we review toddlers' lexical activation on the basis of purely semantic cues. In a study examining English monolinguals at 18 and 21 months of age, Arias-Trejo and Plunkett (2009) presented taxonomically *and* associatively related or unrelated word pairs using the Intermodal Preferential Looking (IPL) paradigm. Twenty-one-month-olds, but not 18-month-olds, demonstrated semantic priming between related words. That is, in the IPL paradigm, although pure phonological priming is evinced as early as 18 months of age (Mani & Plunkett, 2010), semantic priming emerges later, at 21 months. In a subsequent study, Arias-Trejo and Plunkett (2013) explored the nature of semantic priming effects by comparing priming between two types of semantic relationships in 21- and 24-month-olds: taxonomic *or* associative. This time 24-month-olds, but not 21-month-olds, evinced priming effects. How do we reconcile these seemingly disparate results? In the first study (Arias-Trejo & Plunkett, 2009), 21-month-olds were exposed to word pairs that were *both* associatively and taxonomically related. In the follow-up study, word pairs were *either* associatively *or* taxonomically related. The support of multiple semantic cues in the first study provided a "priming boost" that allowed the 21-month-olds to detect the semantic relationship between the presented words (Arias-Trejo & Plunkett, 2013, p. 217). A similar pattern of results was reported in an earlier study: 24-month-olds, but not 18-month-olds showed evidence of semantic priming (Styles & Plunkett, 2009). Semantic priming continues to develop in the second year, such that by 24 months children can access word meaning for basic nouns even in the absence of a visual referent (Willits, Wojcik, Seidenberg, & Saffran, 2013).

Toddlers also show rich semantic knowledge for verbs, such that they predict the upcoming subject of a verb based on semantic relatedness. Specifically, by age 2, children will fixate on an edible referent after hearing a semantically related verb, such as *eat*, within a sentence (Mani & Huettig, 2012). This ability to predict the upcoming referent was correlated with expressive vocabulary size, such that children with higher expressive vocabularies reliably predicted the upcoming referent. Indeed, semantic knowledge about a verb includes an understanding about the type of objects that can be taken as arguments, and children use this knowledge even when learning a new noun. Nineteen-, but not 15-month olds, can learn a novel noun by using the representations of known verbs (Ferguson, Graf, & Waxman, 2014).

The development of lexical-semantic networks that takes place over the second year of life is also evident in studies using event-related potentials (ERP). In an auditory priming paradigm in which children heard semantically related and unrelated word pairs, 24-month-olds showed reliable N400 semantic incongruity effects for the unrelated word, whereas only 18-month-olds with high expressive vocabularies showed comparable processing, suggesting a relation between breadth of word knowledge and lexical processing and organization (Rämä, Sirri, & Serres, 2013). Similarly, in a picture-word mismatch paradigm, 20-month-olds showed N400 modulation for basic-level known words given between- and within-category semantic violations (von Koss Torkildsen et al., 2006). This ERP evidence suggests that young monolinguals can detect semantic violations even for objects within the same category and that vocabulary size is related to more mature lexical processing.

Recent evidence suggests that the ability to categorize words extends to newly learned words even for visually similar referents at age 2 (Wojcik & Saffran, 2013). Furthermore, 2-year-olds show stronger word learning for words that form part of a well-known category relative to words that are part of lesser-known categories (Borovsky, Ellis, Evans, & Elman, 2015). That is, a child who already knows many words for the animal category is more likely to learn the name of a new animal relative to a word from a category for which the child knows only a few words. These findings demonstrate that monolingual toddlers encode similarity between referents, and that this information guides word learning.

In conclusion, monolingual toddlers evince a lexical network that interacts at phonological, grammatical, and semantic levels. Furthermore, this network modulates subsequent word learning. Lexical-semantic networks also continue to develop over the second year of life, such that by 24 months, monolinguals are sensitive to the taxonomic and associative links between words.

Bilinguals. Bilinguals, on the other hand, face a different type of lexical organization task. Do lexical-semantic connections emerge in bilinguals on the same developmental time course as monolinguals? There is reason to believe that the development of a semantic network might differ as a function of language exposure. Bilinguals must learn to connect words both *within and across* languages. Bilinguals must organize known words, and categorize newly learn words into their existing lexical system. After all, these connections between lexicons are thought to lead to parallel processing in adults. But *when* do bilinguals achieve this? Given that monolingual infants show priming for phonologically and semantically related words, the question remains whether similar relations exist *across* languages for bilinguals.

There is some evidence in the word learning literature in support of an *earlier*-emerging lexical-semantic system in bilinguals relative to monolinguals. In a word learning task, Byers-Heinlein and Werker (2013) found that 17- to 18-month-old bilinguals, in contrast to monolinguals, are more likely to accept a novel name for a previously named object. This propensity varies as a function of the number of translation equivalents known across languages: Bilinguals who knew many translation equivalents were more likely to show this effect relative to bilinguals who knew fewer translation equivalents. The authors propose the *lexicon structure hypothesis,* which suggests that bilingual infants with knowledge of many translation equivalents have richer semantic organization relative to monolingual peers, as the relationship between words and concepts across two languages supports a many-to-one mapping structure. That is, bilinguals are more likely to map two separate words onto a single concept than monolinguals, and they are more likely to do so *earlier* in development as well by virtue of their dual language exposure.

Similarly, using the Computerized Comprehension Task (CCT), a touch-based response measure, Poulin-Dubois, Bialystok, Blaye, Polonia, and Yott (2013) found that 24-month-old bilinguals with knowledge of many translation equivalents show faster lexical

access than bilinguals with fewer translation equivalents, suggesting a facilitative priming effect that follows from a many-to-one lexical organization. These findings are in-line with adult research that demonstrates faster picture naming for words with known translation equivalents (Costa & Caramazza, 1999; Gollan, Montoya, Fennema-Notestine, & Morris, 2005).

Extending previous work in monolinguals, Von Holzen and Mani (2012) examined whether bilinguals' second language primed the first language given phonologically related word pairs between 21 and 43 months of age. Remarkably, bilingual toddlers showed facilitated target recognition, even in cases where the phonological prime was mediated by a translation equivalent. For example, children showed facilitated recognition of the dominant German language target *stein* given the nondominant English language prime of *leg* because of the phonological overlap between the target (*stein*) and the L1 translation of the prime, *bein*. This finding demonstrates two key points. First, German-English bilinguals activate phonological knowledge from the nondominant language to the dominant language. Second, like monolinguals, bilinguals exhibit implicit activation of words, in this case for translation equivalents, when processing in their nondominant language after age 2. These results parallel the findings and theoretical accounts of adult bilingual language representation, as cross-language phono-semantic coactivation extends, at least in this case, to early toddlerhood.

In a study of 30-month-old Chinese–English bilinguals, Singh (2014) extended prior studies to include cross-linguistic priming in the context of semantic primes (e.g., 椅子 [chair] and *table*) within and across the dominant and less-dominant language. Within-language semantic priming was observed for the dominant, but not the nondominant, language. Furthermore, cross-language priming was unidirectional, such that the dominant language primed the nondominant language, but the opposite was not true. Thus, there is evidence to suggest the existence of language nonselective activation in the context of translation equivalents and semantic primes that is modulated by language dominance early in the third year of life to parallel that in adults. Similarly, Marchman, Fernald, and Hurtado (2010) observed differences in speed of spoken word processing based on language dominance, such that 30-month-olds showed faster word recognition in the dominant versus the nondominant language.

Language dominance effects are also evinced in ERP investigations of 19- to 22-month-old bilingual toddlers. Processing in the nondominant and the dominant language shows distinct patterns of temporal and spatial neural activation (Conboy & Mills, 2006). These differences in neural processing vary as a function of total conceptual vocabulary size (a measure of the number of lexicalized concepts across languages). Although the dominant and nondominant language elicit independent and different patterns of neural activity, the combined vocabulary across languages affects processing for both the dominant and nondominant language, suggesting an independent but connected semantic system across languages early in bilingual development. This suggests that, like monolinguals, bilinguals are able to categorize words within and across languages based on word meaning. Indeed, even in cases in which monolinguals and bilinguals overextend word meanings, they do so within category boundaries (e.g., Holowka, Brosseau-Lapré, & Petitto, 2002; Kay & Anglin, 1982). For example, young children will extend *cow* to *horse* but never to *brush*. Even though the representation for cow may be relatively weak, children already have some knowledge about its category membership.

Summary of Empirical Findings in Infants and Toddlers

Taken together, the findings across studies suggest the emergence of lexical-semantic connections early in the second year of life that are more robust by the end of the second year. Furthermore, just like young children show comprehension of words in the absence of a referent as early as 18 months, they can also activate words that are semantically related to a target word without visual referents by 24 months (Willits, Wojcik, Seidenberg, & Saffran, 2013). That is, over the first and into the second year of life, children form semantic representations of words that are decontextualized. At the same time that word representations are becoming stronger, semantic organization is taking place, such that it is not only evident for known words, but drives referent selection for novel words (e.g., Bion, Borovsky, & Fernald, 2013). That is, the available evidence suggests the existence of a dynamic, multidimensional process, in which individual words and lexical organization take place in tandem and are mutually interactive. For bilinguals, tasked with learning words in both languages, similar word learning mechanisms are observed but these mechanisms are utilized over developmental periods that contrast with observations from the monolingual literature. Furthermore, bilinguals show evidence of cross-linguistic activation to parallel that in adults as early as the third year of life. That is, toddlers exhibit knowledge of translation equivalents and semantic primes that provide evidence for an interconnected lexical-semantic system across languages (Poulin-Dubois Bialystok, Blaye, Polonia, & Yott, 2013; Byers-Heinlein & Werker, 2013; Von Holzen, & Mani, 2012; Singh, 2014).

Models of Bilingual Language Organization and Processing

We now turn our attention to a review of existing models to discuss their ability to explain the available evidence on early bilingual lexical processing. We argue that the period of early development provides important contributions to these models. Most of the early research in adult bilingualism focuses on visual word recognition or word naming as dependent measures. Several psycholinguistic models of adult bilingual language representation have been proposed. Many of these models are relatively static, and represent adult lexical processing (e.g., the Distributed Feature Model, Van Hell & De Groot, 1998; the Bilingual Interactive Activation Plus, Dijkstra & Van Heuven, 2002; the Revised Hierarchical Model, Kroll & Stewart, 1994). In the interest of space and the scope of the present review, we focus on models of auditory comprehension, rather than visual word recognition, as they are more appropriate to early language acquisition. In addition, we review models that provide a mechanism for language acquisition that can be evaluated based on the available empirical evidence. Namely, we discuss the SOMBIP, DevLex-II, and the PRIMIR model, and evaluate their ability to account for the data on the development of lexical-semantic knowledge in young infants and toddlers.

SOMBIP

SOMBIP is a computational model that attempts to account for spoken word recognition in bilingual language comprehension (Li & Farkas, 2002). As its name suggests, the model presents two self-organizing maps: a semantic and phonological map (Figure 1). These self-organizing maps are two-dimensional spaces made up of independent but interconnected units that develop representations based on the patterns derived from a training data set. These representations are distributed across the two-dimensional self-organizing map itself. Self-organizing maps like these are thought to mirror the type of topographic organization found in many sensory and motor areas in the human brain. To train the system, Li and Farkas provided conversational bilingual child input from the CHILDES corpus. English and Cantonese were presented intermittently but importantly, no explicit language tags were presented to the system. Through Hebbian learning, the model was able to categorize words appropriately into each language across the semantic and phonological maps. The representations on the phonological and semantic map were also linked through associative connections. Furthermore, words were categorized into word class, such that nouns, verbs, and prepositions were also accurately classified within each language.

One of the notable strengths of the SOMBIP is its ability to incorporate spoken word corpus data as the training set to mirror the type of auditory input a bilingual child might encounter. In addition, the model uses learning constraints that are thought to exhibit the type of processing that might occur in the human brain. SOMBIP is able to model the way in which a bilingual child might accurately disentangle two separate language representations despite mixed input. However, important for the present discussion, it does not explain how bilinguals ultimately form associations across languages. SOMBIP shows associative links between phonological and semantic represents *within* each language, but does not model links between similar phonological and semantic representations *across* languages. In SOMBIP, both language representations are separate. As we have reviewed, the ability to associate words across languages based on meanings seems to be in place early by the second year of life, such that bilingual children show evidence of phono-semantic and semantic priming across languages (Von Holzen & Mani, 2012; Singh, 2014). In addition, these cross-language associations are modulated by language dominance, such that priming in both adults and 30-month-olds differs based on whether priming occurs from the dominant to the non-dominant language, and vice versa. Thus, although SOMBIP models how a child might arrive at separable language systems, it fails to account for the available evidence that demonstrates early parallel processing in bilingual language acquisition.

DevLex-II

The DevLex-II computational model shows many similarities to SOMBIP, but has the added benefit of incorporating a learning mechanism to explain links across languages, as well as semantic priming differences between early and late learners of a second language (Zhao & Li, 2013). Like SOMBIP, DevLex-II uses self-organizing maps to represent semantic and phonological space. It also incorporates a third map: an output layer to represent articulatory sequences necessary for production (Figure 2). Also like SOMBIP, through Hebbian learning, DevLex-II is able to connect units across all three maps, effectively linking phonological input to word meaning and then to an articulatory phonological representation. Input to DevLex-II was provided in the form of 500-word list derived from the MacArthur Bates Communicative Development Inventories (MCDI) for English and Chinese, respectively (Fenson et al., 2006). The MCDI is a list of the most frequently used words in each language, and therefore reflects the earliest words in children's vocabularies.

One of the critiques of SOMBIP was its inability to model connections between lexicons. DevLex-II, however, incorporates lateral connections *within* each map to simulate the process of cross-language connections for translation equivalents and semantic primes. DevLex-II also captures reaction time (RT) effects elicited in priming studies, such as those measured during lexical decision tasks. To do so, changes in lexical density, or neighborhood effects, are modeled within the semantic map. Specifically, activation of one word causes residual activation to spread across related meanings. A measure of RT is therefore derived from this

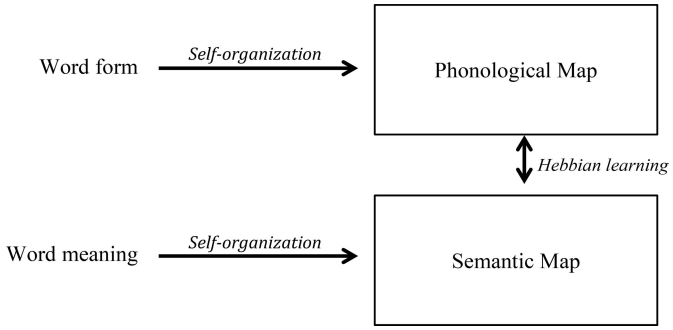

Figure 1. A graphical representation of Self-Organizing Model of Bilingual Processing (SOMBIP) adapted from "A self-organizing connectionist model of bilingual processing," by P. Li and I. Farkas, 2002, *Advances in Psychology, 134,* 59–85. Copyright 2002 by Elsevier. The two self-organizing maps form associative connections through Hebbian learning.

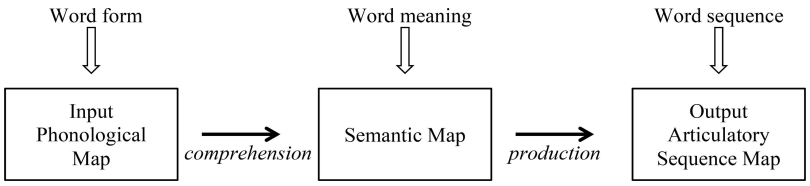

Figure 2. DevLex-II uses three self-organizing map to model auditory word comprehension and speech production that form associative connections within and across languages. Figure adapted from "Bilingual lexical interactions in an unsupervised neural network model," by X. Zhao and P. Li, 2010. *International Journal of Bilingual Education and Bilingualism, 13,* 505–524. Copyright 2010 by Taylor & Francis.

density measure, such that words with higher density exhibit stronger interference and therefore slower target recognition. This interference can also occur within and across languages in the model.

In computer simulations of DevLex-II, Zhao and Li (2010, 2013) demonstrated that the degree of overlap between two languages predicts the ease with which semantic activation occurs between related representations across semantic space. For example, translation equivalents (e.g., *perro* and *dog*) have strong lateral connections because of the large overlap in meaning, whereas semantic primes have indirect connections because of less overlap in meaning (e.g., *perro* and *cat*). This leads to larger priming effects (and faster RTs) for translation equivalents than for semantic primes consistent with adult findings (Basnight-Brown & Altarriba, 2007; Zhao, Li, Liu, Fang, & Shu, 2011). In addition, previous simulations show that simultaneous bilinguals and early L2 learners demonstrate clear separation between L1 and L2, whereas late L2 learners show representations intermixed with the existing L1 network (Zhao & Li, 2010). The latter organization is also known as "parasitic" organization, because the L2 attaches to the existing L1 (Hernandez, Li, & MacWhinney, 2005; Zhao & Li, 2010).

How well does DevLex-II explain early bilingual first language acquisition? As is, the model provides an account of the language dominance differences observed between sequential and simultaneous bilinguals. That is, it describes how *temporal* variables associated with exposure to L1 and L2 might affect language representation. However, within simultaneous bilinguals, language dominance effects arise despite encountering language simultaneously because of differences in the *amount* of exposure to each language. The available evidence suggests that even for simultaneous bilinguals, language dominance effects emerge because of the differences in time spent hearing each language. For example, Conboy and Mills (2006) demonstrate distinct patterns of temporal and spatial neural activation in the nondominant and the dominant language of exposure as early as 19 months of age using ERP. In addition, behavioral paradigms have elicited similar findings, such that cross-language priming occurs only from the dominant to the nondominant language for semantic primes in 30-month-old bilinguals (Singh, 2014). As is, it is unclear how DevLex-II might account for such unidirectional priming effects.

Nevertheless, the RT simulations from DevLex-II correspond with the some of the available evidence in infants and toddlers. For example, behavioral findings demonstrate priming from the nondominant to the dominant language for translation equivalents (Von Holzen & Mani, 2012) but not semantic primes (Singh, 2014). Although it is unclear why priming was not achieved for semantic primes, the disparity between translation equivalents and semantic primes in favor of translation equivalents is predicted by DevLex-II and in line with adult findings.

Specifically, DevLex-II predicts *faster* RTs for translation equivalents. This is in line with to recent findings documenting *faster* RTs for children with *higher* proportions of known translation equivalents than those with knowledge of fewer translation equivalents (Poulin-Dubois, Bialystok, Blaye, Polonia & Yott, 2013). Recall that translation equivalents have the highest degree of featural overlap, therefore providing the highest level of activation within DevLex-II. According to Poulin-Dubois et al. (2013), the translation equivalent in the nontarget language provides a facilitative effect because of the underlying shared conceptual representation.

These findings also highlight possible differences in comprehension and production that are important for lexical access. In comprehension, the bilingual is tasked with retrieving meaning from word form, in which case the additional activation of related meanings from neighboring words may be facilitative. In production, one must retrieve a word form given a conceptual representation, in which case neighboring words might activate competing word forms leading to an interference effect. Adult research documents a dissociation between production and comprehension, as there is evidence of *slower* picture naming but not classification for bilinguals (Gollan, Montoya, Fennema-Notestine, & Morris, 2005). Indeed, in a word comprehension task like the one used in Poulin-Dubois et al. (2013), it is possible that knowledge of translation equivalents provides a richer conceptual representation leading to faster RTs. Because the output layer in DevLex-II models articulatory processes, it is possible that it corresponds with production rather than comprehension.

Nevertheless, a strength of DevLex-II is that it provides a semantic architecture that can readily extend to encompass the sort of weaker semantic representations found in early development. As such, the model might predict a protracted account of semantic connections within and across languages in bilinguals, much like the *resource limitation hypothesis* that has been proposed for phonological acquisition (Costa, & Sebastián-Gallés, 2014; Fennell, Byers-Heinlein & Werker, 2007; Fennell & Werker, 2003; Stager & Werker, 1997; Werker & Fennell, 2004; Werker, Fennell, Corcoran & Stager, 2002).

According to DevLex-II, the emergence of semantic priming is a result of strengthened connections that activate words with

overlapping features in semantic space. This gives rise to stronger activation for translation equivalents (in which there is a maximal amount of semantic feature overlap) than for semantic primes (in which there is some semantic feature overlap). That is, as children encounter more exemplars of *dog* and *cat*, they activate an increasing number of overlapping semantic features that leads to semantic priming effects.

The bilingual's experience with the world is split between two languages. Suppose a young bilingual infant encounters the word *chair* for the first time when sitting in a car seat, but hears *silla* for the first time in the presence of a bar stool. In this case, there would be very little, if any, overlap in meaning, as the word *chair* and *silla* would activate relatively separate sets of semantic features. As the child encounters different exemplars of each word across languages, an increasing number of overlapping semantic features would be created, linking *silla* and *chair* at the semantic level. Importantly, although we can assume that the bilingual child encounters the same number of chairs as the monolingual, bilinguals receive half as many exemplars per lexical item. If the emergence of semantic priming is brought about by the strength of semantic representations (as a function of the number of overlapping semantic features as modeled by DevLex-II), it follows that bilinguals might have a more protracted development of semantic connections relative to their monolingual peers, as there are fewer overlapping semantic features for related lexical items. This account predicts slower and later-emerging lexical-semantic priming for monolinguals relative to bilinguals. Indeed, as we previously reviewed, empirical evidence in line with the *resource limitation hypothesis* suggests a longer period of flexibility in using phonological and pitch cues to guide word learning for bilinguals relative to monolinguals (Costa, & Sebastián-Gallés, 2014; Fennell, Byers-Heinlein & Werker, 2007; Fennell & Werker, 2003; Stager & Werker, 1997; Werker & Fennell, 2004; Werker, Fennell, Corcoran & Stager, 2002).

Currently, however, there is no available empirical evidence to evaluate whether this extends to semantic development, such that bilinguals form lexical-semantic connections across languages at a slower rate than their monolingual counterparts. We discuss this as an area of future research in more detail later.

PRIMIR

A recently proposed model of early language acquisition is the PRIMIR (Curtin, Byers-Heinlein, & Werker, 2011). This model focuses on the links between phonology and lexical representations in monolingual and bilingual infants. Although rich in its description of the emergence of phono-lexical organization, the model makes very few claims about the lexical-semantic organization of the developing bilingual. Nevertheless, the predictions PRIMIR makes about lexical organization are worth noting as they follow those from DevLex-II. For example, Curtin, Byers-Heinlein, and Werker contend that word forms from a single language are separate from the second language, as the languages form "clusters" in *lexical* space based on statistical learning mechanisms in PRIMIR. That is, because words from one language tend to co-occur with other words in that language, separate language clusters for word forms arise. This clustering and its mechanism are identical to those proposed by DevLex-II and SOMBIP as discussed previously. To the extent that code-switching occurs in bilingual language input, all three models lack a mechanism to account for language differentiation in the case of mixed linguistic input.

In PRIMIR, unlike in SOMBIP and DevLex-II, a second learning mechanism (a comparison-contrast strategy) accounts for the clustering of words with related word meanings across languages. Specifically, as word forms link to semantic representations, words with related meanings within and across languages cluster together. In this respect, PRIMIR is different from DevLex-II and SOMBIP in that it suggests that shared semantics across languages can operate on the organization of word forms, thus resulting in partially overlapping language representation (Figure 3). In this way, it accounts for the type of cross-language connections demonstrated in the empirical literature.

Another important contribution of the PRIMIR model for the current discussion is its use of domain-general learning mechanisms. There is a rich literature documenting strong statistical learning skills that are in place early in development as we have previously reviewed. Indeed, languages are rich with statistical patterns and regularities that help form sound, syllable, and word categories for the monolingual infant (Saffran, Aslin, & Newport, 1996). For example, bilingual infants can discriminate their native languages from an unfamiliar language (Bosch & Sebastián-Gallés, 1997). Critically, Spanish-Catalan bilinguals can discriminate *within* their native languages as well, as early as 4 months of age even when both languages are rhythmically similar (Bosch & Sebastián-Gallés, 2001). Newborns with prenatal bilingual exposure also show the ability to discriminate between two rhythmically distinct languages soon after birth (Byers-Heinlein, Burns, & Werker, 2010). Young infants and toddlers are able to track statistical regularities in word-object mappings and are able to draw category boundaries based on whether objects receive consistently distinct labels, or a single label across all objects (Plunkett, Hu, & Cohen, 2008; Vouloumanos & Werker, 2009).

Together, this research demonstrates that infants, even soon after birth, are able to make use of statistical patterns to aid in forming language categories. Indeed, PRIMIR suggests that this domain-general mechanism plays a role at all levels of language,

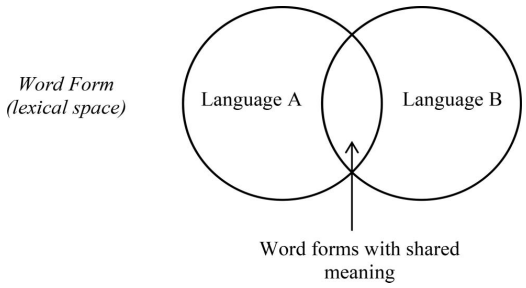

Figure 3. According to Processing Rich Information from Multidimensional Interactive Representations (PRIMIR), words from separate languages tend to co-occur, giving rise to relatively separate language clusters in lexical space. At the same time, semantics can operate on language organization, because words with shared meanings across languages may also cluster together, resulting in some overlap in word form.

allowing the young bilingual to disentangle complex input into overlapping but separable systems at the phonological, syntactic, semantic, and lexical levels. In this way, PRIMIR offers the most ecologically valid model on how children categorize language representations. It offers the most testable hypotheses about the development of a lexical-semantic system based on well-established statistical learning strategies. However, as it stands, PRIMIR makes few hypotheses that extend to semantic development, likely because of the dearth of empirical evidence for semantic, relative to phonological, bilingual acquisition.

Unanswered Questions and Directions for Future Research

As we have reviewed, the few available models of language acquisition largely map onto the available empirical evidence. Nevertheless, there are currently gaps in our understanding of the development of the early lexical-semantic system in bilinguals across the empirical and modeling literatures.

To begin, behavioral and electrophysiological evidence to delineate the time course of lexical-semantic connections within and across languages is currently lacking. For example, research in the monolingual literature indicates a very clear emerging pattern of lexical-semantic priming that begins in the early second year of life (Arias-Trejo & Plunkett, 2009, 2013). Although current findings suggest cross-language activation at 30 months of age in bilinguals (Singh, 2014; Von Holzen, & Mani, 2012), it is currently unknown whether bilingual infants follow the same developmental time course exhibited in monolingual acquisition.

In addition, few studies provide a direct comparison between monolingual and bilingual infants and toddlers. Research comparing these two populations could be fruitful for understanding the implications of language coactivation for bilinguals. For example, adult research indicates *slower* lexical access for bilinguals relative to monolinguals (Ivanova & Costa, 2008). The interpretation is that bilinguals exhibit inhibition from the activation of the second language. There is some evidence that these findings may not extend to early language acquisition. Specifically, speed of online word processing did not differ at 16 and 22 months of age between monolingual and bilingual toddlers (Legacy et al., 2015). This suggests that dual language experience does not modulate word comprehension in the second year of life. Additional empirical studies and theoretical models linking the findings in toddlers to adulthood, however, are lacking.

Similarly, a model of bilingualism that extends from infancy through adulthood is needed. However, drawing parallels between the infant and adult literatures requires considering differences in task demands. Currently, research on priming in early infancy relies heavily on well-established looking-time and electrophysiological measures. Conversely, adult methods often employ lexical decision tasks or rapid naming, for example. To provide a complete account on the development of lexical access from infancy to adulthood, it is important for future research to draw clear connections between these two bodies of literature. Typically, adult methods require a volitional response in the form of word production or haptic responses (i.e., button presses). Recent work in the infant literature provides support for the utility of haptic response measures within the second year of life prior to significant growth in vocabulary production (Friend & Keplinger, 2003; Friend & Keplinger, 2008; Friend, Schmitt, & Simpson, 2012; Friend & Zesiger, 2011; Hendrickson, Mitsven, Poulin-Dubois, Zesiger, & Friend, 2015; Poulin-Dubois et al., 2013). Hendrickson et al. suggest that a comparison of gaze and haptic responses in children as young as 18 months of age can provide a window into partial lexical knowledge states. Thus, a possible avenue for future research is to investigate what passive measures (such as gaze) and volitional responses (such as haptic responses) reveal about the development of lexical networks in adult and child bilinguals, and how the strength of early word representations relates to lexical-semantic organization.

Future work should also aim to disentangle the factors that affect the emergence and strength of lexical networks. As in adults, one factor that might relate to the emergence of lexical networks is language proficiency, which can be operationalized as vocabulary size in young infants and toddlers. It has been speculated that a possible dynamic relation exists between word knowledge and lexical organization. For example, the more words a child knows, the more likely it is that the child will be able to organize and categorize the words along relevant dimensions. A recent extension of TRACE, a computational model of speech perception (McClelland & Elman, 1986), to early word recognition suggests that phonological word recognition is influenced by lexical breadth and depth (e.g., vocabulary size and content; Mayor & Plunkett, 2014) and it is able to account for a number of behavioral findings using IPL tasks. An implementation of TRACE into the semantic domain would be an appropriate extension of the extant literature. Currently, however, a model or empirical evidence to extend this to semantic development is lacking. It may be the case that as more words enter the lexicon, semantic similarities and differences among words become more apparent, fostering connections and category formation within the lexicon. Indeed, children learn words faster if they have knowledge of many words of the same category (e.g., Borovsky et al., 2015). However, mixed findings have been reported with respect to the relation between vocabulary size and lexical-semantic coactivation in the monolingual and bilingual literature (e.g., Arias-Trejo & Plunkett, 2009; Conboy & Mills, 2006; Friedrich & Friederici, 2004; Marchman, Fernald, & Hurtado, 2010; Singh, 2014; Willits, Wojcik, Seidenberg, & Saffran, 2013). As a consequence, is not well understood how lexical breadth relates to lexical organization for bilingual and monolingual acquisition alike.

One possible reason for the mixed findings across studies has to do with the measures employed to inventory word knowledge. Developmental researchers most often rely on parent reports of vocabulary knowledge, which does not correlate consistently with direct visual RT measures of lexical access (e.g., speed of word processing; Fernald, Perfors, & Marchman, 2006; cf. Marchman et al., 2010). In a study examining speed of word processing in children between 15 and 25 months of age, Fernald et al. (2006) reported comparable processing speeds across words reported as known or unknown by parents. This suggests that online measures may index emerging word knowledge that is not captured by parent reports. Thus, the mixed findings on the question of vocabulary size and lexical organization might be explained by the variability associated with comparing direct (child behavior) and indirect (parent report) measures of lexical breadth and processing. To clarify these findings, future work must attend to the issue of

method variance and take care to use comparable measures of word knowledge and lexical processing.

Future work on theoretical and computational models should also include explicit study of the stages of development. Currently missing in existing models is an account of what lexical-semantic structure looks like in cases of weak representations and sparse neural architecture, as is the case of early infancy and toddlerhood. A fruitful extension of the computational models we have reviewed would be to provide insight into the architecture of lexical-semantic representation *before* learning is completed. That is, what type of organization is observed early in learning? In addition to modeling differences between sequential and simultaneous bilinguals, computational models can vary the amount of words presented in each language to mirror the type of language exposure differences within early simultaneous bilinguals.

Conclusion

As we have reviewed, empirical evidence across monolingual and bilingual language acquisition suggests the emergence of a lexical-semantic system within the second year of life. Furthermore, for bilinguals, there is evidence of cross-linguistic processing to parallel that found in adults, suggesting the existence of language nonselective access at the earliest stages of bilingual first language acquisition. Available models of acquisition provide a number of predictions that remain to be tested and highlight additional areas of research, but continue to be limited in their ability to link early infancy and adulthood. Finally, understanding language coactivation and its emergence will help illuminate early differences across monolingual and bilingual acquisition. An integrative goal for future research is to work toward a truly developmental model of lexical-semantic structure that extends from early acquisition through adulthood.

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Received March 6, 2015
Revision received October 29, 2015
Accepted November 17, 2015 ■

Chapter 2, in full, is a reprint of material as it appears in DeAnda, S., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). Lexical Processing and Organization in Bilingual First Language Acquisition: Guiding Future Research. *Psychological Bulletin,* 142(6), 655-667. The dissertation author was the primary investigator and author of this paper.

Chapter 3: The Language Exposure Assessment Tool: Quantifying language exposure in infants and children

JSLHR

Research Article

The Language Exposure Assessment Tool: Quantifying Language Exposure in Infants and Children

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Purpose: The aim of this study was to develop the Language Exposure Assessment Tool (LEAT) and to examine its cross-linguistic validity, reliability, and utility. The LEAT is a computerized interview-style assessment that requests parents to estimate language exposure. The LEAT yields an automatic calculation of relative language exposure and captures qualitative aspects of early language experience.
Method: Relative language exposure as reported on the LEAT and vocabulary size at 17 months of age were measured in a group of bilingual language learners with varying levels of exposure to French and English or Spanish and English.
Results: The LEAT demonstrates high internal consistency and criterion validity. In addition, the LEAT's calculation of relative language exposure explains variability in vocabulary size above a single overall parent estimate.
Conclusions: The LEAT is a valid and efficient tool for characterizing early language experience across cultural settings and levels of language exposure. The LEAT could be a useful tool in clinical contexts to aid in determining whether assessment and intervention should be conducted in one or more languages.

Around the world, children growing up in bilingual homes are the norm rather than the exception (United Nations Educational, Scientific and Cultural Organization, 2003). Indeed, even in the United States, where the majority of the population speaks a single language, the proportion of residents who report speaking a language other than English has risen to one in five (U.S. Census Bureau, 2011). The rapid growth of this population in the United States as well as the growing awareness that multilingualism is a common phenomenon around the world have prompted an increase in bilingual research. One particular source of difficulty in conducting bilingual research, however, is assessing language exposure and obtaining reliable estimates of daily, weekly, and overall distribution of the input languages in heterogeneous groups of dual language-learners (for an overview, see Byers-Heinlein, 2015). The focus of the present study is to provide a reliable tool for assessing relative language exposure in infants and young children on the basis of a detailed parental interview. Relative language exposure generally refers to the proportion of input in each language (Grüter, Hurtado, Marchman, & Fernald, 2014). For example, bilingual children may receive relatively balanced (50%–50%) or unbalanced (75%–25%) exposure to each of their languages.

The extant literature provides robust evidence that relative language exposure is an important source of variability for bilingual language proficiency (Bedore et al., 2012; David & Wei, 2008; Eilers, Pearson, & Cobo-Lewis, 2006; Pearson, Fernandez, Lewedeg, & Oller, 1997; Place & Hoff, 2011; Poulin-Dubois, Bialystok, Blaye, Polonia & Yott, 2013). However, assessment of relative language exposure in bilingual infants and children who are unable to report on their language experience presents a unique problem for researchers and clinicians. Thus, the majority of extant measures of language exposure are based on parent report (Bosch & Sebastián-Gallés, 2001; Conboy & Mills, 2006; David & Wei, 2008; Gutierrez-Clellen & Kreiter, 2003; Pearson et al., 1997; Place & Hoff, 2011). Whereas a number of researchers have developed valid and reliable self-report assessments of language experience to be used in adult populations (e.g., Li, Sepanski, & Zhao,

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Editor: Rhea Paul
Associate Editor: Margarita Kaushanskaya

Received July 3, 2015
Revision received October 29, 2015
Accepted March 16, 2016
DOI: 10.1044/2016_JSLHR-L-15-0234

Disclosure: *The authors have declared that no competing interests existed at the time of publication.*

2006; Marian, Blumenfeld, & Kaushanskaya, 2007), the research on early dual-language acquisition continues to suffer from inconsistency in the assessment of exposure. The present study seeks to provide an efficient and valid measure to reach an accurate estimate of relative language exposure for young children that can be used across research and clinical settings.

Prior Approaches to Measures of Language Exposure

Assessment of relative language exposure varies across studies in early child language research. For example, language exposure has been measured by recording direct-language input to a child in the home during the course of a day and calculating the amount of exposure in each language (Grüter et al., 2014). A more common and efficient approach is to measure language exposure on the basis of parent report. This can be in the form of a daily diary during the course of several days (e.g., De Houwer & Bornstein, 2003; Place & Hoff, 2011) or through a questionnaire assessing exposure across the lifespan (e.g., Bosch & Sebastián-Gallés, 2001; Gutierrez-Clellen & Kreiter, 2003). Other assessments include amount of language exposure reported from each conversational partner as rated on a scale (Conboy & Mills, 2006; De Houwer, 2007), and others simply ask parents to estimate the percentage of exposure to each language (David & Wei, 2008; Pearson et al., 1997). Thus, language exposure assessments vary in terms of the time period they assess (e.g., one day, several days, or the entire lifespan), the tools they use to assess it (e.g., direct language input or parent report), and the administration time.

Effects of Quantity and Quality of Language Exposure in Bilinguals

Parent reports of language exposure have been shown to relate to various aspects of early bilingual first language acquisition, thereby providing preliminary support for their reliability. These findings highlight the effects of several quantitative and qualitative aspects of exposure on language acquisition. In the monolingual literature, the seminal work by Hart and Risley (1995) demonstrated that the quantity of language input correlated with vocabulary size in English speakers. This finding is supported by more recent work documenting a relation between the amount of child-directed speech and speed of real-time language processing in Spanish speakers (Weisleder & Fernald, 2013). Similar results have been extended to bilingual language acquisition. For example, parent reports of relative language exposure across the lifespan correlate with size of vocabulary in young dual-language learners, such that greater exposure to a language relates to a larger vocabulary size (David & Wei, 2008; Eilers et al., 2006; Hoff et al., 2012; Pearson et al., 1997; Poulin-Dubois et al., 2013). In addition, the classification of participants into bilingual and monolingual groups derived from parent reports of relative language exposure also predicts performance on executive function and memory tasks (Brito & Barr, 2012; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). In their study, Byers-Heinlein and Werker (2009) found differences in the application of disambiguation, a word-learning heuristic, in monolingual, bilingual, and trilingual infants as classified by parent-reported relative language exposure. Using a similar tool, Garcia-Sierra et al. (2011) showed differences in electrophysiological responses between groups of infants also classified by parent reports of language exposure. Other quantitative variables such as parent reports of age of initial exposure to a second language have implications for language mastery in the context of reading, lexical development, and fast mapping in young children (e.g., Jia, Kohnert, Collado, & Aquino-Garcia, 2006; Kan & Kohnert, 2008; Kovelman, Baker, & Petitto, 2008), whereas recent language exposure is a better predictor of semantic and morphosyntactic language measures (Bedore et al., 2012).

Qualitative aspects of language exposure that contribute to variability in early language acquisition have been documented in monolingual acquisition. Previous work demonstrated that word frequency, grammatical complexity, and gender differences in language input influence early vocabulary size and growth (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Snow, 1972). In a similar way, several dimensions of maternal responsiveness predict children's acquisition of language milestones as early as 9 months of age (Tamis-LeMonda, Bornstein, & Baumwell, 2001) and even into the fourth year of life (Hudson, Levickis, Down, Nicholls, & Wake, 2015). Qualitative aspects of language exposure have been much less studied in the bilingual literature. Hoff and others (for a review, see Hoff & Core, 2013; Hoff, Welsh, Place, & Ribot, 2014; Place & Hoff, 2011) investigated various qualitative aspects of language exposure and how they related to children's vocabulary size and grammatical complexity. These qualitative variables were measured using a language diary in which parents documented exposure during the course of several days. Their findings showed that the number of different conversational speakers who interact with the child was a significant predictor of bilingual language proficiency at age 2. That is, increased variability in the input provides support for early language development. In addition, the proportion of input coming from native-language speakers explained variability in vocabulary size. It is important to note that these qualitative measures of exposure demonstrated significant effects on vocabulary after controlling for the relative amount of exposure. That is, qualitative aspects of language exposure as reported by parents exert an additional influence over the quantity of exposure on acquisition. In terms of grammar, Place and Hoff (2011) found that the number of exclusively English conversational partners and the amount of different sources of English exposure correlated with children's English grammatical complexity.

The Current Study

Although prior work has demonstrated the value of parental reports of exposure, there remains a need to evaluate

the reliability and validity of this approach. The present study aims to address current issues in measuring and quantifying relative language exposure by proposing an assessment protocol that can be used across languages and settings. The current study presents the Language Exposure Assessment Tool (LEAT), which captures aspects of language exposure by incorporating features from a number of existing instruments in an easy-to-use, systematic assessment format. Given that the literature demonstrates strong links between exposure and parent-reported vocabulary, the present study uses two measures of early vocabulary size (the MacArthur Communicative Development Inventory [MCDI], Fenson et al., 2006; and the Computerized Comprehension Task [CCT], Friend & Keplinger, 2008; Friend & Zesiger, 2011) to explore the criterion validity of the LEAT's measure of relative language exposure. The MCDI provides a parent-report measure of early vocabulary size. However, because method bias could lead to a significant relation between parent-reported vocabulary and parent-reported language exposure, we used a behavioral and laboratory-based measure of vocabulary comprehension (the CCT) as an additional test of the validity and reliability of parent-reported language exposure on the LEAT.

The LEAT provides a parent-report measure of relative language exposure through a systematic interview. For example, the LEAT acquires information on the number of communicative partners, the languages they speak, the amount of time the child interacts with each person in each language, and how this varies over time (Bedore et al., 2012; Bosch & Sebastián-Gallés, 2001; Conboy & Mills, 2006; Fennell, 2000; Marchman, Martínez-Sussmann, & Dale, 2004; Parra, Hoff, & Core, 2011; Peña, Gutierrez-Clellen, Iglesias, Goldstein, & Bedore, 2014; Place & Hoff, 2011; Thordardottir, Rothenberg, Rivard, & Naves, 2006). The ability to extract these variables aids in identifying those aspects of language exposure that influence acquisition in young dual-language learners. In addition, it can assist clinicians in clarifying the basis for dissociations in proficiency in the first and second language when assessing young dual-language learners. The central motivation for investigating the detailed nature and computational power of the LEAT is to provide a standard measure that can be efficiently administered across settings to facilitate research on early language acquisition in dual-language learners and assist in clinical assessment. Here, we describe three unique contributions of the LEAT to the measurement of early language exposure.

First, the LEAT is based in Excel software (Microsoft Corp., Redmond, WA) to facilitate data acquisition and language exposure calculation in the laboratory, clinic, or field. Because the LEAT consists of protected, fillable cells for calculation, data are easily captured across contexts and sites. In the past, researchers have characteristically completed the language assessments in a paper format. Calculating exposure to multiple languages manually can be tedious and may increase the possibility of error. In the LEAT, parents' responses to queries automatically generate relative language exposure calculations through built-in formulas. This fillable electronic format allows researchers and clinicians to quickly calculate relative language exposure in a systematic way and to conduct the assessment easily in person or over the phone. It also provides the benefit of facilitating export to analysis software through the use of built-in macros. Last, electronic documents facilitate data sharing and data backup.

Second, we present a user manual that documents a method of administration for the LEAT in the online supplemental materials (see Supplemental Materials S1, S2, and S3). For many years, researchers and clinicians have relied on orally transmitted instructions and informal, unpublished user guidelines (but for children 4;0 to 6;11 [years;months], see Peña et al., 2014). This article provides the documentation for assessing early language exposure in infants, toddlers, and young children prior to 4 years of age in an effort to standardize measurement of language exposure across laboratories.

Last, we present data from 98 bilingual toddlers to establish the internal consistency, utility, and criterion validity of the LEAT across languages, cultures, and laboratories. Whereas the LEAT has high face validity, and similar paper-and-pencil assessments have been used in many studies, to our knowledge, this is the first time that the validity of parent report of language exposure in infants and toddlers has been directly assessed and documented. In addition, a goal of the present study was to provide an efficient and reliable tool to assess language exposure. As such, it was important to ensure that the detailed questioning on the LEAT explained variance beyond that provided by an overall parent estimate of relative language exposure. In particular, the research questions were the following:

1. What is the internal consistency of the LEAT?
2. Does the LEAT's relative language exposure calculation demonstrate criterion validity such that it explains significant variance in language outcomes?
3. What is the utility of the LEAT? That is, does it explain variance in vocabulary measures beyond that provided from an overall parent estimate of relative language exposure?

Method

Participants

Participants in the current study formed part of a larger longitudinal study aimed at documenting relations between early language acquisition and subsequent development. For the purposes of the present study, we selected participants with no more than 80% exposure to one of the input languages, so that exposure to the other language was at least 20%. This 80%–20% distribution is often the limit for inclusion of bilingual participants in a sample (Byers-Heinlein, 2015; Pearson et al., 1997). This provided the opportunity to evaluate the LEAT's validity across a wide range of second-language exposure.

The present sample consisted of ninety-eight 17-month-old toddlers (M = 17;14, SD = 1.01, range = 14;22 to 19;24; 41 girls, 57 boys). Children were exposed to either Spanish and English or French and English. An additional three children were tested but not included in the sample as a result of experimenter error (n = 1) or failure to complete the behavioral task (n = 2). Children and their families were recruited through flyer postings, mailings, and child-oriented events. In addition, birth record information was acquired from local health agencies. Letters and response cards were sent to 17-month-old children within a 10-mile radius of the laboratory. Response cards were then reviewed to ensure children met inclusionary criteria, and parents were then contacted to participate in the study.

Participants resided in one of two geographical locations: Children exposed to French and English resided in Montréal, Canada (n = 54), and those exposed to Spanish and English resided in San Diego, California (n = 44). The language exposure contexts across these locations vary greatly and allow us to test the LEAT's psychometric properties cross-linguistically. In Montréal, although the official language is French, more than half of residents speak both French and English (Canadian Census, 2011). In San Diego, the majority language is English, but Spanish is a significant minority language, such that 27% of California residents report speaking Spanish (American Community Survey, 2010).

All participants were typically developing and had healthy hearing and vision. The average maternal and paternal education was at college level (maternal: M = 15.20 years of education, SD = 2.60; paternal: M = 14.71 years of education, SD = 2.75). Note that there was no difference in maternal and paternal education based on language of exposure, $F(2, 89) = 0.66$, $p = .52$. The majority of children (n = 87) received exposure to two languages (French and English or Spanish and English; average exposure to the dominant language = 61%, SD = 7.35, range = 50%–79%). The other 11 children received exposure to a third language in addition to French and English or Spanish and English (average exposure to the dominant language = 56%, SD = 8.52, range = 40%–70%), but exposure to a third language was minimal (≤ 20%). All but four of the children resided in two-parent homes. On average, the children lived with approximately four family members (M = 3.84, SD = 1.3, range = 2–8 people), which most often included a combination of parents, grandparents, and siblings. All of the children in the current study received early, simultaneous exposure to their dominant and non-dominant language (i.e., simultaneous exposure to French and English or Spanish and English). For the purposes of the present study, we define the dominant language in terms of the LEAT's calculation of relative exposure (i.e., the dominant language is that with the highest level of exposure; Grosjean, 2010), which does not necessarily reflect proficiency. Indeed, a central question of the present study is whether exposure, as calculated by the LEAT, predicts proficiency to evaluate its utility and criterion validity.

Measures

LEAT

The LEAT is an Excel-based (Microsoft Corp.) interview assessment that relies on parent reports of exposure to measure both quantitative and qualitative aspects of language exposure (see online Supplemental Materials S1, S2, and S3). The LEAT was designed in a manner that would allow parents to easily and systematically report on features of their child's language exposure without compromising validity. For this reason, the LEAT is separated into two major sections that together allow for the calculation of relative language exposure. In the first section, parents are asked to list the people who interact with the child at least once a week, the language(s) they speak, and whether they are native speakers of the language(s) (e.g., "Who interacts with your child on a regular basis?" "What is their primary/secondary language?"). This list automatically populates the second section, which inventories the amount of time that the child spends hearing each conversational partner in each language. This information is broken down by day of the week and by age, thereby capturing exposure that happens on specific days of the week and at specific ages in the child's life (e.g., "At what age did the child start receiving language input from Person A?" "Has Person A's interaction with your child been consistent in the past or were there times when he/she spent more or less time with your child, such as maternity leave, moved, etc.?" "During the week, what days is Person A interacting with your child?"). Next, parents are asked to estimate the amount of input children receive on average for each conversational partner given the ages and days of the week during which they interacted ("On an average day, how many hours is your child exposed to Person A speaking in Language A?"). A detailed list of queries as well as information about exposure calculations can be found in the LEAT user manual (see online Supplemental Materials S1, S2, and S3). This conceptual organization allowed parents to report on the timing, frequency, and amount of language exposure in a stepwise fashion from who interacts with the child to the languages they speak with the child to more specific information regarding time of exposure (i.e., child's age, days per week, hours per day). In this way, parents are able to easily provide estimates for each aspect of language exposure rather than provide an overall estimate that may conflate important sources of variability.

The detailed responses provided on the LEAT yield several variables. Relative language exposure is calculated by weighting the hours of exposure according to the duration of exposure to each source of input relative to the child's age. That is, if a 12-month-old infant heard 4 hours of French per day from her grandmother in the first 6 months of her life, these hours of French would receive a weight of one half to reflect the fact that this exposure did not continue for the first full year. In contrast, if the same infant heard 6 hours of English per day from her mother for the entire first year, these hours would receive a weight of one. From

these weighted estimates for each language, the LEAT calculates relative language exposure (total weighted hours of exposure to Language A divided by total weighted hours of exposure to Language A and Language B). As we reviewed in the introduction, various qualitative variables have been found to exert a significant effect on early vocabulary development (e.g., Place & Hoff, 2011), and these are also captured on the LEAT. Given that parents are asked to enumerate conversational partners, the languages they speak, and whether they are native speakers, the LEAT is able to document the following qualitative variables: the number of sources of input the child is exposed to, the number of speakers who speak more than one language to the child, the amount of native and nonnative language exposure, and the absolute hours of language input.

Trained interviewers were taught to use specific questions to probe parents about the child's language exposure outlined in a detailed manual (see online Supplemental Materials S1, S2, and S3). These questions use parent-friendly terminology to help respondents provide responses easily. To maintain consistency across administrations, each specific question is overlaid onto the electronic version of the LEAT. Interviewers are able to hover over each section and view the required dialogue to probe parents for responses. All of the parents in the present sample were able to respond to the interviewer's trained line of questioning with ease and completed the LEAT within about 15 minutes. In addition, parents demonstrated remarkable understanding of the constructs in question because their estimates of language exposure across speakers fell within the expected range of waking hours (M = 4.3 hours; range = 1.74–9.38).

MCDI

The MCDI is a widely used parent-report measure of early language. The Words and Gestures inventory, intended for children between 8 and 18 months of age, is a checklist for parents to mark the words their child understands and says. The inventory provides researchers with an indirect account of the child's vocabulary comprehension. The MCDI, originally developed in English, has good reliability and validity and has been adapted for use in more than 50 languages and dialects, including Spanish and Canadian French (Fenson et al., 2006; Jackson-Maldonado et al., 2003; Kern, 1999; Trudeau, Frank, & Poulin-Dubois, 1999). These adaptations were used in the present study for the Spanish- and French-learning children.

The MCDI yields a measure of vocabulary size based on the number of words identified by parents on the checklist. Because children were evaluated in both languages, two separate measures of vocabulary size were calculated for each participant. From these measures, relative vocabulary size in the child's dominant language of exposure was computed for each participant (vocabulary size in Language A divided by the sum of vocabulary size across Languages A and B). This allowed us to compare the LEAT's relative exposure calculations to a relative measure of vocabulary and assess criterion validity.

CCT

The CCT contains 41 pairs of images presented on a touch-sensitive screen, following the method of Friend and colleagues (Friend & Keplinger, 2003; Friend, Schmitt, & Simpson, 2012). Children are prompted to touch the target by an experimenter ("Where is the shoe? Touch shoe."). The task begins with four training trials followed by a test phase consisting of nouns, verbs, and adjectives of varying difficulty. During the test phase, the experimenter presents the pairs of images immediately following the first mention of the target word in the prompt. After 7 s elapse, if no response has been made, the trial ends and the pair of images disappears. The CCT yields a total vocabulary score based on the number of correctly identified words (defined as a first touch to the target item).

The CCT has shown significant immediate test–retest reliability across English, Spanish, and French adaptations, thus demonstrating that performance is systematic in children as young as 16 months of age. The CCT also demonstrates convergent validity with MCDI reports of vocabulary comprehension and 4-month test–retest reliability (Friend & Keplinger, 2008; Friend & Zesiger, 2011) and accounts for significant variance in subsequent vocabulary production (Friend et al., 2012).

Once again, relative vocabulary size in the child's dominant language of exposure was computed for each participant based on the number of correctly identified words on the CCT in each language (vocabulary size in Language A divided by the sum of vocabulary size across Languages A and B).

Procedure

Approximately 1 week before the children's visit to the lab, the LEAT was administered over the phone with the primary caregiver. The interviewers administering the assessment were fluent bilingual speakers of English and Spanish or English and French and were trained to follow the LEAT manual outlining specific questions to be asked to elicit the caregiver's responses. The LEAT was administered in English, Spanish, or French depending on the parents' language preference. During the visits to the lab, vocabulary size was assessed using the MCDI and CCT in both of the bilingual children's languages (Pearson et al., 1997).

During the visit to the lab, the children were first given a few minutes to warm up to the lab environment and the experimenter. Children and their parents were then escorted to a dimly lit room to administer the CCT. Parents wore blacked-out sunglasses and noise-cancelling headphones while their children sat on their lap and completed the CCT. Following the CCT, parents filled out the MCDI. The MCDI was given to the expert reporter for each language (see Table 1).

Planned Analyses

Internal consistency refers to the homogeneity of a test or the degree to which all items on a test measure the

Table 1. Descriptive information for vocabulary size across measures.

	Average	*SD*
Dominant language		
CCT	9.18	6.1
MCDI	165.79	91.26
Nondominant language		
CCT	9.35	5.79
MCDI	146.64	94.65

Note. CCT = Computerized Comprehension Task; MCDI = MacArthur Communicative Development Inventory.

same construct. That is, the items on a test should correlate if they indeed represent the construct of interest. High internal consistency suggests that the construct of interest has been consistently measured and that the derived scores are reliable (Henson, 2001). Thus, to answer our first question regarding the internal consistency of the LEAT, we assessed its four quantitative measures of language exposure: the overall parent estimate, the LEAT's calculation of hours per week, hours per day, and relative language exposure. The overall parent-report estimate is obtained by asking parents to provide overall percentages of relative exposure for each language that the child has been exposed to since birth, whereas the other three measures are derived from the detailed day-to-day hourly exposure reported throughout the assessment. Although all of the measures are based on parent report, the LEAT calculations are based on careful questioning about the timeline of exposure on a day-by-day basis. This is in contrast to the overall parent estimate, for which parents provide a single estimate of relative language exposure for their child's lifespan. We conducted an analysis of the internal consistency of these estimates to assess their reliability in measuring language exposure (Tavakol & Dennick, 2011).

The second research question concerned the LEAT's criterion validity. *Criterion validity* refers to the relation between a test and performance on another theoretically related measure (DeVon et al., 2007; Waltz, 2005; Woehr & Arthur, 2003). Following the approach of similar adult assessments (Marian et al., 2007), we evaluated the criterion validity of the LEAT by asking whether the relative language exposure calculation predicts language outcomes. In the case of young toddlers, we expected that relative language exposure would predict scores on our vocabulary measures (David & Wei, 2008; Eilers et al., 2006; Hoff et al., 2012; Hurtado, Grüter, Marchman, & Fernald, 2014; Pearson et al., 1997; Poulin-Dubois et al., 2013). According to Grüter et al. (2014), analyses between exposure and language outcomes should be conducted in the same terms (either absolute or relative). For example, Hurtado et al. (2014) demonstrated a strengthened correlation between exposure and proficiency in Spanish- and English-speaking 30- and 36-month-olds when both measures were assessed in relative terms (e.g., relative exposure and first language [L1]: second language [L2] ratios). Thus, in the present analyses, relative language exposure served as our independent measure of interest, and relative vocabulary size in L1 and L2 (rather than a raw vocabulary score) served as our dependent measure. Recall that the LEAT's estimate of relative language exposure was calculated by weighting the hours of exposure per day according to the duration of exposure to each source of input relative to the child's age (see LEAT under Method and online Supplemental Materials S1, S2, and S3 for more detail). From these weighted hour estimates, the LEAT calculates relative language exposure (e.g., hours of exposure to Language A divided by sum of hours of exposure to Languages A and B).

The final question of the present study was aimed at investigating the utility of the LEAT. In particular, does it provide more explanatory power than simply asking parents to give an overall estimate of exposure? To this end, we investigated whether the detailed nature of the LEAT explained more variance than the single parent-report estimate of relative language exposure.

To answer our research questions concerning the utility and criterion validity of the LEAT, we ran two hierarchical linear regressions with relative vocabulary size as the dependent variable. The predictor variables for these two models were identical. In the first model, we assessed the utility and criterion validity of the LEAT using CCT scores as the dependent measure. Because there are established effects of age and socioeconomic status (SES) on raw vocabulary size, we included these in our models as control variables. However, it is important to note that there was no a priori reason to expect age or SES to influence children's relative vocabulary across their two languages. On the first step of the model, we included maternal education as a proxy for SES (e.g., Hoff, 2003; Hoff & Tian, 2005) and age to examine whether LEAT variables explained additional variance in language proficiency (vocabulary) above these two factors. On the second step, we included language (English, Spanish, or French) to evaluate language-specific effects on relative vocabulary size. On the third step, we included the overall parent estimate of relative language exposure to the dominant language. Recall that this was a separate parent estimate that was not derived from the LEAT's calculations, in which parents were asked to provide an overall estimate of percent language exposure from birth. On the final step, we entered the LEAT's calculation of relative exposure to the dominant language, derived from the detailed parent-report estimates provided throughout the assessment. The second model assessed the utility and criterion validity of the LEAT using MCDI scores as the dependent measure. All predictors were identical across the two models. Thus, these models evaluated the LEAT's utility by examining whether the LEAT's calculation of exposure, derived from a detailed parent report of day-by-day language input, explained significant variance in relative vocabulary size (as measured by the MCDI and CCT) above simply asking parents to provide an overall estimate. In addition, the analyses evaluated the LEAT's criterion validity by asking whether the LEAT's

relative language exposure calculation was a significant predictor of a theoretically related measure (vocabulary).

We expected that, consistent with previous research, an increase in relative language exposure would be associated with a larger proportion of known words in that language. Furthermore, the regression analyses evaluated language-specific effects between participants by holding language of exposure and vocabulary size constant within participants and asking whether the relation between the LEAT and vocabulary varies with language. That is, English exposure was considered in relation to English vocabulary for a single participant, Spanish exposure to Spanish vocabulary, and French exposure to French vocabulary. We opted for this single-model approach rather than evaluating separate models for each language. In this way, we avoided reducing power by breaking up the sample and decreased the possibility of capitalizing on chance by running separate analyses for each language.

Results

Internal Consistency

Cronbach's alpha was calculated for the overall parent estimate, the LEAT's calculation of hours per week, hours per day, and relative language exposure. They indicated strong internal consistency ($\alpha = .96$).

Utility and Criterion Validity

Relative Vocabulary Size as Measured on the CCT

To answer our research questions concerning the utility and criterion validity of the LEAT, we first ran a hierarchical linear regression with CCT relative vocabulary size in the child's two languages as the dependent variable. On the first step of the model, we included maternal education and age. On the second step, we included language (English, Spanish, or French). The third step included the overall parent estimate of relative language exposure to the dominant language. On the final step, we entered the LEAT's calculation of relative language exposure to the dominant language. Variance inflation factors were between 1.0 and 1.09, indicating that the predictor variables were not multicollinear and therefore appropriate for the regression analyses (Mansfield & Helms, 1982).

The first, second, and third models with age, maternal education, language, and the overall parent estimate were not significant in explaining relative vocabulary size. In a similar way, the fourth and overall model that included maternal education, age, overall parent estimate, and the LEAT calculation was not significant. However, the LEAT estimate explained significant additional variance in vocabulary ($R^{2\Delta} = .06$, $p = .02$) above maternal education, age, language, and the overall parent estimate. Indeed, removing these nonsignificant predictors yielded a significant model, such that the LEAT calculation predicted significant variance in vocabulary size, evincing a moderate effect size, $F(1, 96) = 4.85$, $p = .03$, $R = .22$ (see Table 2 for model fit statistics). The absence of a relation between vocabulary, age, and SES may seem somewhat surprising; however, recall that the dependent measure used in these analyses is relative vocabulary size rather than overall vocabulary. There is no a priori reason to expect that age or SES would influence vocabulary size in the dominant, relative to the nondominant, language. Figure 1 presents a scatter plot of the LEAT calculation of relative exposure as a function of relative vocabulary size on the CCT across the three language groups. Note that the trend lines are relatively parallel across languages.

Relative Vocabulary Size as Measured on the MCDI

A second hierarchical linear regression was performed but this time with MCDI relative vocabulary size as the dependent variable to parallel the analyses on the CCT. The predictor variables were identical to the ones in the previous regression analysis: The first step included maternal education and age, the second step included language (English, Spanish or French), the third step included the overall parent estimate of relative language exposure, and the fourth step included the LEAT's calculation of relative language exposure. Once again, the predictor variables were not multicollinear and therefore appropriate for the regression analyses (variance inflation factors range: 1.0 to 1.9; Mansfield & Helms, 1982).

Only the overall model that included maternal education, age, language, the overall parent estimate, and the LEAT's calculation was significant in predicting MCDI relative vocabulary size, $F(4, 78) = 2.81$, $p = .02$, $R^2 = .13$ (see Table 2). All of the other models were not significant. Furthermore, as before, only the LEAT calculation explained significant variance above the other predictor variables ($R^{2\Delta} = .07$, $p = .008$). Figure 2 presents a scatter plot of the LEAT calculation of relative exposure and relative vocabulary size on the MCDI across the three language groups. Note that, as for the CCT, the trend lines are relatively parallel across languages. Table 3 provides the bivariate correlations among the outcome and predictor variables across the MCDI and CCT analyses.

Discussion

The validity and reliability of parent report as a measure of relative language exposure has not been previously established despite widespread use in early bilingual language acquisition research. Thus, the aim of the present study was to provide an efficient language exposure assessment that could be used across languages and contexts and to examine the validity, reliability, and utility of the LEAT. Our results indicate that the LEAT demonstrates high internal consistency, criterion validity, and additional explanatory power above simply asking parents for an overall estimate of relative language exposure. It is important to note that these latter effects hold across parent-report and behavioral estimates of vocabulary knowledge.

Prior findings demonstrate that parent reports of relative language exposure correlate with word knowledge such that greater language exposure leads to larger vocabulary

Table 2. Change statistics and model fit analyses for each step in the hierarchical linear regressions using CCT and MCDI vocabulary as the dependent variable (DV), respectively.

	Change statistics		Model fit			
	$R^{2\Delta}$	*p*	β	*F*	*R*	*p*
DV: CCT relative vocabulary size						
1. Maternal education			.12			
Age	.01	.52	.01	0.66	.12	.52
2. Language	.002	.63	.05	0.51	.13	.67
3. Overall parent estimate of relative exposure	< .001	.97	.004	0.38	.13	.82
4. LEAT calculation of relative exposure	.06	.02*	.24	1.42	.27	.22
DV: MCDI relative vocabulary size						
1. Maternal education			.14			
Age	.03	.23	.12	1.50	.17	.23
2. Language	.03	.08	.18	2.04	.25	.11
3. Overall parent estimate of relative exposure	.002	.64	.05	1.57	.25	.19
4. LEAT calculation of relative exposure	.07	.008*	.27	2.81	.36	.02*

Note. CCT = Computerized Comprehension Task; LEAT = Language Exposure Assessment Tool; MCDI = MacArthur Communicative Development Inventory.

*Indicates significant value at $p < .05$.

(David & Wei, 2008; Eilers et al., 2006; Hoff et al., 2012; Pearson et al., 1997; Poulin-Dubois et al., 2013). In a similar way, Place and Hoff (2011) showed that the number of different conversational speakers and amount of native language exposure as reported by parents explained significant variance in lexical knowledge above relative language exposure in children at age 2. Furthermore, the number of language-exclusive sources of input predicted grammatical complexity in English. The link between exposure and language proficiency also held in the present study because language exposure estimated on the LEAT converged with measures of vocabulary size across French, English, and Spanish in young children, indicating strong criterion validity. Indeed, in the current sample of children, exposure to two languages was relatively balanced on average, and this balance was reflected in children's vocabulary sizes as a group (see Table 1).

We also assessed the utility of the LEAT by comparing its calculations to the overall parent-report measure of relative language exposure. That is, what is the utility of a detailed assessment, and what does it provide above the overall estimate a parent could provide? Across both measures of vocabulary, the calculation of relative language exposure based on detailed questioning explained significant additional variance above the overall parent estimate, age, and maternal education. Thus the comprehensive calculation generated by the LEAT based on detailed parent report provides a more robust and reliable measure of language exposure than the overall parent estimate. Together, these results support the idea that the LEAT indeed captures aspects of language exposure underlying early vocabulary growth, consistent with prior research. Given the widespread variability in parent reports of early language exposure, the LEAT introduces a valid, reliable, and systematic approach to assessing language exposure across studies.

The present findings also have implications for the assessment of exposure to better discern the sources of variability in early language acquisition research. Moreover,

Figure 1. Scatter plot for Computerized Comprehension Task (CCT) relative vocabulary measure as a function of the Language Exposure Assessment Tool relative language exposure by dominant language.

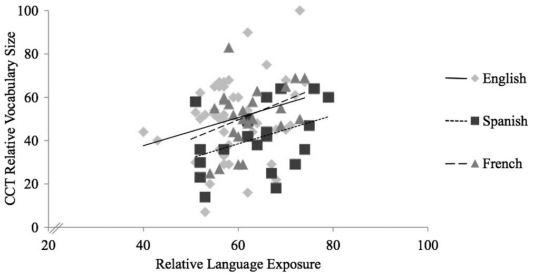

Figure 2. Scatter plot for MacArthur Communicative Development Inventory (MCDI) relative vocabulary measure as a function of the Language Exposure Assessment Tool relative language exposure by dominant language.

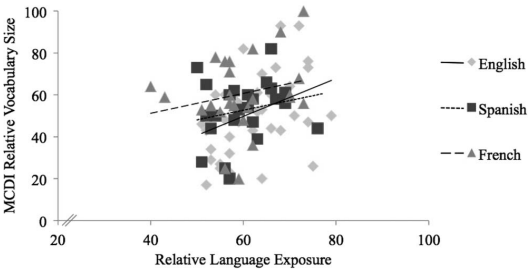

Table 3. Bivariate correlations for all predictor and outcome variables in regression analyses.

Measure	1	2	3	4	5
1. CCT relative vocabulary size					
2. MCDI relative vocabulary size	.12				
3. Age	−.02	−.14			
4. Maternal education	.13	−.11	−.04		
5. Overall parent estimate of relative exposure	.01	−.01	.08	.11	
6. LEAT estimate of relative exposure	.24*	.26*	.09	−.04	.23*

Note. CCT = Computerized Comprehension Task; MCDI = MacArthur Communicative Development Inventory; LEAT = Language Exposure Assessment Tool.

*Indicates significant value at $p < .05$.

and from a clinical perspective, the LEAT provides speech and language pathologists with a relatively easy, quick, and reliable tool for evaluating relative language exposure and determining whether language assessments and subsequent intervention should be conducted in one or more of a child's languages. For example, if both languages are functionally relevant for the child, it is recommended that both languages be assessed (Hoff & Core, 2013; Kohnert, 2013). Qualitative information on a child's significant conversational partners also informs the clinician and the researcher about the relevant communication settings for the child. The LEAT can also be readministered longitudinally to document the changing nature of a child's language exposure, thereby informing the changing communicative needs of the child. In addition, the current study contributes to the systematic measurement of language exposure in young bilingual and multilingual infants, building on previous language assessments. The LEAT can be used with other measures to inform educational policy with regard to the design of pre-K programs aimed at school readiness and K–12 curriculum, especially in communities with large immigrant populations. Last, the LEAT may also be particularly useful for immigrant populations in conjunction with currently available assessments to aid in determining the proper educational setting for children with varying degrees of exposure to the majority language.

Limitations

We now turn to potential limitations of the LEAT in capturing language exposure. As with all forms of self-report, there is a risk of reporting bias in using the LEAT. Highlighting this point, preliminary research by Grüter et al. (2014) has shown that parental reports of exposure do not correlate with a home language sample during a single, typical day. It is important to note that this finding is based on a small sample of 10 children between the ages of 36 and 40 months. As children enter the period of early childhood, it is likely that they are exposed to multiple speakers. Thus a single, overall parent report on language input may be insufficient to capture the richness of the language environment.

In addition, one caution in using the LEAT (or any parent-reported measure of exposure) is that estimates are likely to be most veridical for infants and toddlers for whom parents have substantial opportunity to observe sources of language input. This limitation could be mitigated by obtaining assessments from multiple sources (e.g., parents, teachers, other caregivers). For example, findings from Bornstein, Putnick, and De Houwer (2006) using parent reports of vocabulary on the MCDI demonstrate the importance of obtaining information from all possible sources of information to provide a broader estimate of early vocabulary.

An additional caution is that memory limitations should be taken into account when asking parents to estimate past language exposure. In the present study, we asked parents to estimate exposure during the course of the child's 17 months of life. Such retroactive estimates can become increasingly difficult as children get older and may therefore diminish the reliability of the LEAT. In these cases, it is possible to record more recent exposure estimates on the LEAT to ensure more accurate estimates (Bedore et al., 2012).

It is also important to note that although the LEAT's calculation of relative language exposure is associated with language outcomes (size of the lexicon), it is not itself an estimate of language proficiency. The LEAT should therefore not replace assessments of language levels in both languages for children in dual-language contexts. Instead, it can be a useful tool in clinical contexts for determining whether to examine proficiency in one or two languages. In a similar way, the LEAT does not capture all aspects of language exposure, but measures a subset of important factors that together are associated with vocabulary. For example, it does not assess fine-grained measures of language input that also affect early acquisition, such as number of words, speech rate, and maternal responsiveness, as these are variables that cannot be obtained from parental reports but through direct observation, usually in home settings (e.g., Hart & Risley, 1995; Tamis-LeMonda et al., 2001).

Conclusion

The heterogeneity of bilingual populations requires a valid characterization of the linguistic environment. Introducing consistency in the way in which we measure early language exposure in young children is a step in the

direction of providing consistent assessments. This article has introduced the LEAT, an electronic scoring tool, and a detailed user manual. Furthermore, we have provided evidence for the utility, validity, and reliability of the LEAT with data from toddlers across English–French and English–Spanish exposure contexts. Given that the majority of language exposure assessments in young children are parent reports, the present adaptation of the LEAT provides a unified assessment of relative language exposure variables in research and clinical contexts while contributing ease and consistency in administration through its electronic interface.

Materials

The LEAT will be made available at the Child Language Data Exchange System website in a downloadable Excel format (http://childes.psy.cmu.edu/) as well as in the supplemental information available online for this publication (see Supplemental Materials S2 and S3). The LEAT also has an accompanying manual that provides instructions as well as suggested dialogue for the researcher and clinician to elicit appropriate responses from parents (see online Supplemental Material S1). The manual also includes details on the calculations of exposure and instructions for creating spreadsheets with summary variables for each participant that can be exported into data analysis software using macros built into the LEAT. These materials can also be obtained directly from the first and senior authors.

Acknowledgments

This research was supported by National Institutes of Health awards 5R01HD068458 and HD068458-02S1 to the senior author and 1F31HD081933 to the first author and does not necessarily represent the views of the National Institutes of Health. Additional funding was provided by the Ministry of Economy and Competitiveness (PSI-2011-25376) to the second author and by the Natural Sciences and Engineering Research Council of Canada (2003–2013) to the third author. We gratefully acknowledge Zaira Flores, Kristi Hendrickson, Anya Mancillas, Tamara Patrucco, and Monyka Rodrigues for assistance in participant recruitment, data collection, and coding and all of the parents and infants who devoted their time to participate in this research. Parts of the research included in this manuscript were presented at the Society for Research and Child Development Special Topics meeting on Developmental Methods (September 2014).

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Chapter 3, in full, is a reprint of material as it appears in DeAnda, S., Bosch, L., Poulin-Dubois, D., Zesiger, P., & Friend, M. (2016). The Language Exposure Assessment Tool: Quantifying exposure for bilingual research in young infants and children. *Journal of Speech Language and Hearing Research* [Advance online publication], 1-11. The dissertation author was the primary investigator and author of this paper.

Chapter 4: Lexical access in the second year: a study of monolingual and bilingual vocabulary development

Bilingualism: Language and Cognition: page 1 of 14 © Cambridge University Press 2017 doi:10.1017/S1366728917000220

Lexical access in the second year: a study of monolingual and bilingual vocabulary development*

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(Received: September 14, 2016; final revision received: March 31, 2017; accepted: April 6, 2017)

It is well established that vocabulary size is related to efficiency in auditory processing, such that children with larger vocabularies recognize words faster than children with smaller vocabularies. The present study evaluates whether this relation is specific to the language being assessed, or related to general language or cognitive processes. Speed of word processing was measured longitudinally in Spanish- and English-learning monolinguals and bilinguals at 16 and 22 months of age. Speed of processing in bilinguals was similar to monolinguals, suggesting that the number of languages to which children are exposed does not influence word recognition. Further, cross-language associations in bilinguals suggest that the dominant language supports processing in the non-dominant language. These cross-language associations are consistent with general language and cognitive efficiency accounts in which the relation between word processing and knowledge relies on experience within a language as well as on general and cognitive properties of language learning.

Keywords: lexical access, bilinguals, vocabulary, toddlers

Introduction

Previous research documents a significant increase in vocabulary size and speed of oral (or spoken) word recognition in monolinguals throughout the 2nd year of life. Moreover, there is a relation between these measures across English- and Spanish-speaking monolinguals, such that children with larger vocabularies demonstrate faster word recognition than children with smaller vocabularies (Fernald, Perfors & Marchman, 2006; Fernald, Pinto & Swingley, 1998; Hurtado, Marchman & Fernald, 2007). What's more, this relation becomes more robust from 18 to 24 months (Fernald, Marchman & Weisleder, 2013). However, few studies have examined the development of speed in word processing in young bilinguals and whether improvements in word processing are related to vocabulary growth in both languages (Legacy, Zesiger, Friend & Poulin-Dubois, 2016; Marchman, Fernald & Hurtado, 2010). The present investigation compares the developmental changes in spoken word processing and vocabulary growth between monolingual English, Spanish, and bilingual English–Spanish learners during the 2nd year.

The study of speed of word processing in bilinguals offers both applied and theoretical implications. From an applied perspective, it has been shown that both vocabulary size and speed of word processing predict later language development within MONOLINGUAL populations (Marchman & Fernald, 2008). Despite our rich understanding of the development of monolingual word processing and comprehension, it is estimated that a large majority of the world's population speaks more than one language, and this population is rapidly growing within the US (US Census Bureau, 2011). Therefore an understanding of language differences that result from culturally and linguistically diverse environments is essential to the practice of Speech-Language Pathologists who serve an increasingly diverse population (American Speech-Language-Hearing Association, 2007). To this end, researchers must first establish consensus in the literature with regard to the rate of development of early bilingual vocabulary knowledge and speed of processing in order to appropriately identify atypical deviations within the multilingual population. Further, it is important to establish whether models of monolingual language acquisition apply to multilingual learners. Toward this

* This research was supported by NIH awards 5R01HD068458 and HD068458-02S1 to the senior author and 1F31HD081933 to the first author, and does not necessarily represent the views of the National Institutes of Health. We gratefully acknowledge all of the parents and children who have devoted their time to participate in this research.

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end, the present study aims to investigate the within- and cross-language associations between vocabulary size and speed of word recognition in early bilingual first language acquisition. We argue that examining within- and cross-language links sheds light on 1) the relation between vocabulary size and speed of processing, 2) how this relation extends to bilinguals, and 3) the importance of timing and language dominance on this relation.

Examining vocabulary size and speed of word recognition

Although monolingual children as young as 16 months demonstrate strong relations between vocabulary knowledge and speed of word recognition (Fernald et al., 2006; Fernald, Swingley & Pinto, 2001; Hendrickson, Mitsven, Poulin-Dubois, Zesiger & Friend, 2015; Hurtado et al., 2007; Legacy, Zesiger, Friend & Poulin-Dubois, 2015; Zangl, Klarman, Thal, Fernald & Bates, 2005), the nature and specificity of this relation is not well understood. There are three possible explanations for this relation. One hypothesis is that the relation between vocabulary size and word processing is based on experience within a language (language-specific hypothesis). In the case of bilinguals, this would mean that processing speed and vocabulary knowledge are dissociable across languages, such that processing speed in one language is related to within- and NOT cross-language vocabulary knowledge. Alternatively, it is possible that the relation between word processing and vocabulary does not rely on experience within a language, but instead, general language experience (general language hypothesis). That is, language skills broadly construed (e.g., auditory, phonological, lexical, semantic, and syntactic processes) subserve vocabulary across languages. From this view, processing speed and vocabulary size in bilinguals would be related both within and across languages. A final possibility is that the association between vocabulary knowledge and word processing speed is not mediated by language experience but instead by general cognitive efficiency (cognitive efficiency hypothesis). For example, general processing mechanisms (e.g., speed of processing, associative learning, etc.) influence the rate of vocabulary development. Thus, from a theoretical perspective, the study of lexical processing within bilinguals affords the opportunity to examine whether improvements in word processing are dissociable across languages within a single language learner (DeAnda, Poulin-Dubois, Zesgier & Friend, 2016c).

One way to begin teasing apart these possibilities is to investigate the WITHIN- and CROSS-LANGUAGE ASSOCIATIONS between vocabulary size and speed of processing within bilinguals. That is, if within-language associations arise in the absence of cross-language associations, this would support the language-specific hypothesis. Alternatively, the existence of cross-language associations would support the general language and cognitive efficiency hypotheses. However, most studies to date have focused on the relation between vocabulary and speed of word processing WITHIN, as opposed to between, languages, leaving open the question of cross-language associations. From this work, it has been shown that processing speed and vocabulary size are related within the non-dominant language at 17 months in French–English bilinguals and in both languages by 22 months (Legacy et al., 2015, 2016). By 30 months, English–Spanish bilinguals show significant correlations between speed of word processing and vocabulary size within each language, but not across languages (Marchman, Fernald & Hurtado, 2010). However, Marchman et al. (2010) reported a marginal association between total conceptual vocabulary and processing speed in Spanish and English, respectively, suggesting shared variance between languages in bilinguals. The present paper seeks to confirm and extend these findings by evaluating changes over time in the relation between vocabulary size and speed of word recognition in a longitudinal study of monolingual and bilingual children. Further, we examine this relation as a function of language dominance in bilinguals.

Vocabulary size and speed of word recognition in young bilinguals

Longitudinal cross-language associations between speed of processing and vocabulary size in early bilingual language acquisition can elucidate the extent to which these relations in bilinguals parallel those observed in monolingual children, the timing of these relations, and their dependence on language dominance. There is a dearth of literature on how word processing in bilinguals compares to the monolinguals' case across the 2nd year of life. In the only study to date to compare lexical access across monolingual and bilingual toddlers, French–English bilinguals in Canada showed comparable speed of processing for words in both of their languages at 17 months of age, as well as comparable speed of processing relative to their French monolingual counterparts in Switzerland (Legacy et al., 2015). This is in contrast to adult findings that indicate differences in lexical processing in bilinguals versus monolinguals across picture naming and lexical decision tasks (Ivanova & Costa, 2008; Gollan, Montoya, Fennema-Notestine & Morris, 2005; Ransdell & Fischler, 1987).

The role of timing and language dominance

With regard to timing, it is unknown how cross-language associations develop OVER TIME in early

language acquisition, and in particular at a time when young children are beginning to negotiate the semantic organization of words from two languages (i.e., 16 to 24 months; Arias-Trejo & Plunkett, 2009; 2013; Styles & Plunkett, 2009; von Koss Torkildsen, Sannerud, Syversen, Thormodsen, Simonsen, Moen, Smith, & Lindgren, 2006; Willits, Wojcik, Seidenberg & Saffran, 2013). Indeed, findings suggest that lexical-semantic organization follows a developmentally incremental process, such that 24-, but not 18-month-old, monolinguals demonstrate semantic priming between words with related word meanings (e.g., Arias-Trejo & Plunkett, 2009). Of interest is whether cross-language lexical associations in bilinguals demonstrate a similar developmental shift over the second year of life. That is, to what extent do cross-language relations in bilinguals develop on a similar developmental timetable to within-language associations in monolinguals?

To the extent that there is evidence of cross-language relations, it is important to evaluate the influence of language dominance on these associations. Prominent models of adult bilingual language organization posit differential effects of language dominance on processing (e.g., Kroll & Stewart, 1994). For example, the Revised Hierarchical Model suggests that differences in language dominance (due to language proficiency and age of acquisition) can impact the connections between lexicons and the conceptual store (for a review see Kroll, van Hell, Tokowicz & Green, 2010). This leads to differences in both the efficiency and accuracy of translation production from L2 to L1 and from L1 back to L2. Recent evidence suggests that this may extend to young toddlers, as Mandarin–English bilinguals exhibit lexical priming from the dominant to the non-dominant language, but not from the non-dominant to the dominant language (Singh, 2014). Similar effects of dominance have been found for syntactic priming in young children (Vasilyeva, Waterfall, Gámez, Gómez, Bowers & Shimpi, 2010; Yip & Matthews, 2000). Together these findings suggest that cross-language associations between processing speed and vocabulary size may also be modulated by language dominance in adults and children. The present study evaluates cross-language relations between speed of processing and vocabulary size and the effect of timing and language dominance on these relations. It does so by contrasting Spanish–English bilingual first language toddlers with monolinguals in each language, within the same geographic location and sociolinguistic strata longitudinally.

Study aims and hypotheses

The overall purpose of the present study is to compare speed of processing and vocabulary within bilinguals and monolinguals longitudinally throughout the 2nd year of life. Importantly, in an approach unique to this paper, bilingual speed of processing and vocabulary size will be compared to two monolingual samples (one for each of the bilingual sample's languages). The first aim is to evaluate changes in speed of word processing from 16 to 22 months within the dominant and non-dominant languages in bilinguals and to contrast this with monolingual processing in each language over the same period. We expect speed of processing to improve over time across all language groups, consistent with monolingual and bilingual findings (Hurtado et al., 2007; Fernald et al., 2006). Of particular interest is whether a) dominance influences speed of word processing over time and b) speed of processing changes within bilinguals, relative to monolinguals, between 16 and 22 months.

It is important to note that the present study employs a haptic measure of speed of processing unlike the gaze responses employed in several studies (e.g., Fernald et al., 2006). We expected that haptic reaction times would be as sensitive to speed of processing as gaze responses for several reasons. First, previous work has shown that visual reaction time and haptic response are significantly correlated at 16 months of age (Hendrickson et al., 2015). Further, several speed of processing findings using gaze as a measure have been replicated using a haptic measure. For example, Legacy et al. (2015, 2016) demonstrated that speed of processing and vocabulary size are significantly correlated in monolinguals and bilinguals in the second year of life. Finally, haptically-assessed speed of processing becomes faster with age and vocabulary size, a finding consistent with the literature employing gaze measures. The benefit to using a haptic measure is that we were able to obtain estimates of both speed of processing and vocabulary size from the same behavioral measure, thus reducing the influence of method variance on our findings.

The second aim is to examine the relation between speed of word processing and vocabulary development in bilinguals in comparison to monolinguals over the same period. Following previous research, we hypothesize that within-language associations are present in monolingual and bilingual children at both 16- and 22-months of age. However, within bilinguals, we expected that cross-language associations between speed of word recognition and vocabulary size would not be evinced after controlling for within-language vocabulary. This hypothesis is contingent upon a strong within-language correspondence between lexical processing and vocabulary size. Finally, we anticipated that language dominance would modulate associations between processing speed and vocabulary size such that the relation between word recognition and vocabulary would be strongest in the dominant language relative to the non-dominant language at both 16 and 22 months.

Method

Participants

Participants were drawn from a larger longitudinal project assessing language comprehension in the 2nd year of life. Participants were obtained through a database of parent volunteers recruited through birth records, internet resources, and community events in a large metropolitan area in Southern California. All participants were full-term and had no diagnosed impairments in hearing, vision, language, and cognition. A final sample of 187 children was then divided into three groups based on language exposure as assessed on the Language Exposure Assessment Tool at 16 months (LEAT, DeAnda, Bosch, Poulin-Dubois, Zesiger & Friend, 2016b, see below for a description of the tool): English monolingual, Spanish monolingual, and Spanish–English bilingual toddlers. Exposure at 16 months was used for grouping participants at initial testing. Exposure remained remarkably stable between 16 and 22 months of age (*M change in exposure* = 2.47%, *SD* = 5.22%).

The final sample included 79 monolingual English-hearing toddlers (41 females, 38 males), 64 monolingual Spanish-hearing toddlers (31 female, 33 male), and 44 bilingual English–Spanish hearing toddlers (17 females, 28 males). Each participant was tested at 16-months (English: *M* = 16;20, range = 15;15 – 18;2; Spanish: *M* = 17;3, range = 15;15 – 20;21; Bilingual: *M* = 17;23, range = 14;23 – 19;21), and 22-months (English: *M* = 23;2, range = 21;6 – 25;12; Spanish: *M* = 23;21; range = 21;0 – 21;15; Bilingual: *M* = 24;15; range = 21;3 – 26;18). The average maternal education for the English monolinguals was approximately completion of a 4-year college degree (*M* = 15.45 years, *SD* = 2.08, range = 12 – 18). On average, mothers in the Spanish monolingual and bilingual group completed about one or two years of college (Spanish: *M* = 13.05 years, *SD* = 3.35, range = 6 – 18; Bilinguals: *M* = 14.62, *SD* = 2.32, range = 8 – 18). An ANOVA revealed that maternal education differed significantly across language groups ($F(3, 460) = 20.95$, $p < .001$). Therefore, we evaluated the effect of maternal education on latency in our analyses.

Apparatus

The study was conducted in a sound attenuated room. Stimuli were presented on a 51 cm 3M SCT3250EX touch capacitive wall-mounted monitor. An HD video camera was mounted above and behind the touch monitor to capture haptic response to the visual stimuli. Two audio speakers were positioned to the right and left of the touch monitor for the presentation of auditory reinforcers that aided in maintaining interest and compliance.

Measures

Language Exposure Assessment Tool (LEAT).

The LEAT (DeAnda et al., 2016b) provides estimates of daily language exposure derived from parent reports of the number of hours of language input by parents, relatives and other caregivers in contact with the child. Trained experimenters followed the LEAT manual to interview parents on the number of speakers who interacted with the child and the number of hours of exposure to each speaker over the course of the child's life.

The LEAT is separated into two major sections that together permit the calculation of relative language exposure. In the first section, parents list the people who interact with the child regularly (i.e., at least once a week), the language(s) they speak, and whether they are native speakers of the language(s). In the second section, the amount of time that the child spends hearing each of these conversational partners in each language is assessed. This information is broken down by day of the week and by age, thereby capturing exposure that happens on specific days of the week and at specific ages in the child's life (e.g., "At what age did the child start receiving language input from person A?"). Finally, parents estimate the amount of input children receive on an average day for each conversational partner.

Thus, the LEAT estimate reflects cumulative language exposure. Parents were not restricted in the number of hours of language input that they could report. Nevertheless, parents' reports of language exposure fell within the expected range of waking hours per day. In the present sample, mean hours of exposure per day were 8.97 (*SD* = 3.18). Relative language exposure was estimated by calculating the proportion of time that the child heard English or Spanish relative to other language input. Proportions, rather than raw hours of exposure, were used to standardize the scale of measurement. This calculation was then used to categorize the three groups. English and Spanish monolinguals were those children with >80% exposure to English or Spanish, respectively. Bilinguals were those with ≤ 80% to the dominant language (English or Spanish) and at least 20% exposure to their non-dominant language (English or Spanish). This 80% cutoff is often the limit for inclusion of bilingual participants in a sample (Pearson, Fernandez, Lewedeg & Oller, 1997; Byers-Heinlein, 2015). On average, bilinguals had 63% exposure to their dominant language, and 37% to the non-dominant language. For most bilingual children, Spanish was the dominant language of exposure (Spanish-dominant: N = 26, English-dominant: N = 18). All but one child had exposure to two languages. One participant had exposure to three languages, but exposure was less than 12%. For our monolingual groups, children received native input primarily from caregivers in the home. For our bilingual group, in the dominant language, all but two

children received native input primarily from caregivers in the home (N = 42). In the non-dominant language, input was from non-native or non-parent sources for 26 participants, with 18 children receiving non-dominant input from a native speaker in the home.

Computerized Comprehension Task (CCT).
The CCT is a behavioral measure that captures children's haptic response to assess early decontextualized receptive vocabulary. The CCT demonstrates strong internal consistency, converges with parent report on the MacArthur-Bates Communicative Development Inventory (MCDI, Fenson, Marchman, Thal, Dale, Reznick & Bates, 2006), and predicts subsequent language production (Friend et al., 2012). Additionally, responses on the CCT are nonrandom (Friend & Keplinger, 2008) and this finding replicates across languages (Friend & Zesiger, 2011) and across monolinguals and bilinguals (Poulin-Dubois et al., 2012). Further, in the present sample, bilingual performance was stable across languages within participants, such that children with high scores in Spanish also achieved a high score in English ($r(53) = .37$, $p < .01$). Similarly, performance on the CCT was significantly and positively correlated with parent report of expressive vocabulary on the MCDI at 16 and 22 months of age (16 months: $r(215) = .31$, $p < .001$; 22 months: $r(163) = .46$, $p < .001$). The English and Spanish CCT have good test-retest reliability, excellent internal consistency, and predict expressive vocabulary size (e.g., Friend & Keplinger, 2008; Friend, Schmitt & Simpson, 2012).

Participants are prompted to touch images on the monitor (e.g., "Where's the *dog?* Touch *dog!"*). A correct touch to the target image (e.g., the dog) elicits a reinforcing sound (e.g., the sound of a dog barking). The CCT presents 4 training trials and 41 test trials in a two-alternative forced-choice procedure. For each trial, two images (a target and distractor image) appeared simultaneously on the right and left side of the touch monitor. The side on which the target image appeared was presented in pseudo-random order across trials such that target images could not appear on the same side on more than two consecutive trials, and the target was presented with equal frequency on both sides of the screen (Hirsh-Pasek & Golinkoff, 1996). All image pairs presented during training, testing, and reliability were matched for word difficulty (easy, medium, hard) based on MCDI norms (Dale & Fenson, 1996), part of speech (noun, adjective, verb), category (animal, human, object), and visual salience (color, size, luminance).

The CCT begins with a training phase to insure participants understand the nature of the task. During the training phase, participants were presented with early-acquired noun pairs (known by at least 80% of 16-month-olds; Dale & Fenson, 1996) and prompted by the experimenter to touch the target. If the child failed to touch the screen after repeated prompts, the experimenter touched the target image for them. If a participant failed to touch during all four training trials, the training trials were repeated once. Only participants who executed at least one correct touch during the training phase proceeded to the testing phase. All of the participants proceeded to the testing phase.

Each test trial ended when the child touched the screen or until seven seconds elapsed. When the child gaze was directed toward the touch monitor, the experimenter delivered the prompt in infant-directed speech and advanced each trial. The experimenter presented each pair of images as she uttered the target word in the first sentence prompt such that the onset of the target word occurred just prior to the onset of the visual stimuli.

Noun prompts
Where is the _____? Touch _____.
Donde esta el/la _____? Toca _____.

Verb prompts
Who is _____? Touch _____.
Quien esta _____? Toca _____.

Adjective prompts
Which one is _____? Touch _____.
Cual es_____? Toca _____.

Procedure

Participants completed testing at 16 months, and 6 months later at 22 months of age. Testing procedures were identical at both ages. English and Spanish monolingual participants were tested using the English or Spanish CCT, respectively. Spanish–English bilingual participants completed testing in both English and Spanish on separate days, approximately one week apart. The order in which each language was tested was counterbalanced.

Toddlers were seated on their caregiver's lap centered at approximately 30 cm from a touch sensitive monitor with the experimenter seated just to the right. Parents wore blackout glasses and noise-cancelling headphones to mitigate parental influence during the task. The assessment followed the protocol for the Spanish and English adaptations of the Computerized Comprehension Task (CCT; DeAnda, Arias-Trejo, Poulin-Dubois, Zesiger & Friend, 2016a; Friend & Keplinger, 2003; 2008; Hendrickson & Friend, 2013; Hendrickson et al., 2015).

Coding

A waveform of the experimenter's prompts was extracted from the video recording (see Hendrickson et al., 2015

for a similar coding procedure). Subsequently the video of participant's haptic responses and the waveform of the experiment's prompts were synced and used to code the onset of the visual stimuli, the onset and offset of the target word, and the frame in which the participant touched the screen for each trial using Eudico Linguistics Annotator (ELAN) (<http://tla.mpi.nl/tools/tla-tools/elan/>, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands; Lausberg & Sloetjes, 2009). Only trials in which the participant touched the prompted word (e.g., target) were included in the analyses of haptic reaction time. Haptic responses were coded over the course of the entire trial (maximum duration = 7 seconds). Trials with short latencies (< 400 ms) likely reflect haptic behavior that was planned prior to hearing the target word (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Fernald, Zangl, Portillo & Marchman, 2008; Poulin-Dubois et al., 2012). For this reason, trials were included in subsequent analyses if the participant touched the screen with a latency > 400 ms. A total of 22 trials were removed with latencies <400 ms.

Coders completed extensive training to identify the characteristics of speech sounds within a waveform, both in isolation and in the presence of coarticulation. Because a finite set of target words always followed the same carrier phrases (e.g., "Where is the ____", "Who is ___", or "Which one is ____"?), training included identifying different vowel and consonant onsets after the words "the" and "is". Coders were also trained to demarcate the onset of vowel-initial and nasal-initial words after a vowel-final word in continuous speech, which can be difficult using acoustic waveforms in isolation. Additionally, coders were required to practice on a set of files previously coded by the second author with supervision and then to code one video independently until correspondence with previously coded data was reached.

Coding for the haptic reaction time (RT) began at image onset, roughly 238 ms after target word onset, and prior to target word offset in the first sentence prompt. Inter-rater reliability coding was conducted for a random sample of 20% of the data for each sample (Monolingual English, Monolingual Spanish, Bilingual). Reliability was established within three frames for target word onset, offset, and touch onset. Reliability coding was completed for each measure with an inter-rater agreement of at least .90.

Results

Haptic RT was used as a measure of word processing speed and the number of target touches executed during the task was used as estimate of vocabulary size (DeAnda et al., 2016a; Friend & Keplinger, 2003; 2008; Poulin-Dubois et al., 2012). Recall that vocabulary knowledge on the CCT converges with parent report on the MCDI and predicts subsequent language production (Friend et al., 2012).

Language dominance was determined based on exposure as measured on the LEAT. To assess the appropriateness of collapsing across languages to assess the relation between dominant language vocabulary size and RT, we conducted two t-tests: one to assess differences in vocabulary size across languages and one to assess differences in RT. There were no differences in total RT and vocabulary size between English-dominant and Spanish-dominant children (all *p*s >.11). This, in conjunction with the good psychometric properties of the CCT, provides support for our analytic approach.

Table 1 provides descriptive statistics for vocabulary size and RT as a function of dominance for all three groups of participants. All analyses were conducted using R Studio (RStudio Team, 2015). To begin, an omnibus ANCOVA with haptic RT as the dependent variable was run to evaluate effects of maternal education and sex. Results revealed no effects of maternal education and sex (all n.s. $p > .3$). These variables were therefore dropped from subsequent analyses.

Development of speed of word processing and vocabulary size

Our first aim was to evaluate changes in speed of word processing from 16 to 22 months within the dominant and non-dominant languages in bilinguals and compare this to monolinguals over the same period. Haptic RT's were the dependent measure in a 2x2 mixed-design ANOVA with one within-subjects variable, Age (16 or 22 months), and one between-subjects variable, Language Group (monolingual or bilingual). Results revealed a significant main effect of Age ($F(1, 372) = 72.80$, $p < .001$), but no significant main effect of Language Group, or significant Age X Language Group interaction (all n.s. $p > .7$), such that children show faster word processing at 22 than at 16 months of age across all groups. These results are presented in Figure 1.

However, although children significantly increased speed (RT) as a group, there was no correlation between individual RT at 16 and 22 months of age. To explore this further, we evaluated individual difference scores between RT at 16 and 22 months of age (RT at 16 months minus RT at 22 months). A review of these scores revealed that most children (79% of participants) decreased in RT by an average of 1 second (M = 1,118.34 ms, SD = 764.07 ms). Further, there was a significant correlation between RT difference scores and RT at each age (RT at 16 months: $r(144) = .70$, $p < .001$; RT at 22 months: $r(144) = -.64$, $p < .001$). Thus, GROWTH in RT over this 6-month period is associated with speed of processing at each age: children who were relatively slow at 16 months made greater gains than children who were relatively fast. Equally, children

Table 1. *Descriptives for vocabulary size and haptic RT across groups at 16 and 22 months of age.*

	Vocabulary Size		Reaction Time (ms)	
	16 months	22 months	16 months	22 months
		M (SD)		
Bilingual Dominant	9.35 (5.82)	18.42 (10.98)	3479.34 (914.79)	2736.27 (989.49)
Bilingual Non-dominant	10.05 (5.67)	20.07 (8.52)	3318.01 (812.09)	2631.95 (664.77)
English Monolingual	11.9 (7.36)	26.82 (7.81)	3450.29 (905.70)	2605.44 (603.60)
Spanish Monolingual	9.19 (5.02)	17.54 (8.41)	3413.55 (737.89)	2853.37 (852.11)

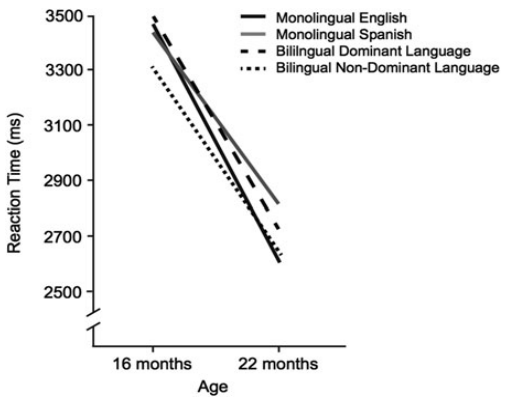

Figure 1. Changes in haptic RT across all groups.

who evinced the greatest improvement in RT had the most rapid RT at 22 months.

Next we evaluated changes in vocabulary size in an analogous analysis with CCT vocabulary size as the dependent variable and Age (16 or 22 months) and Language Group (monolingual or bilingual) as independent variables. Once again, there was a significant main effect of Age ($F(1, 370) = 232.44$, $p < .001$) indicating a significant increase in vocabulary size across all groups. This pattern of results was consistent with the correlational results, such that children's vocabulary size on the CCT was significantly correlated between 16 and 22 months of age ($r(170) = .45$, $p < .001$). There was also a marginal main effect of Language Group ($F(1, 370) = 195.6$, $p = .07$) which reflects the fact that English monolinguals outperformed their bilingual peers when comparing performance in a single language consistent with previous work (e.g., Pearson et al., 1993). There was no significant interaction between Age and Group ($p > .39$).

To evaluate whether there were differences in processing speed in the dominant and non-dominant language within bilinguals we conducted an ANOVA in which Age (16 or 22 months) and Language (Dominant or Non-dominant) were the within-subjects variables and Haptic RT was the dependent measure. Once again there was a significant effect of Age ($F(1, 121) = 20.16$, $p < .001$) but no effect of Language and no significant Age X Language interaction (all n.s. $p > .36$).

To summarize, both speed of processing and vocabulary size show significant gains over the period from 16 to 22 months of age. These findings hold at both the group and individual level. Importantly, Language Group was a significant predictor of vocabulary size at both ages, with bilinguals demonstrating a smaller vocabulary size than their monolingual peers in a single language. However, there was no effect of Language Group on RT. We elucidate these findings and their implications in the discussion.

Relation between speed of word processing and vocabulary

We next examined the relation between speed of word processing and vocabulary within monolinguals and bilinguals, and whether this changed across 16 and 22 months of age.

Monolinguals.

To replicate previous research, we first examined haptic RT and vocabulary size within monolinguals. A 2x2 ANOVA was run with haptic RT as the dependent variable and Age (16 or 22 months), Language (English or Spanish), and CCT Vocabulary within monolinguals. There was a significant main effect of Age ($F(1, 243) = 56.64$, $p < .01$) indicating that haptic RT decreases between 16 and 22 months within the monolingual groups as expected. In addition, there was a significant main effect of Vocabulary ($F(1, 243) = 21.68$, $p < .001$) on haptic RT (see Figure 2). Regression parameters are presented inTable 2. Finally, there was no main effect of Language, nor significant interactions between Age, Language, and Vocabulary (all n.s. $p > .25$).

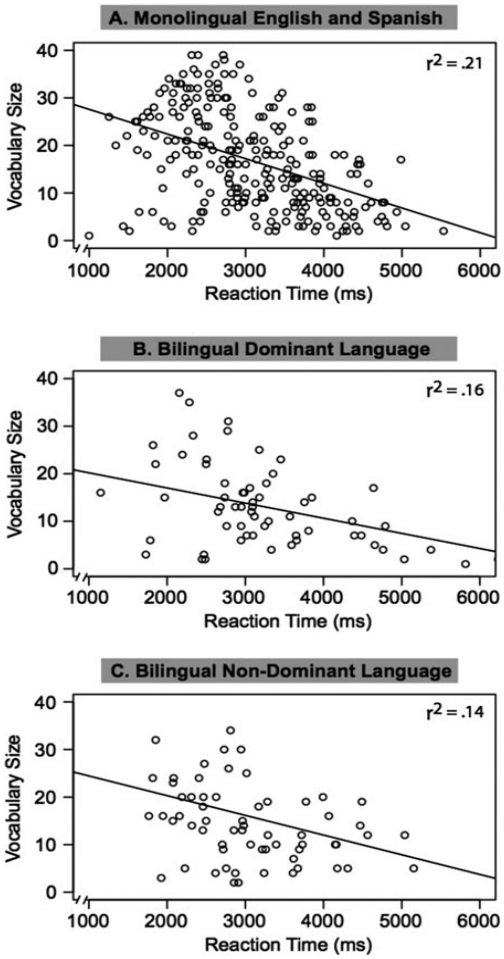

Figure 2. Relation between vocabulary size (CCT) and haptic RT (latency) across groups.

Bilinguals.

Lastly, we tested whether the relation between word processing and vocabulary size extended to bilinguals at both 16 and 22 months of age. We examined RT in the dominant and non-dominant language as a function of Age (16 or 22 months) and total vocabulary on the CCT across languages. Across the dominant and non-dominant language, total vocabulary was a significant predictor of RT (dominant language RT: $F(1, 55) = 4.98$, $p = .03$; non-dominant language RT: $F(1,56) = 4.33$, $p = .04$) replicating monolingual findings.

Next, we sought to examine within- and cross-language associations between vocabulary size and RT in each language. We began by examining haptic RT in the DOMINANT LANGUAGE to evaluate cross-language relations between vocabulary and speed of processing after controlling for within-language associations in the dominant language. A hierarchical linear regression predicting haptic RT in the dominant language was conducted with Age (16 or 22 months) on the first step, Dominant Language Vocabulary on the second step, and Non-Dominant Language Vocabulary on the third step. Results revealed a significant main effect of Age ($F(1, 51) = 7.63$, $p = .008$), and a significant main effect of Dominant Language Vocabulary after controlling for Age ($F(1, 51) = 6.98$, $p = .01$), indicating a significant relation between vocabulary and speed of processing within the dominant language across 16 and 22 months of age. However, there was no significant effect of Non-Dominant Language Vocabulary after controlling for Dominant Language Vocabulary and Age. Further, no significant interactions were observed (all n.s. $p > .3$, see Figures 2 and 3). Regression parameters are presented in Table 3.

Correspondingly, we examined within- and cross-language associations between haptic RT and vocabulary size in the NON-DOMINANT language to evaluate cross-language relations between vocabulary and speed

Table 2. *Regression parameters for monolingual analysis.*

	Regression Parameters			
	β	F	p	η_p^2
DV: Reaction Time				
1. Age	−.42	56.64	<.001	.19
2. Language	.06	1.08	.30	.004
3. Vocabulary	−.36	21.68	<.001	.08

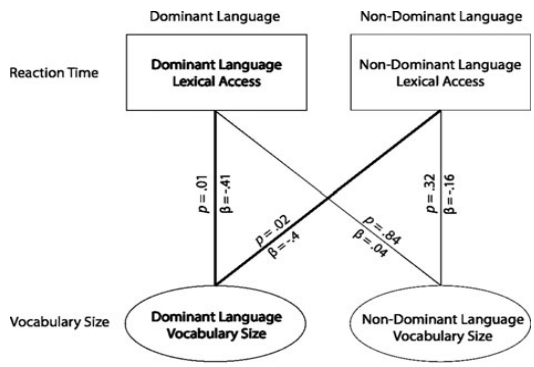

Figure 3. Regression results for within and cross-language relations between speed of processing and vocabulary size within bilinguals after controlling for age.

Table 3. *Regression parameters for bilingual analyses.*

	Regression Parameters			
	β	F	p	η_p^2
DV: RT in the Dominant language				
1. Age	−0.09	7.63	.008	0.13
2. Vocabulary Size in the Dominant Language	−0.41	6.98	.01	0.12
3. Vocabulary Size in the Non-Dominant Language	0.04	.04	.84	0.1
DV: RT in the Non-Dominant language				
1. Age	−0.37	9.64	.004	0.16
2. Vocabulary Size in the Non-Dominant Language	−0.16	1.01	.32	0.02
3. Vocabulary Size in the Dominant Language	−0.4	5.70	.02	0.1

of processing after controlling for within-language associations in the non-dominant language. A hierarchical linear regression predicting haptic RT in the non-dominant language was evaluated with Age (16 or 22 months) on the first step, Non-Dominant Language Vocabulary size on the second step, and Dominant Language Vocabulary size on the third step. Age was a significant predictor of haptic RT in the non-dominant language ($F(1, 52) = 9.64$, $p = .004$). However, Non-Dominant Language Vocabulary did not predict within-language haptic RT after controlling for Age. Nevertheless, cross-language Dominant Language Vocabulary was a significant predictor ($F(1, 52) = 5.7$, $p = .02$, see Figures 2 and 3) even after controlling for Age and Non-Dominant Vocabulary. No interaction terms were significant (all n.s. $p > .3$). Results for vocabulary size and haptic RT across the dominant and non-dominant language are summarized in Figure 3. Regression parameters are presented in Table 3.

By-item analyses.

Finally, to test whether the relation between vocabulary comprehension and RT held across items as well as across participants, we conducted two separate by-item analyses (for monolingual and bilingual groups, respectively) in which accuracy was collapsed across items rather than participants. Within monolinguals, an ANCOVA was performed to evaluate RT as a function of Age (16 or 22 months) and Language (English or Spanish), with Comprehension (proportion of participants who chose the target for each item) as the covariate. There were main effects of Comprehension ($F(1, 147) = 53.17$, $p < .001$), Age ($F(1, 147) = 19.73$, $p < .001$), and a significant Comprehension X Age interaction ($F(1, 147) = 6.91$, $p = .009$) such that the relation between word comprehension and RT became stronger with age (16 month $r = -.07$ and 22 month $r = -.24$). However, this effect was observed only in this analysis and not in the by-participant analyses or the bilingual by-item analyses. Within bilinguals, an ANCOVA was performed to evaluate RT as a function of Age (16 or 22 months) and Language Dominance (Dominant or Non-Dominant), with Comprehension (proportion of participants who chose the target for each item) as the covariate. There were main effects of Comprehension ($F(1, 63) = 4.06$, $p = .04$), and Age ($F(1, 63) = 75.28$, $p < .001$) and no significant interactions (all n.s. $p > .35$). These results, in conjunction with the by-participant analyses support the interpretation that increases in vocabulary size support faster RTs in monolingual and bilingual children across items and participants.

Discussion

In this study we examined speed of word processing and vocabulary within bilinguals and monolinguals longitudinally throughout the 2nd year of life. The first aim of the present study was to evaluate changes in speed of word processing from 16 to 22 months within the dominant and non-dominant languages in Spanish–English bilinguals, and compare this to Spanish and English monolinguals over the same period. Consistent with previous work in French–English bilinguals and French monolinguals, speed of word processing improves at a similar rate in Spanish–English bilinguals (in both the dominant and non-dominant language) and in English and Spanish monolinguals from 16 to 22 months of age (Legacy et al., 2015, 2016). Thus, speed of word processing appears similar across language groups (Bilingual, Monolingual) and across languages (Dominant and Non-Dominant) within diverse populations of bilinguals (Canadian English–French and United States English–Spanish). Further, vocabulary size was stable from 16 to 22 months across languages and language groups. In contrast, speed of processing at 16 months does not predict speed of processing at 22 months: instead it correlates with GROWTH in RT over the 6-month time window. Children who were relatively slow at 16 months made greater gains than children who were

relatively fast. Moreover, children who made the greatest gains also showed greater processing efficiency than their peers at 22 months. These findings are consistent with looking time measures that suggest that RT becomes more stable with age (Fernald et al., 2006).

The similarities in SPEED OF WORD PROCESSING in bilinguals and monolinguals contrast with findings that show smaller VOCABULARY SIZE in bilinguals versus monolinguals when comparing a single language (e.g., Core, Hoff, Rumiche & Señor, 2013; DeAnda et al., 2016a; Legacy et al., 2015; Pearson et al., 1993; Thordardottir, 2011). Whereas these previous studies could be taken to suggest that bilingual children are slower in developing their languages, the speed of processing finding suggests that bilingual children are equivalent to monolingual children in their early language abilities. Notably, the majority of previous studies contrast bilinguals with monolinguals in only one of their languages but not both. However, it is important to note that, when the total conceptual vocabulary of bilingual children is measured across their two languages, their vocabulary size is comparable to that of monolingual children (Pearson, Fernandez & Oller, 1993). Our results with regard to speed of processing are best interpreted in this light. Speed of processing, like total conceptual vocabulary, is not influenced by single or dual language status.

The second aim of the present study was to examine the relation between speed of word processing and vocabulary development within and across languages in bilinguals, and compare this to monolinguals across 16 and 22 months of age. Within monolinguals, vocabulary size was related to speed of word processing, consistent with previous research (Fernald et al., 2006; Hurtado et al., 2007; Legacy et al., 2015) and this relation held for monolingual and bilingual children across items as well as across participants. Nevertheless, there were some notable differences between language groups. For example, the by-item analyses revealed that the relation between vocabulary size and speed of processing strengthened over time, but only for monolinguals. It is possible that the disproportionately smaller vocabulary sizes within each language reduce variance and power to detect a similar trend within bilinguals. It is also possible that the relation between vocabulary size and speed of word processing is more complex in bilinguals, as the by-participant analyses revealed significant language dominance and cross-language effects. Specifically, a significant within-language relation was evinced only within the dominant language, such that vocabulary size was significantly related to speed of word processing within the dominant language. Conversely, vocabulary size and speed of word processing were not related in the non-dominant language. Further, cross-language associations were also observed, but these were unidirectional: vocabulary size in the dominant language explained significant variance in speed of processing in the non-dominant language after controlling for age and within-language non-dominant vocabulary. However, non-dominant vocabulary did not significantly predict speed of processing in the dominant language (see Figure 3).

The results of the present study have implications for existing models of bilingual language processing. Our results showed that only vocabulary size in children's DOMINANT language explained significant variance in speed of word processing in both the dominant and non-dominant language. This result is consistent with some previous findings. Within Mandarin–English bilingual toddlers, lexico-semantic priming effects were observed only when the prime word was in the L1 (Singh, 2014). That is, L1 words primed semantically related words in the L1 and in the L2, but L2 words did not prime L1 targets. This dissociation between languages as a function of dominance was also shown by Legacy et al. (2015), although they found a significant within-language correlation between vocabulary size and speed of processing in the non-dominant language within French–English bilinguals in Canada that was not observed in the present group of Spanish–English learners in the US.

The most likely explanation for this disparity in findings across French–English and Spanish–English learners concerns the quality of input in L2. Poor quality input correlates with weaker speed of spoken word processing in young toddlers and weaker language proficiency (e.g., Hart & Risley, 1995; Hurtado, Marchman & Fernald, 2008; Place & Hoff, 2011). Visual inspection of scatter plots demonstrated a weaker association between processing speed and vocabulary size in the non-dominant language in children for whom input was from non-native or non-parent sources (N = 26) relative to peers with native input from primary caregivers (N = 18). It appears that, for this reason, within-language associations for L2 in the present Spanish–English sample may be attenuated relative to the Legacy et al. (2015) French–English sample. Indeed, both quantity and quality of language input seem to be important to the dissociation between the dominant and non-dominant language. That is, higher quality and quantity of input in the dominant language may lead to richer lexical-semantic associations that foster speed of processing across both languages such that vocabulary size in the stronger language predicts speed of word acquisition in the weaker language as in the present study. Associations from the non-dominant language to the dominant language may emerge at later ages when a sufficient level of language experience has been accumulated, following predictions from computational models of lexical development (Mayor & Plunkett, 2014; McClelland & Elman, 1986). Future research is needed to evaluate the influence of language exposure on speed of processing.

The within- and cross-language findings from the present study support the conclusions of Marchman et al. (2010) suggesting that children's speed of spoken word comprehension is associated with general language ability. That is, general language skills (e.g., auditory, phonological, lexical, semantic, and syntactic processes) subserve lexical knowledge across languages. The present study extends this finding by demonstrating independent yet interrelated linguistic systems in early simultaneous bilinguals that are influenced by language dominance. Specifically, the existence of cross-language relations between word processing and vocabulary size are inconsistent with a strictly within-language account that suggests that speed of word processing and vocabulary knowledge are entirely dissociable across languages. Instead we find these results more in line with an account in which the relation between word processing and vocabulary does not rely solely on experience within a single language, but also on general language experience. That is, language experience in the dominant language predicts additional variance in speed of processing in the non-dominant language, providing evidence against a strictly within-language account. Despite eliminating a language-specific account, this leaves open the possibility that the relation between speed of processing and vocabulary are explained by either general language experience or cognitive efficiency.

Further, although language dominance modulated the relation between vocabulary size and processing, there was no significant difference in speed of word processing between the dominant and non-dominant language, consistent with prior findings (Legacy et al., 2015, 2016; Marchman et al., 2010). Given that weaker word knowledge is related to slower processing (e.g., Fernald et al., 2006; Hurtado et al., 2007), one might expect the non-dominant language to show slower speed of word processing than the dominant language. However, the present study suggests that the dominant language may support processing in the non-dominant language, as there was a significant cross-language relation between languages from the dominant language to the non-dominant language. That is, despite the weak association between processing and vocabulary in the non-dominant language, the cross-language effects suggest that vocabulary in the dominant language may support processing in the less-proficient language. Indeed, findings within young sequential bilinguals show that L1 knowledge supports the weaker L2 (Uccelli & Páez, 2007). These findings contrast with Marchman et al. (2010) who found no significant cross-language associations in young Spanish–English bilingual children at 30 months. However it is important to note that Marchman et al. did not assess the influence of language dominance on cross-language associations, which may account for this difference in findings. Still, our interpretation is consistent with Marchman et al., suggesting that general language knowledge supports speed of processing across languages.

The conclusion that languages within bilinguals are independent yet interrelated, and that language dominance influences processing is consistent with a recently proposed model of bilingual language representation: processing rich information from multidimensional interactive representations (PRIMIR; Curtin, Byers-Heinlein & Werker, 2011). Within this model of language acquisition and organization, bilingual children form language-specific representations that cluster together within languages, but representations also cluster based on shared semantics across languages. That is, languages are separable but interconnected. Further, PRIMIR posits that relations within and between languages are influenced by task demands. In the present study, processing in the dominant versus the non-dominant language influenced the links between vocabulary and speed of processing consistent with PRIMIR. This conclusion is also consistent with adult models of language representation, namely the Revised Hierarchical Model (RHM; Kroll & Stewart, 1994). Although a model of adult language processing during second language acquisition, the model extends to the present study in that it suggests that language proficiency modulates cross-language links between the dominant and non-dominant language. Indeed, in the present study cross-language associations between the dominant and non-dominant language differed as function of language proficiency.

In addition to the theoretical applications above, the present findings inform clinical practices. The finding that the dominant language supports the non-dominant language is consistent with findings in school-age children showing that prior L1 knowledge predicts later L2 attainment (Lewis, Sandilos, Hammer, Sawyer & Méndez, 2015). From a clinical perspective, this supports the idea that bilingual children with language delays and impairments should receive treatment in both languages (e.g., Restrepo & Kruth, 2000). Indeed, a theoretical model that supports links within languages is in line with empirical findings demonstrating the effectiveness of dual language intervention in bilingual populations (Ebert, Kohnert, Pham, Disher & Payesteh, 2014).

Limitations and future directions

Although the present findings argue against a strict language-specific account on the relation between vocabulary size and speed of processing, it remains unknown whether general-language skill or cognitive efficiency drive this relation. Future work must attempt to disentangle the independent effect of cognitive skill on speed of auditory word processing in early language development. In addition, it is unclear whether the present

set of findings would generalize to sequential bilinguals, who make up a significant population of young dual language learners. That is, it is unclear whether the cross-language associations within simultaneous bilinguals presented here extend to sequential bilinguals. Given some of the models reviewed previously, it is possible such cross-language associations would also arise in the case of sequential acquisition. Lastly, one limitation of the current study is that it tells us little about processing at the sentence level, as processing was assessed only at the level of single words. That is, it remains unknown how within and cross-language associations emerge within the grammatical domain.

Conclusion

What do these results reveal about the nature and specificity of the relation between speed of word processing and vocabulary size in young children more generally? The present study evaluated the changes in speed of processing in monolinguals and bilinguals across two critical time points within the second year of life. Speed of spoken word processing in young bilinguals was similar to their monolingual peers, suggesting that exposure to one or two languages does not influence the rate of word recognition. Indeed, despite learning two separate languages, young bilinguals demonstrate cross-language associations such that the dominant language may support processing in the non-dominant language. We find these cross-language relations between word processing and vocabulary size inconsistent with a strictly within-language account that suggests that speed of word processing and vocabulary knowledge are dissociable across languages. Instead we find these results more in line with an account in which the relation between word processing and vocabulary does not rely solely on experience within a language, but also on general language experience.

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Chapter 4, in full, is a reprint of material as it appears in DeAnda, S., Hendrickson, K., Poulin-Dubois, D., Zesiger, P., & Friend, M. (in press). Lexical Access in the Second Year: a Study of Monolingual and Bilingual Vocabulary Development. *Bilingualism: Language and Cognition.* The dissertation author was the primary investigator and author of this paper.

Chapter 5: A Cross-linguistic Investigation of Word Knowledge and Lexical-semantic Development in Toddlers

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Acknowledgments
*This research was supported by NIH awards 5R01HD068458 and 1F31HD081933 and does not necessarily represent the views of the National Institutes of Health. We gratefully acknowledge Kelly Kortright, Lauren Thayer, and Hanna Moon for their help on data collection and all of the parents and children who have devoted their time to participate in this research.

Abstract

The present longitudinal study directly investigated whether vocabulary size at 18 and 24 months of age predicts children's lexical-semantic processing efficiency. In an approach unique to this study, vocabulary size and lexical-semantic processing are examined in two distinct language groups: English-learning and Spanish-learning monolingual toddlers. Results demonstrate that children's vocabulary size is associated with lexical-semantic processing. Though some group differences emerged, the effect of vocabulary size on the efficiency of lexical-semantic processing held across the English- and Spanish-learning samples. Together these findings extend our understanding of the role of vocabulary in supporting lexical-semantic associations in early development.

Introduction

Many models of early language acquisition characterize the second year of life as a period of rapid vocabulary growth. As vocabulary increases, so does the rate of word learning. Children say their first word around 12 months and learn to produce one or two more words per week. Six months later, around 18 months, children produce up to nine new individual words per day (Goldfield & Reznick, 1990; McMurray, 2007; McMurray, Horst, & Samuelson, 2012). By the end of the second year at 24 months, children use their acquired word knowledge to begin producing their first word combinations. It is clear that children undergo remarkable progression in lexical acquisition during the second year of life. One important area of inquiry in this literature focuses on children's *organization* of the early lexicon. That is, how do children categorize and form lexical networks during toddlerhood, a critical period of remarkable language growth? Of interest in the present study is the role of vocabulary size in promoting early lexical-semantic organization in English- and Spanish-learning toddlers in the United States.

Lexical-Semantic Organization and Priming

Converging evidence across neural and behavioral paradigms supports the emergence of lexical-semantic organization during the second year. For example, children between 12 and 18 months of age recruit the same areas of the brain (i.e., left frontotemporal areas) for semantic processing as adults (Travis et al., 2014). Indeed, toddlers demonstrate remarkable semantic processing efficiency such that by age 2 they make use of semantic inhibition similar to adults during online word recognition (Chow, Aimola Davies, Fuentes, & Plunkett, 2016). Using the head-turn preference

procedure, Delle Luche, Durrant, Floccia, and Plunkett (2014) presented 18-month-olds with lists of semantically related and unrelated words, respectively. Toddlers listened longest to the list of semantically related words suggesting that children are indeed sensitive to the relations between word meanings as early as 18 months of age. Similarly, at 24 months of age, toddlers demonstrate increased looking times to a spoken word if it is preceded by a semantically related word relative to an unrelated word (Willits, Wojcik, Seidenberg, & Saffran, 2014). In fact, 24-month-olds *prefer* to categorize words by their meanings over visual information alone (i.e., color; Mani, Johnson, McQueen & Huettig, 2013) suggesting that they use semantics to organize the lexicon by the end of the second year. This ability to organize words by semanticity interacts with other levels of language representation, namely phonology and grammar. Mani, Durrant, and Floccia (2012) showed that 24-month-olds exhibited lexical priming effects given words that overlapped *both* in phonological and semantic representations. Similarly, by 24 months of age toddlers begin using grammatical information in the absence of semantic cues to guide word recognition (Bobb & Mani, 2013). Together this body of work demonstrates that monolingual toddlers employ semantic, phonological, and grammatical information to guide lexical processing by the end of the second year of life.

Of particular interest in the present study is the development of *semantic* processing in toddlerhood. Recently, researchers have adapted the Intermodal Preferential Looking (IPL) Paradigm to examine lexical-semantic priming in infants and toddlers (e.g. Arias-Trejo & Plunkett, 2009). In this task, children's gaze patterns to target and distractor objects are measured across a series of trials. Critically, each

trial is preceded by either a semantically related or unrelated word. If children are sensitive to the semantic relation between the preceding word and the target object, we expect longer looking times to the target referent in related versus unrelated trials.

In a series of studies, Arias-Trejo et al., showed that monolingual English speakers demonstrated a priming effect that emerges late in the second year. Specifically, 21-month-old, but not 18-month-old, English monolinguals showed longer looking to the target object in related relative to unrelated trials, thereby suggesting that lexical-semantic priming effects emerge around 21 months of age on the IPL task (Arias-Trejo & Plunkett, 2009). Further, 21 month-old monolinguals evinced priming between words that were *both* associatively and semantically related. By 24 months, however, either an associative or a semantic relation was sufficient to elicit priming (Arias-Trejo & Plunkett, 2013). This series of studies is unique in that it suggests a developmental timeline for the emergence of lexical-semantic organization using the same paradigm at 18, 21, and 24 months of age. Together these findings suggest the fragile emergence of lexical-semantic structure by 21 months of age that becomes more robust by the end of the second year at 24 months. It remains unclear, however, what gives rise to the emergence of lexical-semantic priming effects at approximately 21 months of age. One potential source of variability is vocabulary size, which also grows significantly late in the second year.

Vocabulary Size and Lexical-Semantic Processing

An important question with regard to the development of lexical-semantic processing is whether vocabulary size predicts children's lexical organization. One hypothesis in the literature is that children's vocabulary breadth supports the

emergence of lexical-semantic networks (e.g., Hills, Maouene, Maouene, Sheya, & Smith, 2009). That is, increased word knowledge may allow semantic similarities and differences among words to become apparent, fostering connections and category formation within the lexicon. As such, children with larger vocabularies should show greater lexical-semantic processing efficiency relative to children with smaller vocabularies. Similarly, strong lexical-semantic networks make it easier to acquire new words. Indeed, 2-year-olds are more likely to learn words from categories in which they already know many words (e.g., animals) relative to less-known categories (Borovksy, Ellis, Evans, & Elman, 2016), which suggests that a rich semantic network may make it easier for children to learn new words that incorporate existing semantic associations. Similarly, Mani and Huettig (2012) showed that children with large expressive vocabularies can anticipate the upcoming subject of a verb at age 2. Together this line of research suggests that children use semantic breadth to guide word learning and sentence processing. It is therefore possible that vocabulary size supports lexical-semantic processing just as it supports new word learning and sentence comprehension.

The idea that vocabulary size is linked with children's semantic organization and categorization skills has a long history in the literature (e.g., Gopnik & Meltzoff, 1987; 1992). For example, early work found that the ability to link a new word to a category is associated with increases in expressive vocabulary size between 16 and 20 months of age (Mervis & Bertrand, 1994). Similarly, Nazzi and Gopnik (2001) showed that 20-month-olds, but not 16-month-olds, were able to use naming to form a new object category. Specifically, 20-month-olds were able to use an object name to

identify and combine objects that did not possess obvious visual similarities. This suggests that children use language to guide categorization by 20 months of age. Further, 20-month-olds' name-based categorization was linked to increases in expressive vocabulary, such that children's ability to form new categories based on lexical items showed a moderate correlation with expressive vocabulary size at 20 months of age.

More recently, event-related potentials (ERP) and eye-tracking have extended early behavioral work by examining how vocabulary size relates to spoken language processing efficiency. Torkildsen et al., (2008; 2009) demonstrated that 20-month-olds with large expressive vocabularies exhibited N400 incongruity effects to semantic violations of newly-trained words whereas children with small expressive vocabularies did not. Further, those children with large expressive vocabularies needed only three presentations of a novel word-referent pair to recognize the novel word, whereas children with small expressive vocabularies required five presentations. Similarly, a body of research has shown that vocabulary is a stronger predictor of concurrent and future auditory word processing than is age (Fernald, Swingley, & Pinto, 2001; Zangl, Klarman, Thal & Bates, 2001). For example, children with the largest vocabulary size at 25 months of age and those with the fastest vocabulary growth across the second year were fastest in auditory word recognition (Fernald, Perfors, & Marchman, 2006). Thus, individual differences in trajectories of vocabulary acquisition predict subsequent processing efficiency. Further, the relation between vocabulary size and speed of processing was strongest at the end of the second year.

The Present Study

As we have reviewed, vocabulary size predicts children's conceptual categorization skill, word learning, and speed of auditory word recognition late in the second year. Thus, there is empirical support for the notion that vocabulary size may be associated with lexical-semantic organization. That is, children with large vocabularies may possess stronger links between words of similar semantic categories leading to stronger lexical-semantic priming effects. The present longitudinal study seeks to test this hypothesis directly by asking whether vocabulary size at 18 and 24 months of age predicts children's lexical-semantic priming abilities. We examine lexical-semantic processing and vocabulary size by employing direct behavioral measures to investigate whether vocabulary size predicts semantic organization. Further, in order to understand the robustness of this effect, the present study seeks to examine vocabulary size and processing in two distinct language groups: English-learning and Spanish-learning monolingual toddlers in the United States (U.S.). Spanish is the second most spoken language in U.S. and the number of people who report speaking Spanish has almost doubled since 1990 (U.S. Census, 2011). Thus, the present study seeks to examine lexical-semantic development in the two largest language groups in the U.S.

Method

Participants

English and Spanish monolingual toddlers participated in the present longitudinal study at 18 (N = 73, 38 females, 35 males) and 24 months of age (N = 53, 27 females, 26 males). One participant was excluded due to language impairment

diagnosis, and 20 children from the original sample of 73 did not return at 24 months leaving us with a final longitudinal sample of 53 participants. For the purposes of this study however, all data at each age group were analyzed. An a-priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted to determine the appropriate sample size based on the smallest effect size reported in a similar study (Arias-Trejo & Plunkett, 2009). Results indicated that a sample size of at least 20 participants in each language group was required to achieve appropriate power ($1-\beta > .9$). Spanish monolinguals (18 months: $N = 32$, M = 18;18, range = 17;21 – 20;6, 24 months: N = 26, M = 25;12, range = 23;15- 27;18) had an average maternal education of approximately 1 year of college attendance (M = 13.09 years, SD = 3.36, range = 6-18) and an average family income of approximately $45,000 ($SD$ = 40,788, range = 15,000 – 152,000). English monolinguals (18 months: $N = 41$, M = 18;7, range = 17;9 – 19;3; 24 months: $N = 27$, M = 24;12, range = 22;27- 25;15) had an average maternal education at approximately 4 years of college attendance (M = 16.2, SD = 1.7, range = 12-18) and a relatively high average family income of approximately $90,000 ($SD$ = 48,944, range = 18,000 – 240,000). All children received at least 80% exposure to their dominant language of exposure (either English or Spanish) as measured on the Language Exposure Assessment Tool (LEAT, DeAnda et al., 2016). Participants were obtained through a database of parent volunteers recruited through birth records, internet resources, community organizations, and events in a large metropolitan area in Southern California. All participants were full-term and had no diagnosed impairments in hearing, vision, language, and cognition.

Measures

English and Spanish adaptations of the Computerized Comprehension Test (CCT)

The CCT is a behavioral measure that captures children's haptic response to assess early decontextualized receptive vocabulary. The CCT demonstrates strong internal consistency, converges with parent report on the MacArthur-Bates Communicative Development Inventory (MCDI, Fenson, Marchman, Thal, Dale, Reznick & Bates, 2006), and predicts subsequent language production (Friend, Schmitt, & Simpson, 2012). Additionally, responses on the CCT are nonrandom (Friend & Keplinger, 2008) and this finding replicates across languages (Friend & Zesiger, 2011) and across monolinguals and bilinguals (Poulin-Dubois, Bialystok, Blaye, Polonia, & Yott, 2013). The CCT has shown significant immediate test-retest reliability across English and Spanish adaptations, thus demonstrating that performance is systematic in children as young as 16 months of age. The CCT also demonstrates convergent validity with MCDI reports of vocabulary comprehension and 4-month test-retest reliability (Friend & Keplinger, 2008; Friend & Zesiger, 2011) and accounts for significant variance in subsequent vocabulary production (Friend, Schmitt, & Simpson, 2012).

Participants are prompted to touch images on the monitor (e.g., "Where's the *dog?* Touch *dog!"*). A correct touch to the target image (e.g., the dog) elicits a reinforcing sound (e.g., the sound of a dog barking). The CCT presents 4 training trials and 41 test trials in a two-alternative forced-choice procedure. For each trial, two images (a target and distractor image) appeared simultaneously on the right and left side of the touch monitor. The side on which the target image appeared was presented in pseudo-random order across trials such that target images could not

appear on the same side on more than two consecutive trials, and the target was presented with equal frequency on both sides of the screen (Hirsh-Pasek & Golinkoff, 1996). All image pairs presented during training, testing, and reliability were matched for word difficulty (easy, medium, hard) based on MCDI norms (Dale & Fenson, 1996), part of speech (noun, adjective, verb), category (animal, human, object), and visual salience (color, size, luminance).

The CCT begins with a training phase to insure participants understand the nature of the task. During the training phase, participants were presented with early-acquired noun pairs (known by at least 80% of 16-month-olds; Dale & Fenson, 1996) and prompted by the experimenter to touch the target. If the child failed to touch the screen after repeated prompts, the experimenter touched the target image for them. If a participant failed to touch during all four training trials, the training trials were repeated once. Only participants who executed at least one correct touch during the training phase proceeded to the testing phase. All of the participants proceeded to the testing phase.

Each test trial ended when the child touched the screen or until seven seconds elapsed. When the child gaze was directed toward the touch monitor, the experimenter delivered the prompt in infant-directed speech and advanced each trial. The experimenter presented each pair of images as she uttered the target word in the first sentence prompt such that the onset of the target word occurred just prior to the onset of the visual stimuli.

The MacArthur Bates Communicative Development Inventory (MCDI)

The MCDI: Words and Gestures is a widely used parent report measure of early language. The inventory is a checklist allowing parents to mark the words their child understands and says. The inventory provides researchers with an indirect account of the child's vocabulary comprehension and has been normed on a large sample of children from 8 to 18 months of age. The MCDI, originally developed in English, has good reliability and validity and has been adapted for use in over 50 languages and dialects, including Spanish (Fenson et al., 2006; Jackson-Maldonado, Thal, Fenson, Marchman, Newton, & Conboy, 2003). The Spanish adaptation, the Inventario de Dessarrollo de Habilidades Comunicativas (IDHC) was used in the present study to evaluate vocabulary size as reported by parents for the Spanish monolingual group. The Words and Gestures inventory was used at both 18 and 24 months of age as a parent report measure of both receptive and expressive vocabulary to complement the behavioral assessment of receptive vocabulary (the CCT). In this way, we obtain both a parent report and child performance measure of the same underlying construct however this comes with the limitation that we can only compare our sample-specific data to the MCDI norms at 18 months and not at 24 months.

Intermodal Preferential Looking Priming Task

Stimuli.

We used an adaptation of the Intermodal Preferential Looking Task (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987), which has previously been used to investigate lexico-semantic priming in young toddlers (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009; Singh, 2014). A total of 27 words known by 60% or more of 18-month-olds were chosen in each language (English and Spanish) based on

the Macarthur-Bates Communicative Development Inventory (MCDI) and the Inventario de Desarrollo de Habilidades Comunicativas (IDHC) norms (Dale & Fenson, 1996). One third of these words served as auditory primes, another third as target, and a final third as distractor images (see Table 5-1).

In the current study, semantic relatedness is determined by the cosine value between two words: a calculation of the feature overlap between pairs of words based on adult norms (Buchanan, Holmes, Teasley, & Hutchison, 2012). Features can be physical, functional, and categorical. A cosine of 0 represents no semantic overlap between two words, whereas 1 represents complete overlap. Previous work has found semantic priming in children at these same ages using English adult norms and has extended English-speaking norms to other languages (e.g. Mandarin; Singh, 2014). The lexical items in the current study are highly imageable and early occurring nouns known by the majority of toddlers.

Experimental Design

Participants were presented with Related and Unrelated trial types. On Related trials, the prime word was semantically related to the target word (e.g., banana and apple). Primes and targets were highly related and had an average cosine value of .32 (*SD* = .11, range = .14 - .55). On unrelated trials pairs of unrelated words with a cosine value of 0 (e.g. pillow and apple, “I saw a pillow… apple!”) were presented.

Children participated in 3 Related trials and 3 Unrelated trials per block. There were 2 blocks (one for each language) of 6 trials each for a total of 12 trials (6 Related and 6 Unrelated). Trial presentation was pseudo-randomized within blocks such that no more than two trials of the same type were presented consecutively. Side of target

presentation was also counterbalanced across participants. Target and distractor pairs were yoked across participants and were semantically unrelated (cosine = 0). The target and distractor images were non-continguous (approximately 10cm apart) so as to reduce possible error associated with determining the location of gaze on the screen (Holmqvist et al., 2011). In addition, each yoked pair of images appeared equally across all three trial types to counterbalance any systematic effects of picture salience. Children saw each target and distractor pair only once. Distractor images were never named and appeared with equally frequency across trial types. Primes were counterbalanced such that they appeared equally across trial types. A female native speaker produced all auditory stimuli in infant-directed speech. Each word and sentence frame was recorded in isolation.

Trials began with the presentation of a carrier phrase ("I saw a…") ending with the prime word (e.g., "banana"). An attention-getter (i.e., a spinning water wheel, Delle Luche, Durrant, Poltrock, & Floccia, 2015, see Figure 5-1) appeared on screen for a total of 1000 ms during the presentation of the carrier phrase and prime word. Two hundred ms after the offset of the prime word, the auditory target word (e.g., "apple") was presented in isolation. Two hundred ms after the offset of the target word, the yoked target and distractor images were presented for a total of 2500 ms. A short prime-target inter-stimulus interval (ISI) and stimulus-onset asynchrony (SOA) of 200 ms each have been previously used with infants (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009, 2011) and correspond to parameters for lexical priming in adults.

Data processing

Eye-tracking data collected in infants and toddlers is inherently noisy, and recent studies reveal the influence of low-quality data on several key eye gaze measures (e.g. Wass, Smith, & Johnson, 2013; Wass, Forssman, & Leppnen 2014; Saez de Urabain, Johnson, & Smith, 2015). As such, researchers have proposed a number of ways to process data so as to maximize its accuracy. Wass, Forssman, and Leppänen (2014) recommend the use of a median moving window and interpolation to reduce noise in infant data when analyzing proportion looking (the dependent variable of interest in the present study). Following these recommendations, we applied a median moving window filter to the raw eye-tracking data, in which data was chunked in 100 ms windows and a single median was calculated. A median was calculated even when data for only a single eye was available (Saez de Urabain, Johnson, & Smith, 2015). Although some studies suggest single-eye data may be indicative of poor quality (Wass et al., 2014) Saez de Urabain, Johnson, and Smith (2015) recommend including such samples in the interest of collecting the highest number of fixations. Similarly, gaze data were interpolated when a gap of no more than 150 ms was encountered (Saez de Urabain, Johnson, and Smitth, 2015; Wass, Forssman, & Leppanen, 2014). Interpolation was achieved through scaling gaze samples from before and after the gap to create a continuous trajectory (Olsen, 2012). Further, we excluded trials in which toddlers fixated on the target and distractor less than 25% of the trial. In addition, trials in which toddlers fixated only the target or only the distractor were excluded to increase the probability that the data reflected active lexical-semantic processing (e.g., Mani & Plunkett, 2010). Following these procedures, proportion looking was evaluated by calculating total looking to the target

divided by the sum of total looking to the target and distractor using the *eyetrackingR* package (Dink & Ferguson, 2015) in RStudio (RStudio Team, 2015).

Procedure

After a short warm-up play period between the toddler and the experimenter, children and their caregivers were escorted to a dimly-lit room which houses the CCT setup. Following the CCT, children and their parents moved to a second room to complete the IPL task. For the IPL procedure, infants sat approximately 25 inches away from a 27" Dell monitor with a 1920x1080 resolution. A Tobii X120 recorded eye gaze and was placed 3 inches below and 5 inches in front of the monitor. Auditory stimuli were presented through Dell AX210 multimedia stereo audio speakers positioned behind the monitor. Spanish monolinguals were administered the Spanish adaptation of the CCT, the Spanish block of the preferential looking task, and the IDHC, in that order. Conversely, English monolinguals were administered the English CCT, the English block of the preferential looking task, and the MCDI.

Planned Analyses

The first step in the analyses was to replicate previous findings by aggregating over the entire time window of interest and asking whether proportion of total looks differed significantly between related and unrelated trials using paired t-tests. We next asked whether children's vocabulary knowledge predicts lexical-semantic priming. Finally, we conducted growth curve analyses to determine if looking behavior differed between related and unrelated trials over the course of the time window of interest, and whether this varied as a function of children's word knowledge.

Results

English Monolinguals

18 months

There was wide variability in vocabulary size on the CCT (*M* = 17.58 *, range* = 5 – 31 words) and MCDI (*M* = 202.51*, range* = 22 – 329 words). MCDI scores corresponded to the 1st through the 85th percentiles. Figure 5-2 depicts the average proportion of time that toddlers spent looking at the target object relative to the distractor in related versus unrelated trials. Proportion of total looking was not significantly different between related and unrelated trials at 18 months and this is consistent with previous findings in British English monolinguals (e.g., Arias-Trejo & Plunkett, 2009).

Next we asked whether vocabulary size correlated with children's looking times on related trials. As can be seen in Figure 5-3, receptive vocabulary size as measured on the CCT was significantly correlated with average looking time on related trials ($r(51) = .28$, $p = .04$) only and not on unrelated trials. This correlation held even when controlling for Socioeconomic Status (operationalized as family income) in a post-hoc partial correlation ($r(51) = .30$, $p = .02$). However, neither receptive nor expressive vocabulary as reported by parents on the MCDI correlated with looking time to the target across related and unrelated trials.

To further explore the relation between vocabulary size and lexical-semantic priming, children were split into two vocabulary size groups. Given that vocabulary size on the CCT correlated with children's eye gaze behavior, children were divided into high (N = 19) and low (N = 18) vocabulary groups based on the median vocabulary size on the CCT (*median* = 19). To assess the contribution of Vocabulary

Group (high vs. low vocabulary size) to children's looking behavior across Trial Type (unrelated vs. related trials), we submitted the data to a Growth Curve Analysis (Mirman, Dixon, & Magnuson, 2008) using maximal-likelihood linear mixed-effects models with and without each factor using –2 log-likelihood ratio tests (LRT; Baayen, Davidson, & Bates, 2008). LRT is a deviance statistic distributed as chi-square that examines whether including a parameter (or a set of parameters) significantly increases the fit of the model, similar to R^2. With LRT, higher is better as it compares the likelihood of the observed data to be explained by the full model relative to the null model. Results indicated a significant Vocabulary Group by Trial Type interaction for the linear and quadratic terms, suggesting significant change over time as a function of Vocabulary Group and Trial Type, with the linear and quadratic terms explaining similar variance (linear: LRT = 15.80, $p < .001$; quadratic: LRT = 15.52, $p < .001$). The Vocabulary Group by Trial Type interaction suggests that looking behavior for related and unrelated trials differed based on whether children had large or small vocabulary size. The significant linear and quadratic terms indicate that this difference emerged over the 2500ms time window. There were no main effects of Trial Type (consistent with the t-test results) and Vocabulary Group. As seen in Figure 5-4, children in the high vocabulary group evinced a different pattern of looking behavior between related and unrelated trials, with longer looks to the target on related versus unrelated trials consistent with priming effects. Conversely, children in the low vocabulary group did not evince a difference in looking time across trials. Thus, there are individual differences in vocabulary size that are related to lexical-semantic priming.

24 months

By 24 months, English monolinguals demonstrated increased vocabulary size on the CCT (*M* = 30.25, *range* = 14 – 37 words) and MCDI (*M* = 329.87, *range* = 222 – 387 words). Further, as seen in Figure 5-2, children's proportion of total looks to the target differed significantly between related and unrelated trials at 24 months ($t(20) = -2.36$, $p = .02$) consistent with previous findings in British English monolinguals (e.g., Arias-Trejo & Plunkett, 2009). Next we evaluated whether vocabulary size would once more correlate with looking times. By 24-months, however, neither vocabulary size as measured by the CCT nor the MCDI was correlated with looking times. The same pattern of correlational results was evinced when controlling for family income. This suggests that vocabulary size does not correlate with children's *total* looking time across the time window within English monolinguals at 24 months, in contrast to the findings at 18 months. We return to this developmental change from the data at 18 months in the discussion.

Growth curve analyses revealed significant a main effect of Trial Type (LRT = 5.62, $p = .02$) and a significant Trial Type interaction with the third-order polynomial term (LRT: 5.50, $p = .02$). This suggests that proportion of total looking varied as a function of Trial Type and over the course of the entire trial.

Unlike the 18 month testing occasion, the t-test and growth curve analyses revealed a total group-level priming effect at 24 months. This allows us to ask whether vocabulary size predicts changes in looking behavior *over the course of the trial* by 24 months. To follow-up on the findings at 18 months, we conducted a time window analysis in the high and low vocabulary size groups. Whereas the correlation

between vocabulary size and looking times collapses over the *entire* trial, the time window analysis asks a different question: whether vocabulary size predicts *when* children demonstrate a priming effect at 24 months. As seen in Figure 5-5, children exhibited different response patterns as a function of vocabulary group. These response patterns suggest two windows of interest before and after approximately 1,500ms. Following Chow, Aimola Davies, Fuentes, and Plunkett (2016) we examined proportion of total looks before and after 1,500 ms creating two windows of equal duration: an Early Window from 0 to 1,500ms and a Late Window from 1,501 to 2,500ms. Results revealed a marginal difference in looking times between related and unrelated trials in the Early Window for the high ($t(17) = -1.98$, $p = .07$), but not low, vocabulary group. Conversely, there was a significant difference in the Late Window for the low ($t(17) = -2.26$, $p = .04$), but not high vocabulary group. Together these results suggest that although both groups of children exhibited a priming effect at age 2, but the high vocabulary group demonstrated an earlier priming effect than the low vocabulary children.

Spanish Monolinguals

18 months

Spanish monolinguals also demonstrated wide variability in vocabulary size at 18 months on the CCT (*M* = 13.78*, range* = 5 – 26 words) and IDHC (*M* = 199.70*, raw score range* = 44 – 378 words. MCDI scores corresponded to the 1st through the 97th percentiles. As seen in Figure 5-6, the proportion of total looks to the target was not significantly different between related and unrelated trials at 18 months in Spanish monolinguals consistent with our findings in the English monolingual group and with

previous studies. However, unlike the English monolinguals, Spanish monolinguals did not evince a significant correlation between looking times on related trials and vocabulary size on either the behavioral assessment (CCT) or parent report (IDHC) at 18 months, and even when controlling for family income.

Although vocabulary size was not associated with proportion looking time to the target, we followed the same analytic procedure in the English monolingual group to examine whether children evinced differences in looking time to the target in related and unrelated conditions over the entire time window. Once again, children were divided into high and low vocabulary groups based on the median vocabulary size on the CCT (*M* = 14). A Growth Curve Analysis assessed the contribution of Vocabulary Group (high vs. low vocabulary size) to children's looking behavior across Trial Type (unrelated vs. related trials). There were no significant main effects of Vocabulary Group and Trial Type and no interaction with any of the linear and quadratic terms. These results suggest no significant difference in looking times as a function of semantic relatedness and vocabulary size at 18 months in Spanish monolinguals.

24 months

Spanish monolinguals demonstrated an increase in vocabulary size on both the CCT (*M* = 25.37, *range* = 9 – 36 words) and IDHC (*M* = 300.54, *range* = 82 – 396 words) from 18 to 24 months of age. Further, in the Spanish monolingual sample, children's proportion of total looks to the target was not significantly different for related versus unrelated trials at 24 months. Further, similar to the 18 month results, vocabulary size on the CCT and IDHC did not predict children's proportion of total

looking times on related trials even when controlling for family income. Thus, unlike their English monolingual peers, Spanish monolinguals do not evince differences in proportion looking times between the related and unrelated trials when averaging over the time window.

Given that there were differences in looking times as a function of vocabulary group in the English monolingual group, we asked whether a similar difference would emerge in the Spanish monolingual sample by 24 months. Once again, children were grouped into a high and low vocabulary group based on the median CCT score (M = 27). A Growth Curve Analysis revealed a significant interaction between Trial Type and Vocabulary Group and the third order polynomial term (LRT = 8.14, p = .004). Thus, although there are no significant differences in trial type when looking times are aggregated over vocabulary group and over the entire time window, there are differences in lexical-semantic processing as a function of vocabulary size and time. As can be seen in Figure 5-7, the high and low vocabulary groups indeed show different patterns of looking behavior over the course of the trial.

Group Comparisons

The next set of analyses examined the differences between the English and Spanish monolingual groups in the variables of interest in the present study. Although family income did not influence the association between vocabulary size and lexical-semantic priming *within* each group, there was a significant difference in the average family income *between* groups ($t(59.5) = 3.67$, $p < .001$). Similarly, there was a significant difference in vocabulary size on the CCT ($t(59.95) = 2.64$, $p < .001$) and proportion of total looks to the target ($t(61.05) = 4.33$, $p = .01$) between groups.

Specifically, English monolinguals had larger vocabulary sizes as well as more looks to the target relative to Spanish monolinguals. Nevertheless, it is important to note that the range of vocabulary scores, relative to the English and Spanish norms, was comparable across groups.

Discussion

The present longitudinal study directly investigated whether vocabulary size at 18 and 24 months of age predicts children's lexical-semantic processing skill. In an approach unique to this study, vocabulary size and processing are examined in two distinct language groups: English-learning and Spanish-learning monolingual toddlers.

To begin, the present study replicated and extended previous findings in English monolinguals. That is, when averaging over the entire time window, lexical-semantic priming effects (e.g., a significant difference between looking times on semantically related versus unrelated trials) were evinced at 24 but not 18 months of age. This is consistent with a series of studies in which British English monolinguals showed lexical-semantic priming effects at 24 but not 18 months (e.g., Arias-Trejo & Plunkett, 2009). The present findings extend these results by showing that that individual differences in vocabulary size are associated individual differences in lexical-semantic processing. Specifically, lexical-semantic priming effects were evinced at 18 months of age, but only in children with large vocabularies. This extends the previous literature by demonstrating that the emergence of lexical-semantic priming late in the second year can be influenced by individual differences in the development of lexical knowledge. In addition, the present study demonstrated

that by age 2, vocabulary size relates to children's processing *efficiency* for semantically related words, such that English-learning children with large vocabularies demonstrated a priming effect earlier in the trial than peers with smaller vocabularies. Together the findings in the English monolingual group provide evidence in favor of a model of early lexical-semantic development that is supported by vocabulary growth. That is, vocabulary is associated with lexical-semantic organization. We return to this discussion below.

In contrast, within Spanish monolinguals, there were no significant differences in looking times on semantically related and unrelated trials at 18 and 24 months of age at the group level. A significant lexical-semantic priming effect was only evinced in children with a large vocabulary size, relative to their peers, and only at 24 months of age. The pattern of findings suggests that Spanish monolinguals evince a developmental trajectory that is similar but perhaps protracted relative to English monolinguals. That is, the effects evinced at 24 months in Spanish monolinguals are similar to the pattern evinced at 18 months in the English-learning group, such that only children in the high vocabulary group showed a semantic priming effect. Indeed, children in the Spanish monolingual sample had significantly smaller vocabulary sizes relative to their English-learning peers at 18 and 24 months of age, suggesting a later shift in lexical acquisition that may influence lexical-semantic processing as well. This supports the conclusion that vocabulary size is necessary to the emergence of the lexical-semantic networks assessed in the priming task. Thus, one prediction is that more robust lexical-semantic priming may be evinced by 30 months in Spanish monolinguals when a sufficient threshold vocabulary size is reached. Indeed, in

English monolinguals, visual inspection of scatter plots at 18 and 24 months showed that children with at least a score of 25 on the CCT all evinced looking times that suggested successful lexical-semantic priming (i.e., proportion of total looks to target above 50%, indicating longer looks to the target relative to the distractor). The median cut points for the high and low vocabulary size groups were approximately 20 and 30 words at 18 and 24 months, respectively. This cut point may reflect differences in the make-up of children's vocabulary. The CCT contains three levels of word difficulty based on developmental norms on the MCDI: one third of the words are classified as easy, one third as moderately difficult, and one third as difficult. A score of 25 on the CCT corresponds to 63% or two thirds of trials being correctly identified. Thus, children who score above 25 are more likely to identify words from the difficult category. As such, children in the high vocabulary group may have the breadth of word knowledge necessary to instantiate the lexical-semantic network indexed by the current priming task.

That is, despite group differences, the pattern of findings across the English and Spanish group reveal that vocabulary size plays an important role in the development of lexical-semantic processing. In both groups, children with larger vocabulary sizes outperformed their lower-vocabulary peers. For example, across language groups, the first signs of lexical-semantic priming effects emerged in the high vocabulary group before appearing in the low vocabulary group. Further, even when both the high and low vocabulary size groups demonstrated a lexical-semantic priming effect in the English monolinguals, there were differences in the *timing* of children's lexical processing that were attributable to vocabulary size: the high

vocabulary group showed an earlier priming effect than the low vocabulary group. Together these findings demonstrate that vocabulary knowledge influences the emergence and efficiency of lexical-semantic processing in early toddlerhood.

The finding that vocabulary size is associated with lexical-semantic processing is in line with our predictions and consistent with other research demonstrating links between processing efficiency, word learning, and vocabulary size across behavioral and electrophysiological evidence. As reviewed previously, 2-year-olds are more likely to learn words from well-known categories (e.g., animals) relative to less-known categories (Borovksy, Ellis, Evans, & Elman, 2016) suggesting that existing semantic knowledge may facilitate subsequent word learning. Indeed, several seminal studies have shown that around 20 months of age children are able to use object naming to guide semantic category formation (Nazzi & Gopnik, 2001) and that this is associated with vocabulary size (Mervis & Bertrand, 1994). ERP evidence corroborates these findings by showing that 20-month-olds with large expressive vocabularies exhibit N400 incongruity effects to semantic violations of newly-trained words whereas children with small expressive vocabularies do not (Torkildsen et al., 2008; 2009). The present findings extend this body of work by showing that vocabulary size is also associated with children's ability to form connections between known words based on semantic relatedness.

Nevertheless, it is unclear whether a large vocabulary size supports lexical-semantic priming due to greater lexical *breadth* or greater lexical *structure.* Recent evidence suggests that lexical structure may be more predictive of children's lexical-semantic processing than vocabulary breadth. For example, Borovsky et al., (2016)

propose a leveraged learning account of early lexical-semantic development in which the lexicon structure (rather than lexicon size) supports word learning for items that share features with known lexical items and categories. Indeed, Mayor and Plunkett's (2014) TRACE simulations illustrate the importance of vocabulary size and composition in word recognition in the phonological domain. According to Mayor and Plunkett (2014), "increasing vocabulary size leads to greater competition motivating the need for inhibitory processes" and "enhanced competition leads to speedier elimination of inappropriate lexical items, and, therefore, faster target recognition" (p. 116). Competition and inhibition are a result of a *network* of lexical connections; increasing vocabulary size leads to greater lexical associations that give rise to competitive and inhibitory connections. These findings are corroborated by behavioral evidence: semantic networks based on parent reported vocabulary size show that children with larger vocabularies demonstrate denser semantic networks (i.e. more links in the network), higher clustering (i.e. more categories), greater robustness (i.e. efficiency), and greater global structure (i.e., lexical-semantic access; Beckage, Smith, & Hills, 2010) as predicted by TRACE. Further, Beckage, Smith, and Hills (2010) contend that these findings provide evidence that children with large vocabulary sizes learn words in a cohesive fashion by making semantic generalizations based on the increased connectivity between known words in the existing network. Indeed, the lexical-semantic priming task employed here tests the existing connections in children's semantic network. Thus, it is possible that vocabulary size is predictive of lexical-semantic priming to the extent that it reflects greater lexical-semantic structure and organization.

An alternative explanation for the association between vocabulary and lexical-semantic priming is that general cognitive efficiency supports both word knowledge and lexical processing. That is, children with strong general cognitive skills may build large vocabularies and process words quickly.

The present findings also highlight the importance of examining millisecond-by-millisecond changes in children's auditory word processing in eye tracking studies. IPL analyses have traditionally averaged over the entire time window. However, it is important to note that information on the *timing* of eye gaze behaviors provide additional information about processing efficiency. Indeed, this point is best illustrated in the findings at 24 months in the English group. Specifically, averaging children's looking times did not correlate with vocabulary size. Nevertheless, children with large and small vocabulary sizes evinced different patterns of results throughout the time window of interest that would otherwise be overlooked if not for the growth curve analyses.

Conclusion

What is the role of vocabulary size in supporting the emergence lexical-semantic processing during the second year of life between 18 and 24 months? The present study provides the first evidence that children's vocabulary size is associated with the efficiency of lexical-semantic processing. Specifically, across English and Spanish learners, children with larger vocabularies outperformed their lower-vocabulary peers. Perhaps most importantly, the first signs of lexical-semantic priming effects emerged in the high vocabulary group before appearing in the low vocabulary group. Further, there were differences in the *timing* of children's lexical

processing that were attributable to vocabulary size such that children in the high vocabulary group showed an earlier priming effect than children in the low vocabulary group. Together these findings extend our understanding of the role vocabulary in supporting lexical-semantic associations in early development cross-linguistically.

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Tables

Table 5-1. Prime-Target pairings for each trial in Spanish and English monolinguals.

Language	Prime	%	Target	%	Semantic relatedness
Spanish	mesa (table)	87.1	silla (chair)	87.1	0.408
	perro (dog)	91.9	gato (cat)	75.8	0.39
	jugo (juice)	66.1	naranja (orange)	59.7	0.385
	lengua (tongue)	64.5	comida (food)	83.9	0.294
	vaso (cup)	90.3	plato (plate)	80.6	0.253
	jabón (soap)	85.5	tina (bathtub)	64.5	0.247
	sol (sun)	69.4	luna (moon)	64.5	0.212
	nariz (nose)	72.6	cara (face)	61.3	0.138
	zapato (shoe)	91.9	calcetines (socks)	75.8	0.396
	Means	*79.92*		*72.6*	*0.30*
English	jacket	60.6	coat	86.4	0.549
	cereal	75.8	toast	62.1	0.48
	arm	63.6	leg	62.1	0.475
	cow	80.3	horse	78.8	0.431
	kitchen	77.3	tummy	84.8	0.146
	bear	71.2	monkey	65.2	0.324
	pig	72.7	bunny	75.8	0.309
	truck	77.3	bicycle	69.7	0.158
	house	68.2	store	66.7	0.142
	Means	*71.9*		*72.4*	*0.33*

Note. Percentages represent the proportion of 18-month-olds who know each word based on norms from the Macarthur-Bates Communicative Development Inventories (Dale & Fenson, 1996). Semantic relatedness refers to the cosine value between two words reflecting their featural overlap (Buchanan, Holmes, Teasley, & Hutchison, 2012). A cosine of 0 represents no semantic overlap between two words, whereas 1 represents complete overlap.

Figures

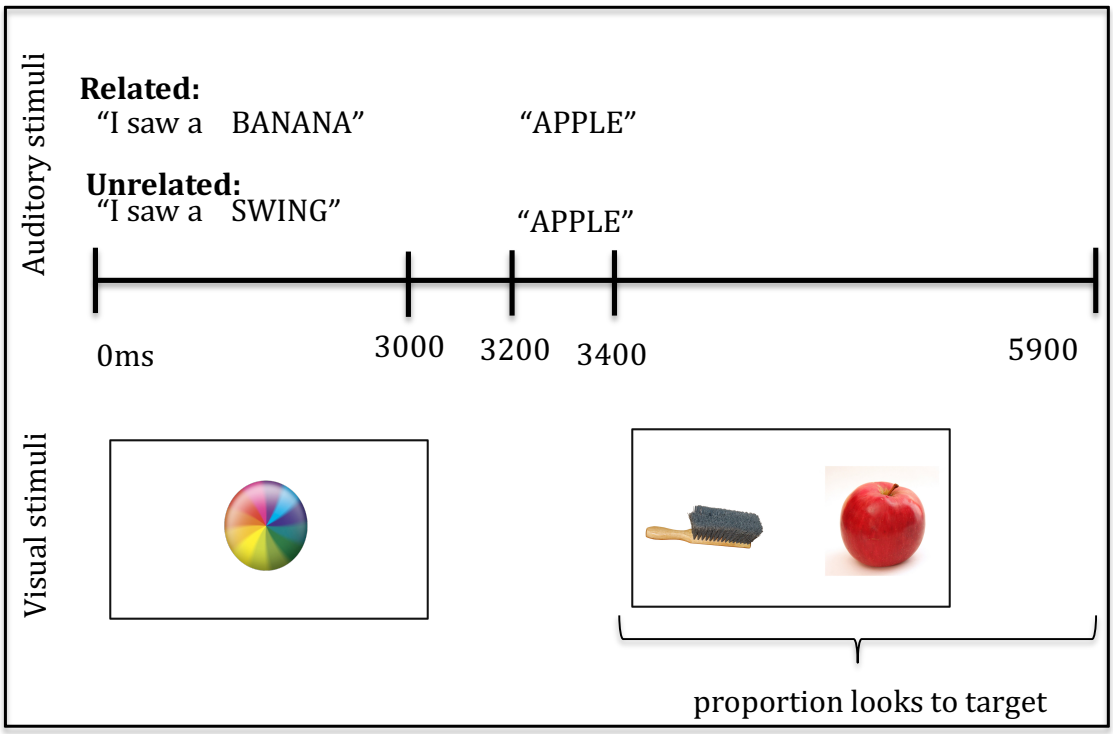

Figure 5-1. Example trial sequence for English monolinguals.

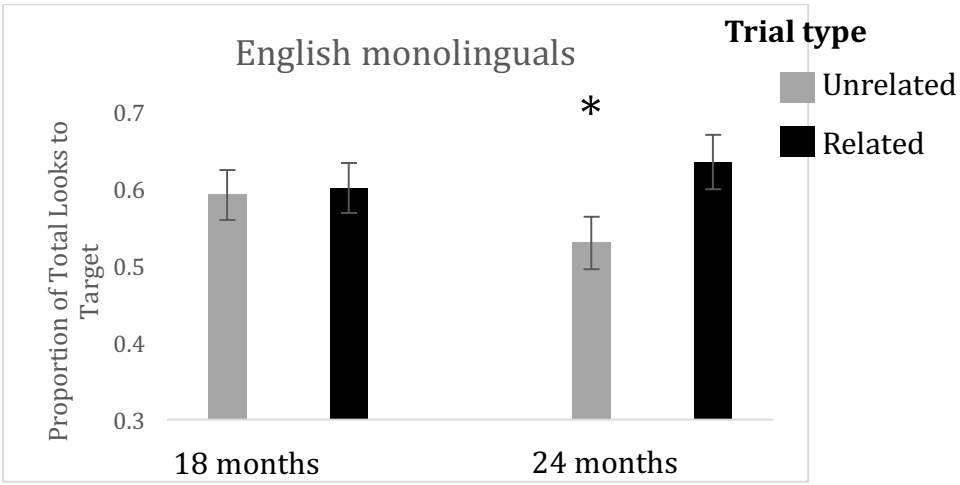

Figure 5-2. Proportion of total looks to target at 18 and 24 months, respectively, within English monolingual group.

Note. * denotes significantly different looking times between related and unrelated trials at 24 months of age.

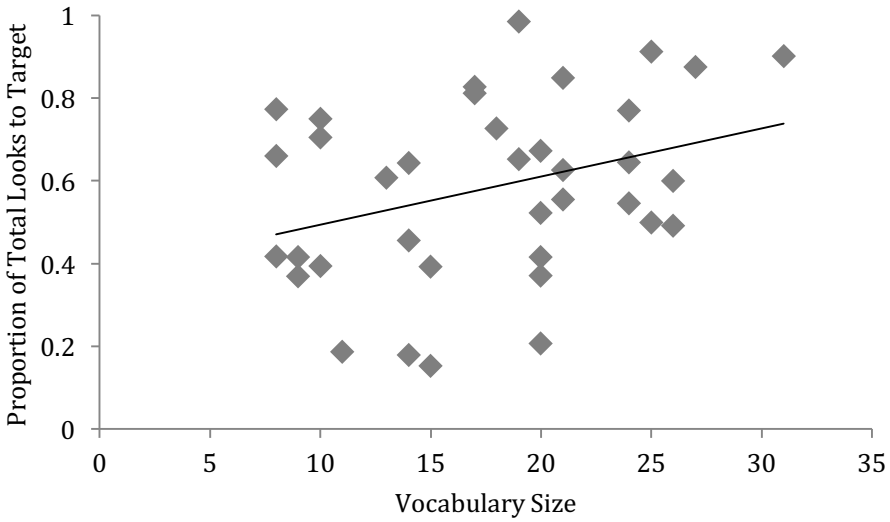

Figure 5-3. Proportion of total looks to the target object as a function of vocabulary size within English monolinguals at 18 months of age.

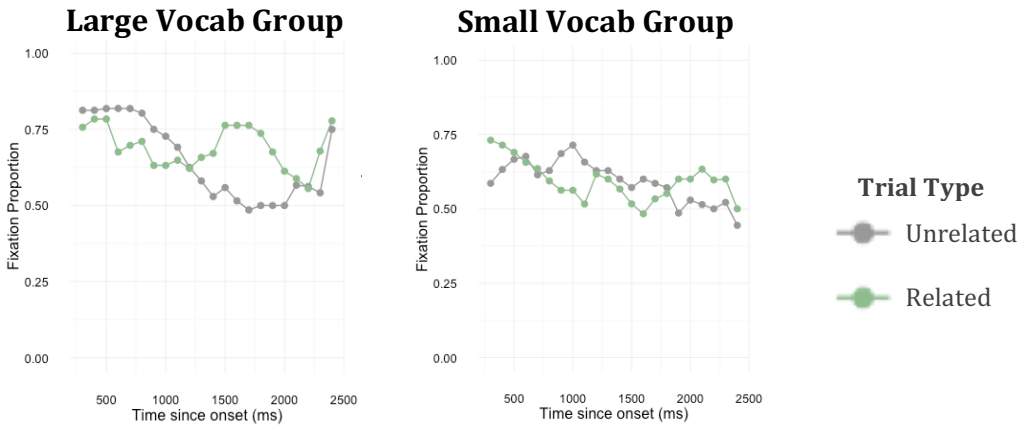

Figure 5-4. Proportion of looks to the target for related and unrelated trials over time at 18 months between the large and small vocabulary groups within English monolinguals.

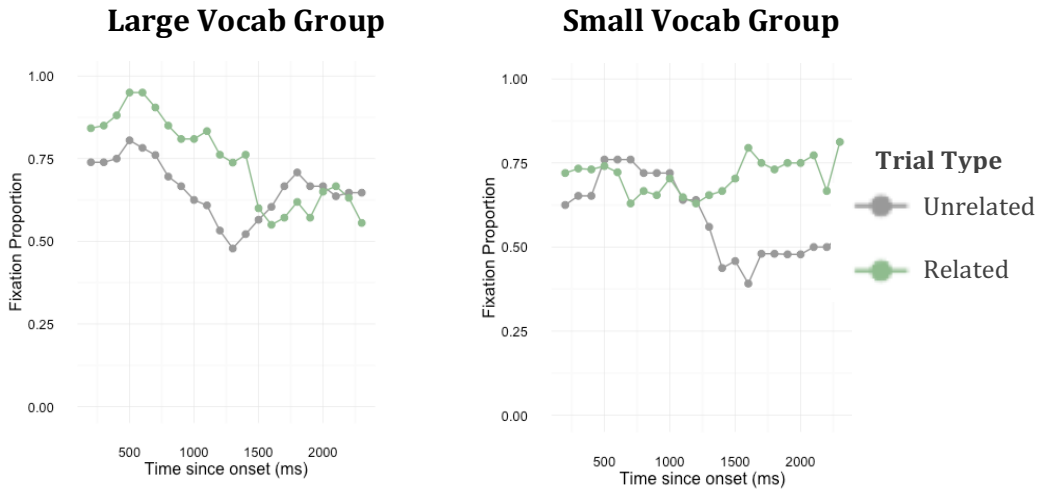

Figure 5-5. Proportion of looks to the target for related and unrelated trials over time at 24 months between the large and small vocabulary groups within English monolinguals.

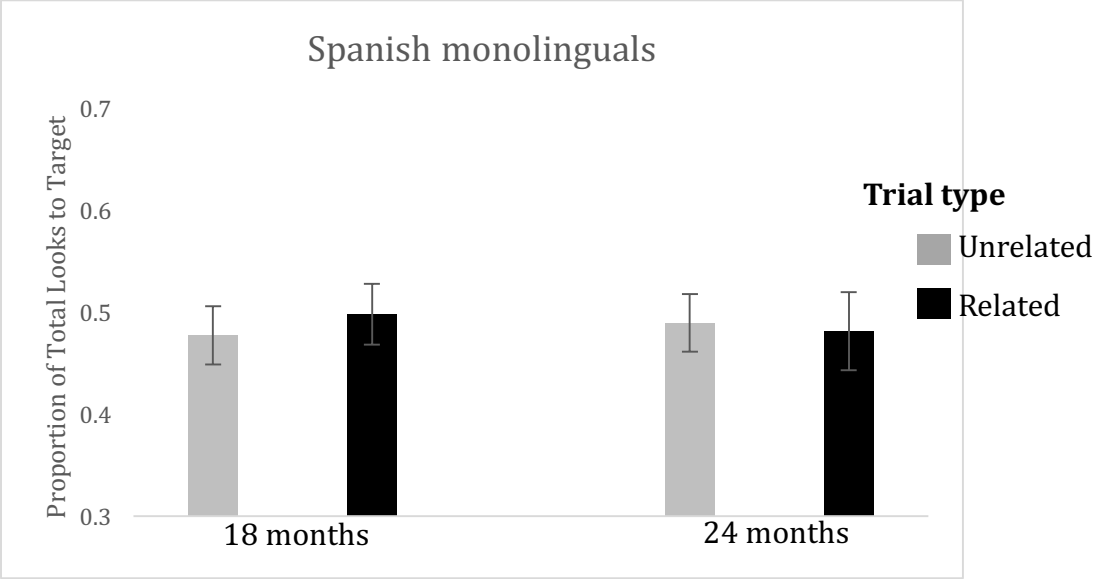

Figure 5-6. Proportion of total looks to target at 18 and 24 months, respectively, within the Spanish monolingual group.

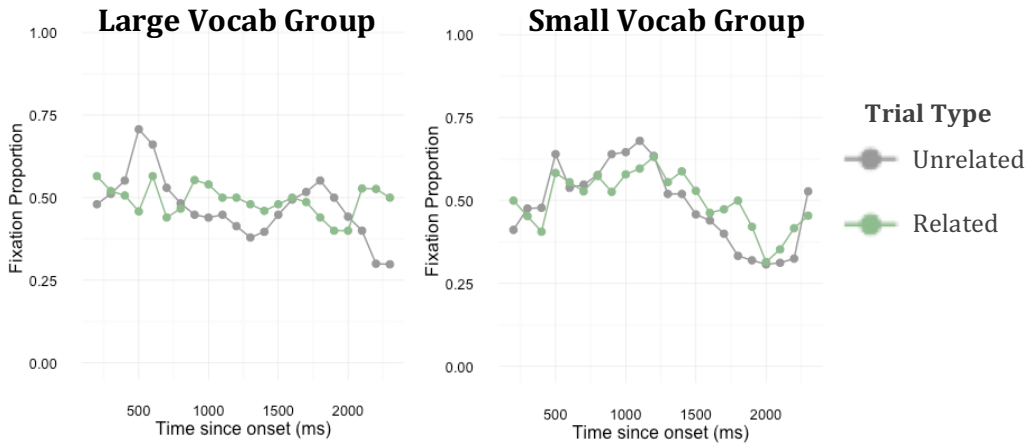

Figure 5-7. Proportion of looks to the target for related and unrelated trials over time at 24 months between the large and small vocabulary groups within Spanish monolinguals.

Chapter 5, in full, is being prepared for submission for publication of the material. DeAnda, S., & Friend, M. (in preparation). A cross-linguistic investigation of word knowledge and lexical-semantic development in toddlers. The dissertation author was the primary investigator and primary author of this paper.

Chapter 6: Lexical-Semantic Processing in Bilingual Toddlers

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Acknowledgments
*This research was supported by NIH awards 5R01HD068458 and1F31HD081933 and does not necessarily represent the views of the National Institutes of Health. We gratefully acknowledge Kelly Kortright, Lauren Thayer, and Hanna Moon for their help with data collection and all of the parents and children who have devoted their time to participate in this research.

Abstract

An important question in early bilingual first language acquisition concerns the development of lexical-semantic associations within and across two languages. The present study investigates the emergence of lexical-semantic priming at 18 and 24 months in Spanish-English bilinguals and its relation to vocabulary knowledge. Results indicate a remarkably similar pattern of development between monolingual and bilingual children, such that lexical-semantic development begins at 18 months and is related to vocabulary size within and across languages. By 24 months, lexical-semantic processing is much more robust but no longer correlated with word knowledge. Together these findings inform our understanding of the relation between word knowledge and lexical-semantic organization in the context of dual language learners and how this changes developmentally.

Introduction

An important area of research in early language acquisition examines developmental changes in lexical growth in preschoolers. This body of work reveals rapid word learning during the first and second year of life, such that young infants begin babbling early in the first year (e.g., Molemans, van den Berg, Van Severen, & Gillis, 2012). They soon approximate words and say their first word around 12 months. By the end of the second year at 24 months, children begin producing their first word *combinations.* Importantly, these language milestones are met at the same time for children learning one or two languages (Pearson, Fernandez, & Oller, 1993; Pearson & Fernandez, 1994). Indeed, monolingual and bilingual use similar word learning strategies and learn words at a similar rate overall (Byers-Heinlein, Fennell, and Werker, 2013; Pearson, Fernandez, & Oller, 1993). Further, recent evidence has shown that bilingual and monolingual toddlers process spoken language at a similar rate (DeAnda, Hendrickson, Zesiger, Poulin-Dubois, & Friend, 2017; Legacy, Zesiger, Friend, & Poulin-Dubois, 2016; 2016).

Despite several similarities between monolingual and bilingual toddlers in word acquisition and processing, it is unclear how dual language exposure influences lexical organization. At present there remains a dearth of studies informing our understanding about the emergence of lexical networks in bilinguals to parallel that in the monolingual literature. Indeed, there is reason to believe that development may differ between bilingual and monolingual toddlers. Bilingual children are tasked with organizing words in a lexicon to encompass *two* languages. Although it is unclear whether the lexical-semantic network within bilinguals is comprised of shared or

separate *representations* across languages, it is clear that lexical *processing* is shared in bilingual adults and in bilingual toddlers as early as 30 months of age (Singh, 2014). Specifically, Chinese-English bilinguals showed lexical-semantic priming when the prime word was presented in the dominant language (the language to which the child was most exposed). These findings establish the existence of lexical-semantic associations early in the third year. However, a series of studies in monolingual English learners reveals an incremental developmental process, in which lexical-semantic priming emerges late in the second year around 21 months of age. Specifically, 21-month-old, but not 18-month-old, English monolinguals showed longer looking to the target object in related relative to unrelated trials, thereby indicating lexical-semantic priming effects emerge around 21 months of age (Arias-Trejo & Plunkett, 2009). Further, 21 month-old monolinguals exhibited priming between words that were associatively *and* semantically related. By 24 months, however, either an associative *or* a semantic relation was sufficient to elicit priming (Arias-Trejo & Plunkett, 2013). Together these findings suggest the fragile emergence of a lexical-semantic structure by 21 months of age that becomes more robust by the end of the second year at 24 months in monolinguals. Of interest in the present study is the influence of dual language exposure on this developmental timeline. Specifically, we ask whether bilinguals exhibit lexical-semantic priming at 18 and 24 months of age in parallel to findings in the monolingual literature.

Previous Studies

To date, few studies have investigated lexical priming in bilinguals. Extending previous work in monolinguals, Von Holzen and Mani (2012) examined whether

bilinguals' second language primed the first language in phonologically related word pairs between 21 and 43 months of age. Remarkably, bilingual toddlers showed facilitated target recognition, even in cases where phonological priming occurred indirectly through a translation equivalent. For example, children showed facilitated recognition of the L1 German target "stein" given the L2 English prime of "leg." This priming relation appeared to be supported by the phonological overlap between the target ("stein") and the L1 translation of the prime, "bein." This finding demonstrates two key points. First, German-English bilinguals activate phonological knowledge from L2 to L1. Second, like monolinguals, bilinguals exhibit implicit activation of translation equivalents when processing in L2 after age 2. These results parallel the findings and theoretical accounts of adult bilingual language representation as cross-language phono-semantic co-activation extends, at least in this case, to early childhood.

There is also evidence of cross-language semantic co-activation early in bilingual development. As mentioned previously, in a study of 30-month-old Chinese-English bilinguals, Singh (2014) investigated bidirectional priming within and across the dominant and less-dominant language. Within-language priming was observed for the dominant, but not the non-dominant, language. Further, cross-language priming was unidirectional, such that the dominant language primed the non-dominant language, but the opposite was not true. Put another way, in contrast to Von Holzen and Mani (2012), priming was only observed when the semantic prime was in the dominant language. That is, bilinguals show priming from the non-dominant to the dominant language when *both* phonological and semantic information are provided in

the third year of life as in Von Holzen and Mani (2012). However, given only semantic information, 30-month-olds show priming effects only when the prime occurs in the dominant language (Singh, 2014). Nevertheless, there are several important differences between these studies that limit our ability to draw conclusions about lexical priming in early bilingual development. One important difference between the Von Holzen and Mani (2012) and Singh (2014) studies is the particular pair of languages to which children were exposed. Some languages pairs (e.g., English and German) offer more opportunity for phonological overlap than others (e.g., English and Chinese). Although phonological priming was not tested in Singh (2014), the language families from which language pairs arise in dual language learners may have implications for phonological organization. A second difference concerns the ages tested in each study. Von Holzen and Mani (2012) include children up to 43 months of age whereas Singh (2014) includes children between 30 and 31 months of age. The additional year of language experience in the German-English bilinguals may have led to increased proficiency in the non-dominant language leading to significant cross-language priming from the non-dominant to the dominant language. A final difference between studies concerns age of acquisition, as most of the bilinguals in Von Holzen and Mani (2012) were exposed to English later in life whereas the bilinguals in Singh (2014) received bilingual exposure from birth.

Nevertheless, the studies by Von Holzen and Mani (2012) and Singh (2014) suggest connections between phonologically and semantically related words are observed late in the second year and into the third similar to monolingual children. In addition, these findings highlight differences between monolingual and bilingual

lexical development: for bilinguals, semantic connections from L2 to L1 can be absent well after age 2, when semantic priming is robust for monolinguals. Still, these findings tell us little about the development of lexical-semantic priming before age 2. In what follows, we will outline a set of predictions about the developmental time course and emergence of lexical-semantic networks.

Predictions About the Development of Lexical-Semantic Priming in Bilinguals

Do bilinguals begin to form lexical-semantic connections between languages, and therefore begin to process both languages in parallel, at the same time that monolinguals form connections between words in their single language? Is the development of lexical-semantic priming a robust process that emerges similarly across single and dual language learners? Under this account lexical-semantic connections between and within languages arise at the same age (approximately the end of the second year) for monolingual and bilingual infants alike. If true, this would suggest that the emergence of lexical networks is unaffected by language exposure. Indeed, many models of early language acquisition consider the end of the second year to be an important time for lexical development. For example, many researchers have documented an acceleration in vocabulary size that occurs at approximately 18 months of age across bilingual and monolingual children (Goldfield & Reznick, 1990; McMurray, 2007; McMurray, Horst, & Samuelson, 2012; Pearson, Fernández & Oller, 1993). This rapid growth in the lexicon might have implications for lexical organization; object categorization might foster connections between related words within and across languages. Thus, under a maturational account, the acceleration in

lexical acquisition around age 2 gives rise to the emergence of lexical networks independent of the number of languages being learned.

A second possibility is that the emergence of lexical organization occurs earlier for bilinguals relative to monolinguals. As we will review below, there are several aspects of bilingual language acquisition that support the notion of precocious development of the lexical-semantic system. That is, it may be that the task of forming connections between two non-translation equivalents across languages (such as *dog* and *gato*) might be easier, and perhaps developed earlier for bilinguals. Bilinguals might be cued into the connections between words given their experience with cognates and translation equivalents. That is, cognates and translation equivalents have a *compound* structure (De Groot, 1993): two separate lexemes are bound to a single concept, thereby forming an indirect connection between two lexemes.

The enhanced compound lexical structure in bilinguals has implications for language learning and word retrieval. One proxy of compound lexical structure in bilinguals is the number of known translation equivalents. Byers-Heinlein and Werker (2013) found that 17-month-old bilinguals, in contrast to monolinguals, are more likely to accept a novel name for a previously named object. This propensity varies as a function of the number of translation equivalents (TEs) known across languages: bilinguals who knew many TEs were more likely to show this effect relative to bilinguals who knew fewer TEs. The authors propose the *lexicon structure hypothesis,* which suggests that bilingual infants with knowledge of many TEs have richer semantic organization relative to monolingual peers, as the relationship between

words and concepts across two languages supports a many-to-one mapping structure. Similarly, Poulin-Dubois, Bialystok, Blaye, Polonia and Yott (2013) found that bilinguals with many TEs show faster lexical access than bilinguals with fewer TEs, suggesting a facilitative priming effect that follows from a many-to-one lexical organization. Extending these findings to semantic relations in the lexicon, it is possible that bilinguals might be cued into the relationship between two non-translation equivalents across languages before age 2. That is, they might form connections between *dog* and *gato* before monolingual children form relations between *dog* and *cat* due to a rich and complex lexical network shared across languages.

A final possibility is that bilinguals might show later emergence of lexical networks than their monolingual peers. This would be consistent with the recently proposed "resource limitation hypothesis" which suggests that bilinguals face more challenges in word learning relative to monolinguals in using phonetic detail, for example (Fennell, Byers-Heinlein & Werker, 2007; Fennell & Werker, 2003; Stager & Werker, 1997; Werker & Fennell, 2004; Werker, Fennell, Corcoran & Stager, 2002). Despite being exposed to greater phonetic breadth than monolinguals, bilinguals may have weaker phonemic representations by virtue of having relatively less exposure, since exposure is split across languages. Although bilinguals learn words at the same rate as monolinguals (Pearson, Fernandez & Oller, 1993), monolinguals seem to utilize phonemic detail to guide word learning earlier. Thus, it is possible that these weak phonemic representations might lead to weaker connections between words, at least at the phonological level.

Extending the Distributed Feature Model (DFM, Van Hell & De Groot, 1998) to early development also suggests the possibility of a protracted account of semantic connections within and across languages for bilinguals. The DFM characterizes lexical-semantic connections as highly contextualized, thereby accounting for subtle differences in meaning in translation equivalents. In monolinguals, the DFM would account for the emergence of semantic priming at age 2 as a result of strengthened semantic representations that activate words with similar meaning. That is, as children encounter more exemplars of *dog* and *cat*, they activate an increasing number of overlapping semantic features which leads to the semantic priming effects observed in the second year of life.

For bilinguals, however, their experience with the world is split between two languages. Suppose a young bilingual infant encounters the word *chair* for the first time when sitting in a car seat, but hears *silla* for the first time in the presence of a bar stool. In this case, there would be very little, if any, overlap in meaning, as the word *chair* and *silla* would activate separate sets of semantic features. As the child encounters different exemplars of each word across languages, an increasing number of overlapping semantic features would be created, linking *silla* and *chair* at the semantic level. Importantly, although we can assume that the bilingual child encounters the same number of chairs as a monolingual, bilinguals receive half as many exemplars per lexical item. If the emergence of semantic priming in monolinguals at age 2 is brought about by the strength of semantic representations (as a function of the number of overlapping semantic features), it follows that bilinguals might have a more protracted development of semantic connections, as there are

fewer overlapping semantic features for related lexical items. This account predicts slower and later-emerging lexical-semantic priming for monolinguals relative to bilinguals.

The Present Study

The present study seeks to examine lexical-semantic development longitudinally at 18 and 24 months of age in Spanish-English bilinguals. As we have reviewed, the dearth of research in this area leaves several possible predictions open with respect to the timing of the lexical-semantic priming. In addition, the present study seeks to examine vocabulary size within and across languages in an effort to understand this source of variability in determine the emergence of lexical-semantic processing. Specifically, the present study asks the following questions:

1) Does lexical-semantic priming emerge at 18 or 24 months?
2) Do within-language vocabulary size, total vocabulary size, and translation equivalents predict lexical-semantic processing?

Method

Participants

A total of 32 bilingual English- and Spanish-learning toddlers (15 females, 17 males) participated in the present longitudinal study at 18-months (*M* = 18;17, range = 17;15 – 20;21), and 24-months of age (*M* = 25;5, range = 23;6 – 27;12). Seven participants from the original sample of 32 did not return for the 24 month testing occasion. We nevertheless analyzed all of the available data within each age group. English-Spanish bilinguals constitute a substantial and growing group in the United States. U.S. Census data show that between 2000 and 2010 the Spanish speaking

population in the United States increased by 43% (U.S. Census, 2011). An a-priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted to determine the appropriate sample size based on the smallest effect size reported in a similar study (Arias-Trejo & Plunkett, 2009). Results indicated that a sample size of at least 20 participants was required to achieve appropriate power ($1-\beta > .9$).

The average maternal education was approximately completion of a 4-year college degree (M = 14.97 years, SD = 2.27, range = 11 – 18). Participants were obtained through a database of parent volunteers recruited through birth records, internet resources, community organizations, and events in a large metropolitan area in Southern California. All participants were full-term and had no diagnosed impairments in hearing, vision, language, and cognition. To be included in the present study, children must have had between 20 and 80% exposure to both English and Spanish as determined by the Language Exposure Assessment Tool (LEAT, DeAnda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016). No children had exposure to a third language. All children received early simultaneous exposure to both English and Spanish.

Measures

The Computerized Comprehension Test (CCT)

The CCT is a behavioral measure that captures children's haptic response to assess early decontextualized receptive vocabulary. The CCT demonstrates strong internal consistency, converges with parent report on the MacArthur-Bates Communicative Development Inventory (MCDI, Fenson, Marchman, Thal, Dale, Reznick & Bates, 2006), and predicts subsequent language production (Friend,

Schmitt & Simpson, 2012). Additionally, responses on the CCT are nonrandom (Friend & Keplinger, 2008) and this finding replicates across languages (Friend & Zesiger, 2011) and across monolinguals and bilinguals (Poulin-Dubois et al., 2012). The English and Spanish CCT have good test-retest reliability, excellent internal consistency, and predict expressive vocabulary size (e.g., Friend & Keplinger, 2008; Friend, Schmitt & Simpson, 2012).

Participants are prompted to touch images on the monitor (e.g., "Where's the *dog?* Touch *dog!"*). A correct touch to the target image (e.g., the dog) elicits a reinforcing sound (e.g., the sound of a dog barking). The CCT presents 4 training trials and 41 test trials in a two-alternative forced-choice procedure. For each trial, two images (a target and distractor image) appeared simultaneously on the right and left side of the touch monitor. The side on which the target image appeared was presented in pseudo-random order across trials such that target images could not appear on the same side on more than two consecutive trials, and the target was presented with equal frequency on both sides of the screen (Hirsh-Pasek & Golinkoff, 1996). All image pairs presented during training, testing, and reliability were matched for word difficulty (easy, medium, hard) based on MCDI norms (Dale & Fenson, 1996), part of speech (noun, adjective, verb), category (animal, human, object), and visual salience (color, size, luminance).

The CCT begins with a training phase to insure participants understand the nature of the task. During the training phase, participants were presented with early-acquired noun pairs (known by at least 80% of 16-month-olds; Dale & Fenson, 1996) and prompted by the experimenter to touch the target. If the child failed to touch the

screen after repeated prompts, the experimenter touched the target image for them. If a participant failed to touch during all four training trials, the training trials were repeated once. Only participants who executed at least one correct touch during the training phase proceeded to the testing phase. All of the participants proceeded to the testing phase.

Each test trial ended when the child touched the screen or until seven seconds elapsed. When the child gaze was directed toward the touch monitor, the experimenter delivered the prompt in infant-directed speech and advanced each trial. The experimenter presented each pair of images as she uttered the target word in the first sentence prompt such that the onset of the target word occurred just prior to the onset of the visual stimuli.

The MacArthur Bates Communicative Development Inventory

The MCDI is a widely used parent report measure of early language. The Words and Gestures inventory is a checklist allowing parents to mark the words their child understands and says. The inventory provides researchers with an indirect account of the child's vocabulary comprehension. The MCDI, originally developed in English, has good reliability and validity and has been adapted for use in over 50 languages and dialects, including Spanish (Fenson et al., 2006; Jackson-Maldonado, Thal, Fenson, Marchman, Newton, & Conboy, 2003). The Spanish adaptation, the Inventario de Dessarrollo de Habilidades Comunicativas (IDHC) was used in the present study to evaluate vocabulary size as reported by parents for the Spanish monolingual group. The Words and Gestures inventory was used at both 18 and 24 months of age as a parent report measure of both receptive and expressive vocabulary

to complement the behavioral assessment of receptive vocabulary (the CCT). In this way, we obtain both a parent report and child performance measure of the same underlying construct however this comes with the limitation that we can only compare our sample-specific data to the MCDI norms at 18 months and not at 24 months. To evaluate the effect of lexical knowledge across languages, Total Vocabulary and Translation Equivalents were calculated. Translation Equivalents were those words that children knew in both English and Spanish. Total Vocabulary was calculated by summing vocabulary size across languages and subtracting known Translation Equivalents.

Intermodal Preferential Looking Priming Task

Stimuli.

We used an adaptation of the Intermodal Preferential Looking Task (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987), which has previously been used to investigate lexico-semantic priming in young toddlers (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009; Singh, 2014). A total of 108 English and Spanish words known by 60% or more of 18-month-olds were chosen based on the Macarthur-Bates Communicative Development Inventory and Inventario de Habilidades Comunicativas (IDHC) norms (Dale & Fenson, 1996). One third of these words served as auditory primes, another third as target, and a final third as distractor images.

In the current study, semantic relatedness is determined by the cosine value between two words: a calculation of the feature overlap between pairs of words based on adult norms (Buchanan, Holmes, Teasley, & Hutchison, 2012). Features can be

physical, functional, and categorical. A cosine of 0 represents no semantic overlap between two words, whereas 1 represents complete overlap. Previous work has demonstrated semantic priming in children at these same ages using English adult norms and has extended English-speaking norms to other languages (e.g. Mandarin; Singh, 2014). Thus we will attempt to extend these norms to Spanish as well since a large corpus comparable to that of Buchanan et al. (2012) is currently unavailable in Spanish. The lexical items in the current study are highly imageable and early occurring nouns known by the majority of English and Spanish monolinguals.

Experimental Design

Participants were presented with Related and Unrelated trial types. On Related trials, the prime word was semantically related to the target word (e.g., banana and apple). Primes and targets were highly related and had an average cosine value of .32 (*SD* = .11, range = .14 - .55). Unrelated trials presented pairs of unrelated words with a cosine value of 0 (e.g. pillow and apple, "I saw a pillow… apple!").

The experiment consisted of four blocks: Spanish prime words to Spanish targets (Spanish-Spanish), Spanish prime words to English targets (Spanish-English), English prime words to English targets (English to English), and English primes to Spanish targets (English-Spanish, see Table 6-1). Each block consisted of 3 Related trials and 3 Unrelated trials. The order of blocks was counterbalanced across participants and trial presentation was pseudo-randomized within blocks such that no more than two trials of the same type were presented consecutively. Side of target presentation was also counterbalanced across participants. Target and distractor pairs were yoked across participants and were semantically unrelated (cosine = 0). The

target and distractor images were non-continguous (approximately 10cm apart) so as to reduce possible error associated with determining the location of gaze on the screen (Holmqvist et al., 2011). In addition, each yoked pair of images appeared equally across all three trial types to counterbalance any systematic effects of picture salience. Children saw each target and distractor pair only once. Distractor images were never named and appeared with equally frequency across trial types. Primes were counterbalanced such that they appeared equally across trial types. A female native speaker of English and Spanish produced all auditory stimuli in infant-directed speech. Each word and sentence frame was recorded in isolation.

Trials began with the presentation of a carrier phrase ("I saw a …") ending with the prime word that was either semantically related or unrelated (e.g., "banana"). An attention-getter (i.e., a spinning water wheel, Delle Luche, Durrant, Poltrock, & Floccia, 2015, see Figure 6-1) appeared on screen for a total of 1000 ms during the presentation of the carrier phrase and prime word. Two hundred ms after the offset of the prime word (e.g., "apple"), the auditory target word was presented in isolation. Two hundred ms after the offset of the target word, the yoked target and distractor images were presented for a total of 2500 ms. A short prime-target inter-stimulus interval (ISI) and stimulus-onset asynchrony (SOA) of 200 ms each have been previously used with infants (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009, 2011) and correspond to parameters for lexical priming in adults.

Children were tested across two separate visits: an English and Spanish visit, respectively. The language of the visit determined the language of the primes and was counterbalanced across participants. Within each visit, the within-language priming

block preceded the cross-language block (e.g., English – English priming block followed by English – Spanish or Spanish – Spanish followed by Spanish – English). This was preferred over counterbalancing all blocks for three main reasons. First, full counterbalancing with the present sample size would yield insufficient power to test for order effects. That is, the current sample would be split into four separate groups to test all possible counterbalancing orders. Second, this organization minimized possible task order effects based on language dominance as seen in adult bilinguals (e.g. Misra, Guo, Bobb, & Kroll, 2012). Third, we designed the task such that within-language priming preceded cross-language priming to make cross-language priming as conservative as possible. Theoretically, the preceding language block would make the first language presented more active than the other. Thus, if priming from the first to the second language occurs despite heightened activation to the prime language it suggests that a robust cross-language priming effect is in place early in the second year of life. Third, the within-language priming block preceded the cross-language priming block to ensure that direct comparison to monolingual findings was possible. Otherwise, it is possible that the cross-language priming may influence subsequent gaze patterns on the within-language priming block, making any bilingual to monolingual comparisons difficult.

Data processing

Eye-tracking data collected in infants and toddlers is inherently noisy, and recent studies reveal the influence of low-quality data on several key eye gaze measures (e.g. Wass et al., 2013; Wass, 2014; Saez de Urabain, Johnson, & Smith, 2015). As such, many researchers have proposed a number of ways to process data so

as to maximize its accuracy. Wass, Forssman, and Leppanen (2014) recommend the use of a median moving window and interpolation to reduce noise in infant data when analyzing proportion looking (the dependent variable of interest in the present study). Following these recommendations, we applied a median moving window filter to the raw eyetracking data, in which data was chunked in 100 ms windows and a single median was calculated. A median was calculated even when data for only a single eye was available (Saez de Urabain, Johnson, & Smith, 2015). Although some studies suggest single-eye data may be indicative of poor quality (Wass et al., 2014) Saez de Urabain, Johnson, and Smitth (2015) recommend including such samples in the interest of collecting the highest number of fixations. Similarly, gaze data were interpolated when a gap of no more than 150ms was encountered (Saez de Urabain, Johnson, and Smitth, 2015; Wass, Forssman, & Leppanen, 2014). Interpolation was achieved through scaling gaze samples from before and after the gap to create a continuous trajectory (Olsen, 2012). Further, we excluded trials in which toddlers fixated on the target and distractor less than 25% of the trial. In addition, trials in which toddlers fixated only the target or only the distractor were excluded to increase the probability that the data reflected active lexical-sematic processing (e.g., Mani & Plunkett, 2010). Following these procedures, proportion looking was evaluated by calculating total looking to the target divided by the sum of total looking to the target and distractor using the *eyetrackingR* package (Dink & Ferguson, 2015) in RStudio (RStudio Team, 2015).

Procedure

Bilinguals visited the lab for an English and a Spanish visit, respectively, scheduled approximately one week apart. After a short warm-up play period between the toddler and the experimenter, children and their caregivers were escorted to a dimly-lit room which houses the CCT setup. Following the CCT, children and their parents moved to a second room to complete the IPL task. For the IPL procedure, infants sat approximately 25 inches away from a 27" Dell monitor with a 1920x1080 resolution. A Tobii X120 recorded eye gaze and was placed 3 inches below and 5 inches in front of the monitor. Auditory stimuli were presented through Dell AX210 multimedia stereo audio speakers positioned behind the monitor.

Results

18 months

Children demonstrated increased vocabulary on the CCT behavioral measure from 18 months (English CCT: *M* = 14.16, *range* = 4 – 25; Spanish CCT: *M* = 12.07, range = 4 – 21) to 24 months of age (English CCT: *M* = 23.08, *range* = 2 – 35; Spanish CCT: *M* = 19.35, *range* = 6 – 26) across English and Spanish adaptations of the CCT. Parent reports of receptive vocabulary on the MCDI and IDHC were relatively balanced across English and Spanish at 18 months (MCDI: *M* = 190.71, range = 22 – 373). Scores on the MCDI corresponded to the 1st to the 99th percentiles and for the IDHC (*M* = 180.43, *range* = 26 – 355) corresponded to the 1st to the 90th percentiles. The pattern was similar at 24 months of age (MCDI: *M* = 285.5, *range* = 59 – 396; IDHC: *M* = 226.0, *range* = 14 – 396). Within expressive vocabulary, scores on the MCDI corresponded to the 1st through the 86th percentiles (MCDI: *M* = 44.97, *range* = 3 – 155). Scores on the IDHC corresponded to the 1st through the 92nd

percentile (*M* = 35.64, *range* = 0 – 154). By 24 months, parents reported increased expressive vocabulary size across languages (English: *M* = 145.55, *range* = 3 - 293; Spanish: *M* = 91.10, *range* = 1 - 331).

The first step in the analysis was to replicate previous findings by aggregating over the entire time window of interest and asking whether proportion of total looks differed significantly as a function of language and trial types. Thus, an ANOVA was conducted to examine whether proportion of total looks differed as a function of Language (Dominant or Non-Dominant Language), Prime Type (Within- or Cross-Language), and Trial Type (Related and Unrelated Trials). Results revealed a significant main effect of Language ($F(1, 252) = 6.25$, $p = .01$) and a marginal Language X Prime Pair interaction ($F(1, 252) = 3.44$, $p = .06$). As seen in Figure 6-2, the interaction reflects the fact that children evinced the longest looking times in the within-language condition in the dominant language.

Next we asked whether looking times differed over the course of the trial through growth curve analyses. Results revealed a significant quadratic term indicating a Trial Type interaction (LRT = 5.89, $p = .015$). This interaction suggests that looking patterns differed over the course of the trial. As can be seen in Figure 6-3, children spent more time looking to the target object on the related trial versus unrelated trials between 1000 and 1500ms, a relatively short period of time during the time window of interest.

Vocabulary and Lexical-Semantic Processing

Next we examined the effect of vocabulary on looking times across trials. We ran a series of ANCOVAs with Trial Type (Related and Unrelated Trials) as the

independent variable, total vocabulary size as the covariate, and proportion looks to the target as the dependent measure. Results revealed a marginal effect of total CCT vocabulary ($F(1, 28) = 3.59$, $p = .07$) and total MCDI vocabulary ($F(1, 28) = 6.29$, $p = .02$) on looking times. Similarly, in a second series of ANCOVAS, within-language vocabulary on the MCDI and CCT were entered as covariates, with Language (Dominant vs. Non-Dominant) and Trial Type (Related vs. Unrelated) as the independent variables and proportion looks to the target as the dependent variable. Results showed effects of within-language receptive vocabulary size on the MCDI ($F(1, 28) = 4.30$, $p = .04$) and CCT ($F(1, 28) = 4.23$, $p = .04$), but no interaction with Language in either model indicating that that vocabulary size across languages was a significant predictor of children's looking times. A final ANCOVA was conducted with Trial Type as the independent variable, number of Translation Equivalents as the covariate, and proportion looks to the target as the dependent measure. There was a main effect of number of known Translation Equivalents on the MCDI ($F(1, 28) = 7.70$, $p = .01$). Together, these analyses reveal that vocabulary knowledge irrespective of the specific language and knowledge combined across languages (i.e., total vocabulary and translation equivalents) support lexical-semantic processing at 18 months.

24 months

An ANOVA was conducted to examine whether proportion of total looks differed as a function of Language (Dominant or Non-Dominant Language), Prime Type (Within- or Cross-Language), and Trial Type (Related and Unrelated Trials) at age 2. Results revealed a significant main effect of Trial Type ($F(1, 378) = 4.66$ $p =$

.03) and Language ($F(1, 378) = 4.65$, $p = .03$). The main effect of Trial Type indicates a significant difference in looking time between related and unrelated trials by 24 months of age. The main effect of Language reveals children's tendency to look longer following primes in the dominant language as can be seen in Figure 6-4.

To parallel the analyses at 18 months, we employed a growth curve analysis to examine whether looking behavior changed over the course of the trial as a function of related and unrelated trials. Results revealed a main effect of Trial Type (LRT = 3.9, $p = .04$) consistent with the ANOVA results. However, there was no interaction with any of the polynomial change terms, indicating that looking times did not vary over time. Indeed, as can be seen in Figure 6-5, looking times to the target were consistently above unrelated trials throughout much of the time window.

Vocabulary and Lexical-Semantic Processing

Finally, a series of ANCOVAs with Trial Type (Related and Unrelated Trials) as the independent variable and vocabulary size as the covariate examined the effect of word knowledge on looking times. There were no significant effects of within-language vocabulary size or total vocabulary size on the MCDI and CCT. Similarly, the number of known translation equivalents on the MCDI was not a significant predictor of looking time.

Discussion

The present study sought to examine lexical-semantic development longitudinally at 18 and 24 months of age in Spanish-English bilinguals. In addition, the present study investigated the role of vocabulary size within and across languages in an effort to understand this source of variability in the emergence of lexical-

semantic processing. Specifically, we asked whether lexical-semantic priming emerges at 18 or 24 months of age in bilinguals and whether within-language vocabulary size, total vocabulary size, and translation equivalents were significant predictors of children's lexical-semantic processing.

With respect to the emergence of lexical-semantic priming, results revealed a pattern of development similar to that documented in monolinguals. As reviewed previously, findings within the monolingual literature suggest a fragile emergence of lexical-semantic priming, such that priming was evinced at 21 and 24 months of age, but not at 18 months (Arias-Trejo & Plunkett, 2009; 2013; Styles & Plunkett, 2009). Indeed, traditional ANOVA analyses in the present study showed a significant difference in looking time between related and unrelated trials at 24 but not 18 months of age. That is, when analyses collapse over the time window, a significant difference between semantically related and unrelated trials appears only at 24 months consistent with previous findings. Nevertheless, the growth curve analyses examining the entire time course revealed that the pattern of looking behavior indeed differed throughout the time window at 18 months. Visual inspection of looking times throughout the time window show that children's looking time to the target object differed between semantically related and unrelated trials but only between 1000 and 1500ms at 18 months of age. Conversely, by 24 months, the difference in looking time as a function of semantic relatedness was relatively consistent throughout the entire time window however looking times were no longer related to vocabulary size. This provides evidence for developmental changes occurring from 18 to 24 months that support increasing efficiency in processing the lexical-semantics of auditory language.

What do these findings reveal about the development of lexical-semantic processing? The remarkable similarity in the pattern of results with previous monolingual research is consistent with a large body of work demonstrating that dual language exposure leads to a similar timetable for the acquisition of early words and for the development of semantic networks as does monolingual exposure. Indeed, as reviewed previously, important language milestones, such as babbling, first word production, and word combinations are all met at the same time for children learning one or two languages (e.g., Pearson & Fernandez, 1994; Pearson, Fernandez & Oller, 1993). Similarly, monolingual and bilingual employ similar word learning strategies and learn words at a similar rate (Byers-Heinlein, Fennell & Werker, 2013; Pearson, Fernandez & Oller, 1993). Spoken word processing (i.e., lexical access) is also similar between monolingual and bilingual toddlers at 16 and 22 months of age (DeAnda et al., 2017; Legacy et al., 2015; 2016). Thus, the present findings add to this body of work by demonstrating that early bilingual language learners demonstrate an emerging lexical-semantic system that develops incrementally throughout the second year in a timetable comparable to their monolingual peers.

In addition to examining the development of lexical-semantic processing, the present study sought to examine the influence of vocabulary size on processing ability. At 18 months of age, total vocabulary, within-language vocabulary, and translation equivalents were all significant predictors of children's looking times. However, by 24 months, vocabulary size across all measures was not a significant predictor of looking behavior. These results suggest that early in the second year, at 18 months, vocabulary size is highly predictive of children's lexical-semantic

processing ability. Further, in bilinguals, vocabulary within and across languages supports lexical-semantic processing. This is consistent with previous findings of cross-language associations between vocabulary and lexical access at 16 and 22 months of age in Spanish-English bilinguals (DeAnda et al., 2017). However, by the end of the second year, the relation between vocabulary size and lexical-semantic processing decouples, such that vocabulary size within and across languages no longer predicts lexical-semantic processing. Thus, 18-month-olds appear to employ vocabulary knowledge to support the development of lexical-semantic associations. By 24 months, however, lexical-semantic priming ability may be better explained by other sources of variability, such as cognitive efficiency. For example, children's efficiency in spoken language processing in toddlerhood predicts non-linguistic abilities at age 8 (Marchman & Fernald, 2008), suggesting that cognitive efficiency may influence processing efficiency in both linguistic and non-linguistic domain. Thus it is possible that general cognitive efficiency supports lexical-semantic processing by age 2. For example, early lexical-semantic structure may reflect children's language experience. As such, words with semantically related meanings may co-occur in language input and this increased frequency of co-occurrence guides word-to-word associations. Indeed, infants can recognize semantic similarities between words as a function of statistical regularities in language input (Hills, 2013; Hills, Maouene, Riordan & Smith, 2010). In this way, general learning principles may support the formation of lexical networks.

Nevertheless, the present pattern of findings is consistent with DeAnda and Friend (in prep) which found that vocabulary size in monolingual children correlated

with proportion of total looks on the same IPL lexical-semantic priming task at 18 but not 24 months age. Specifically, English monolinguals with large vocabularies at 18 months demonstrated lexical-semantic priming effects, whereas children with small vocabularies did not. Together these studies suggest that vocabulary size may provide a way to bootstrap organization early in the development of a lexical-semantic system around the time of the vocabulary spurt at 18 months. By 24 months, when the lexical-semantic network may be increasingly complex and when children are faster at processing spoken words, vocabulary size may no longer directly facilitate lexical-semantic priming. This is not to say that vocabulary size no longer matters for lexical-semantic organization after the second birthday, but that vocabulary size might contribute to other aspects of lexical-semantic processing such as timing or interaction with phonology and grammar that were not explicitly tested here.

Relatedly, it may be that the lexical structure itself is more predictive than overall vocabulary size by 24 months. For example, Borovsky et al. (2017) posit a leveraged learning account of early lexical-semantic development, in which young children use known similarities among words to leverage word-learning. Specifically, 24-month-olds are more likely to learn a word from a well-known category relative to less-known category. Thus, it is not necessarily the breadth of the lexicon that supports lexical-semantics by age 2, but rather the specific structure that leverages children's ability to organize words based on meaning. As such, lexical-semantic structure itself may also guide the strength of associations among words to facilitate the type of priming examined in the present study. These findings are corroborated by semantic network modeling based on parent reported vocabulary size. These models

show that children with larger vocabularies demonstrate denser semantic networks (i.e. more links in the network), higher clustering (i.e. more categories), greater robustness (i.e. efficiency), and greater global structure (i.e., lexical-semantic access; Beckage, Smith, & Hills, 2010).

In addition to several similarities between monolingual and bilingual language development observed here, there exist some findings that are unique to the dual language context. In the present study, we examined within- and cross-language priming in the dominant and non-dominant language within bilinguals. Across 18 and 24 months of age, children evinced the longest looking times for primes presented in the dominant language. The disparity between processing in the dominant and non-dominant language is consistent with a similar study at 30 months of age. Specifically, Singh (2014) found that 30-month-old Mandarin-English bilinguals demonstrated priming effects but only when the prime word was in the dominant language. In the present study we extend this finding to Spanish-English bilinguals at 18 and 24 months of age. Thus, in semantic priming, children demonstrate differences in processing efficiency that favor the dominant language. This contrasts with the finding that the less exposed language can contribute to phonological priming in German-English bilinguals (Von Holzen & Mani, 2012). As we suggested earlier, priming effects may differ across phonological and semantic domains, across language pairs, age groups, and age of acquisition. This finding has theoretical implications for bilingual language representation at the earliest stages of acquisition. Several recent studies have posited the existence of a separable but interconnected lexical-semantic system across languages in early development (DeAnda,

Hendrickson, Zesiger, Poulin-Dubois, & Friend, 2017; Marchman, Fernald, & Hurtado, 2010; Singh, 2014). According to PRIMIR (Curtin, Byers-Heinlein, & Werker, 2011), a theoretical model of early language acquisition, the relation between languages is affected by task demands, such that differences in looking time may be explained by increased difficulty in processing the weaker language (i.e., the non-dominant language). Similarly, adult models of second language acquisition, such as the Revised Hierarchical Model (Kroll & Stewart, 1994), posit differences in lexical-semantic processing between the first and second language that are supported by a large body of empirical evidence. Importantly, there is slower semantic access in the weaker second language than the first language at the earliest stages of second language acquisition due to differences in lexical-semantic organization. This pattern of results is consistent with the present study in that we see differences in lexical-semantic processing as a function of language dominance as early as 18 months of age.

Conclusion

The present study investigated whether lexical-semantic priming emerges at 18 or 24 months in Spanish-English bilinguals and whether within-language vocabulary size, total vocabulary size, and translation equivalents were significant predictors of children's lexical-semantic processing. The results indicate a remarkably similar pattern of development between monolingual and bilingual children, such that lexical-semantic development begins slowly at 18 months and becomes more robust by the end of the second year. Further, the present study suggests that word knowledge may be more predictive of children's lexical-semantic processing at 18

months, versus 24 months, when lexical-semantic priming is just emerging. Together these findings provide continuing support for the conclusion that important language milestones are met at the same time across single and dual language learners.

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Tables

Table 6-1. Prime-Target pairings for each trial.

Block	Prime	%	Target	%	Semantic relatedness
Sp-Sp	mesa (table)	87.1	silla (chair)	87.1	0.408
	perro (dog)	91.9	gato (cat)	75.8	0.39
	jugo (juice)	66.1	naranja (orange)	59.7	0.385
	lengua (tongue)	64.5	comida (food)	83.9	0.294
	vaso (cup)	90.3	plato (plate)	80.6	0.253
	jabón (soap)	85.5	tina (bathtub)	64.5	0.247
	sol (sun)	69.4	luna (moon)	64.5	0.212
	nariz (nose)	72.6	cara (face)	61.3	0.138
	zapato (shoe)	91.9	calcetines (socks)	75.8	0.396
	Means	*79.92*		*72.6*	*0.30*
En-En	jacket	60.6	coat	86.4	0.549
	cereal	75.8	toast	62.1	0.48
	arm	63.6	leg	62.1	0.475
	cow	80.3	horse	78.8	0.431
	kitchen	77.3	tummy	84.8	0.146
	bear	71.2	monkey	65.2	0.324
	pig	72.7	bunny	75.8	0.309
	truck	77.3	bicycle	69.7	0.158
	house	68.2	store	66.7	0.142
	Means	*71.9*		*72.4*	*0.33*
Sp-En	plátano (banana)	67.7	apple	77.3	0.479
	pantalón (pants)	61.3	shirt	75.8	0.452
	cuchara (spoon)	88.7	fork	77.3	0.423
	baño (bathroom)	87.1	towel	68.2	0.336
	llaves (keys)	83.9	door	92.4	0.252
	juguete (toy)	66.1	doll	78.8	0.248
	dedos (fingers)	64.5	toe	77.3	0.219
	árbol (tree)	69.4	flower	75.8	0.202
	pan (bread)	88.7	cheese	90.9	0.359
	Means	*75.3*		*79.3*	*0.33*
En-Sp	hat	84.8	suéter (sweater)	61.3	0.448
	balloon	93.9	pelota (ball)	95.2	0.159
	blanket	93.9	cuna (crib)	64.5	0.37
	duck	89.4	pollo (chicken)	67.7	0.371
	pillow	69.7	cama (bed)	95.2	0.379
	train	69.7	carro (car)	80.6	0.31
	bird	90.9	avión (airplane)	69.4	0.282
	pajamas	83.3	cuarto (bedroom)	72.6	0.231
	rain	63.6	cielo (sky)	62.9	0.175
	Means	*82.1*		*74.4*	*0.30*

Note. Percentages represent the proportion of 18-month-olds who know each word based on norms from the Macarthur-Bates Communicative Development Inventories (Dale & Fenson, 1996). Semantic relatedness refers to the cosine value between two words reflecting their featural overlap (Buchanan, Holmes, Teasley, & Hutchison, 2012). A cosine of 0 represents no semantic overlap between two words, whereas 1 represents complete overlap. Blocks denote the four different priming conditions: Spanish to Spanish priming (Sp-Sp), English to English priming (En-En), Spanish to English priming (Sp-En), and English to Spanish priming (En-Sp).

Figures

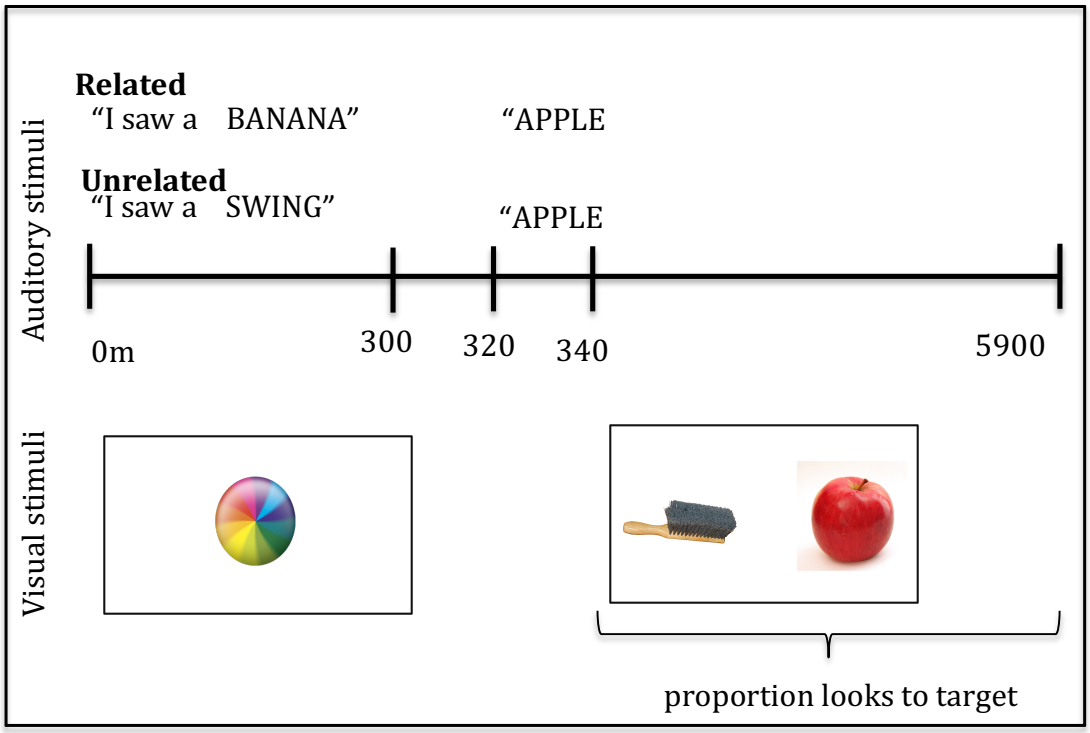

Figure 6-1. Example trial sequence for English block.

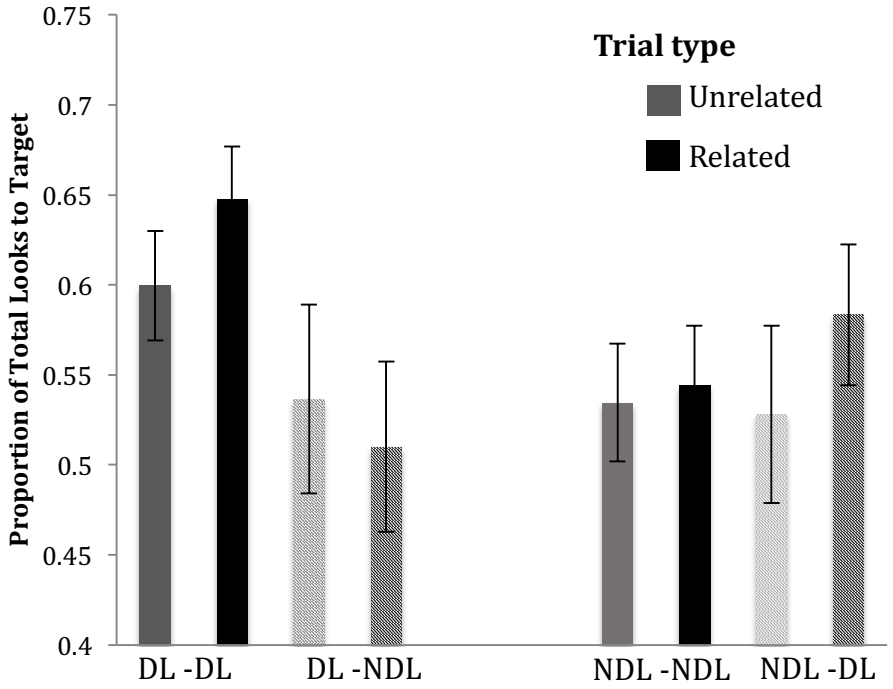

Figure 6-2. Average proportion of time spent looking at the target across related and unrelated trials at 18 months.

Note. DL-DL and NDL-NDL refer to trials in which the prime and target words were both within the dominant or non-dominant language, respectively. DL-NDL refers to trials in which the prime was in the dominant language and the target was in the non-dominant language. NDL- DL refers to trials in which the prime was in the non-dominant language and the target was in the dominant language.

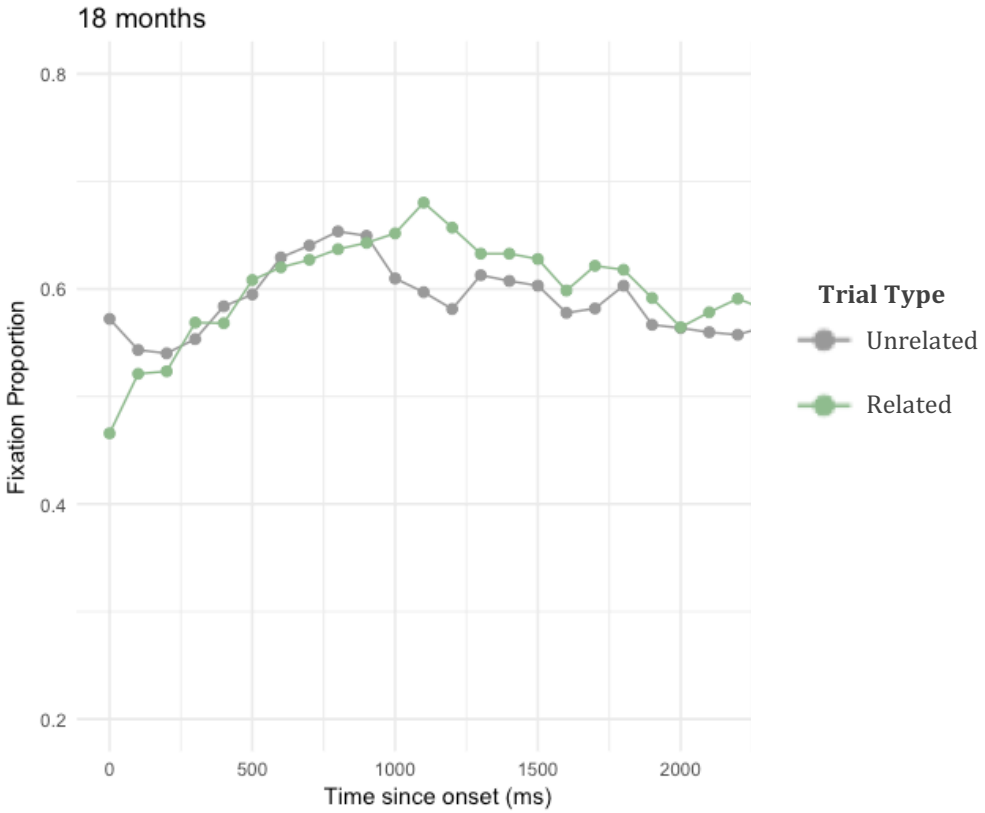

Figure 6-3. Proportion of looks to the target for related and unrelated trials over time at 18 months.

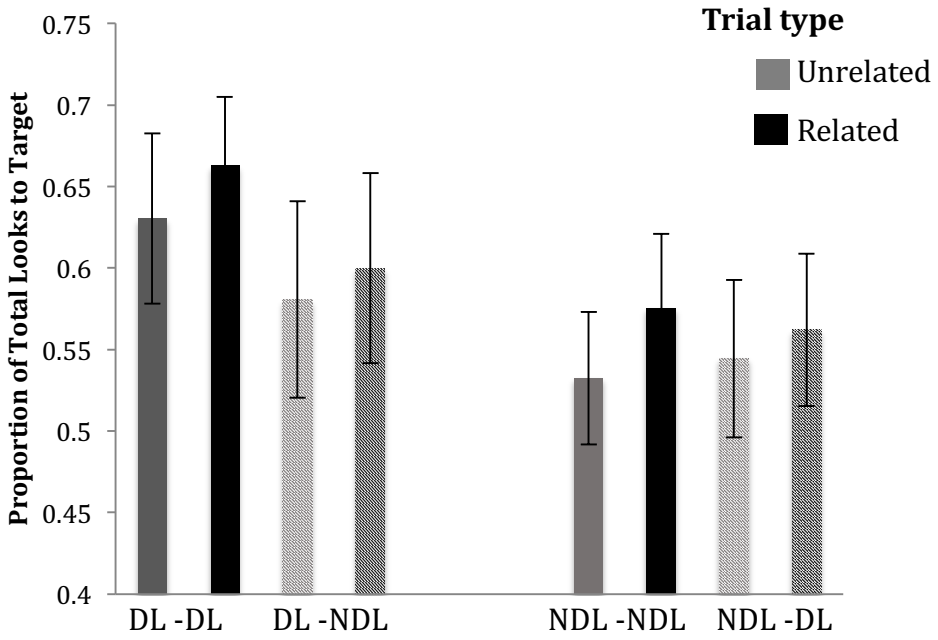

Figure 6-4. Average proportion of time spent looking at the target across related and unrelated trials at 24 months.

Note. DL-DL and NDL-NDL refer to trials in which the prime and target words were both within the dominant or non-dominant language, respectively. DL-NDL refers to trials in which the prime was in the dominant language and the target was in the non-dominant language. NDL- DL refers to trials in which the prime was in the non-dominant language and the target was in the dominant language.

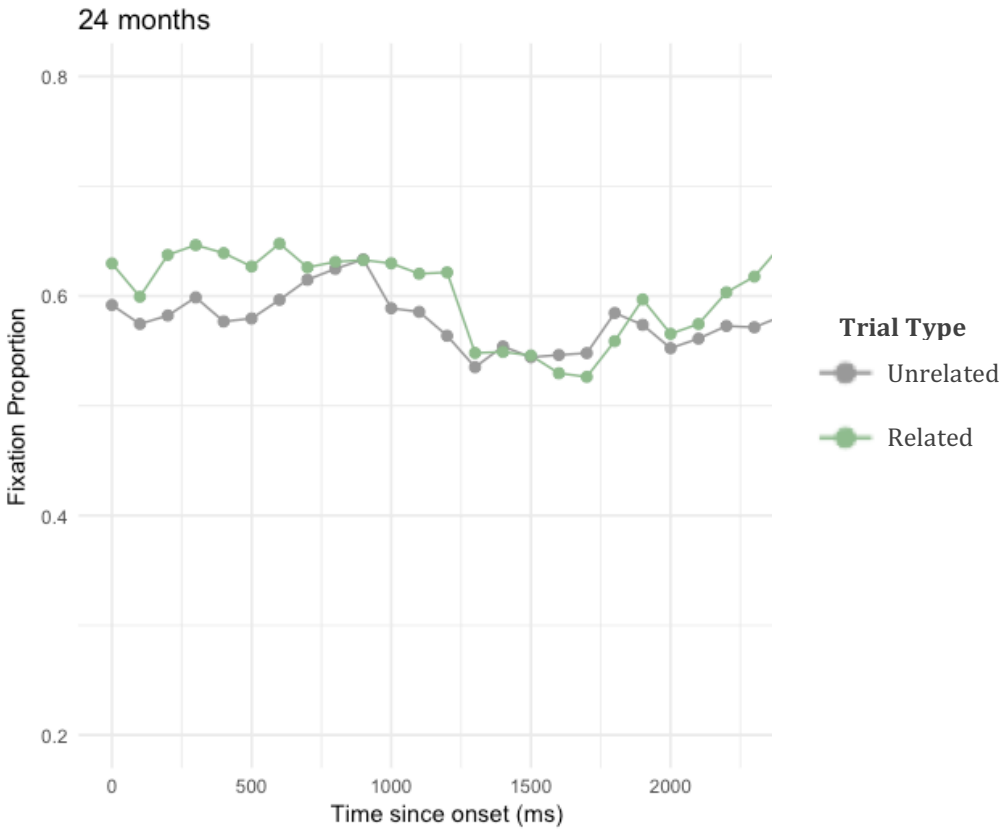

Figure 6-5. Proportion of looks to the target for related and unrelated trials over time at 24 months.

Chapter 6, in full, is being prepared for submission for publication of the material. DeAnda, S., & Friend, M. (in preparation). Lexical-semantic processing in bilingual toddlers. The dissertation author was the primary investigator and primary author of this paper.

Chapter 7: Conclusion

This dissertation set out to investigate the nature of the influence of dual language exposure on early bilingual language acquisition. As reviewed in Chapter 1, there are several unanswered questions with respect to our understanding of the development of the early lexical-semantic system in bilinguals. The empirical findings presented in this dissertation provide important contributions to theoretical models of bilingual language representation. In what follows I review the key findings of each chapter highlighting implications for theories of bilingual language processing and questions for future research.

An important first step in understanding bilingual first language acquisition is to validate the methods used to operationalize dual language exposure in early development. The findings reviewed in Chapter 2 present the first examination of the psychometric properties of the Language Exposure Assessment Tool (LEAT), an interview-style assessment that asks parents to report on their child's language exposure. Results showed that the LEAT has strong internal consistency, predicts concurrent receptive language proficiency, and explains variance above a single parent estimate in bilinguals at 16 months of age. Further, these findings were consistent across Spanish-English and French-English bilinguals in the U.S. and Canada, respectively. Nevertheless, it remains unknown whether the LEAT will continue to hold predictive utility in older bilinguals, when language *output* may become more predictive than language *input* especially in the case of expressive language development. Further, as children get older, language input patterns do not necessarily match language output patterns as children begin to prefer one language over another (Ribot, Hoff, & Burridge, 2017). This suggests that different aspects of

dual language exposure exert different patterns of influence on language acquisition that change over development. Indeed, a new body of work has shown, for example, children's recent language exposure is a better predictor of language proficiency than age of first second language exposure (e.g., Bedore et al., 2012). But what is "recent exposure" and what is the best cutoff for this measure? Which cutoff provides best prediction for concurrent proficiency, and what does this reveal about the role of exposure in language learning over development? Although these questions remain unanswered, the findings in Chapter 2 provide an important first step in validating the use of parent questionnaires as a methodological tool in this area of research.

The adult bilingual literature is rich with models of language representation. However, a model that extends from infancy through adulthood is needed in order to provide an account of developmental changes in language acquisition. At present there remains a dearth of models for language learning occurring *before* adulthood. Most models of adult bilingual language representation present clear interactions between languages. For example, the Bilingual Interactive Activation Plus model (Dijkstra & Van Heuven, 2002) presents language non-selective lexical access, such that processing of both languages is similar early in the processing stream. It is not until late in processing that languages are differentiated. This suggests relatively shared representations of both languages across phonology, semantics, grammar, and orthography and this is supported by many empirical findings. Similarly, the Revised Hierarchical Model (RHM, Kroll & Stewart, 1994) presents a shared semantic space between both languages, with differences in proficiency influencing the course of lexical access. DevLex-II, a computational model, corroborates some of these

findings. DevLex-II models the type of shared lexical-semantic architecture necessary for semantic activation across languages, specifically within translation equivalents (e.g., *perro* and *dog*) and semantic primes (e.g., *perro* and *cat*).

What empirical evidence exists to extend bilingual adult language representation models to early development? The findings from Chapter 3 suggest that the rich interaction between languages as modeled in the adult literature are present in early toddlerhood as well, though there remain important differences. Specifically, results indicated that vocabulary size in the dominant language predicts the speed of lexical access across the dominant and non-dominant language. Conversely, vocabulary size in the non-dominant language was not predictive of lexical access in either language. Thus, although there exists interaction between languages in young bilinguals, it varies as a function of language dominance. That is, word knowledge in the dominant language supports general auditory word recognition across languages. Similarly, in Chapter 5, children showed longest looking times for words within the dominant language. These results are perhaps most consistent with the RHM, in which the less-proficient language makes use of the existing lexical-semantic structure in the stronger language. Thus, following RHM, it is possible that the link between word knowledge and lexical access in the non-dominant language may indeed emerge as proficiency increases with age. That is, as children continue learning words in their non-dominant language, the same types of associations between word knowledge and processing should emerge. An important avenue for future research is therefore an examination of the role of word knowledge in the non-dominant language in supporting lexical-semantic development. Indeed, Chapters 4

and 5 extended theses findings by exploring the influence of vocabulary knowledge in the emergence of lexical-semantic processing.

Vocabulary size is an important factor influencing lexical-semantic associations. As reviewed in detail in Chapter 4, previous work has established that word knowledge influences semantic categorization (Nazzi & Gopnik, 2001; Mervis & Bertrand, 1994), word-learning (Borovsky et al., 2016), and lexical access (Fernald, Perfors, and Marchman, 2006; Torkildsen et al., 2008; 2009). That is, vocabulary breadth supports the organization of semantic space and the strength of connections between lexemes and conceptual categories. But how does word knowledge support lexical-semantic organization and networks? The results across Chapter 4 and 5 suggest that word knowledge has a dynamic relation with lexical processing over the course of development. Specifically, lexical-semantic priming is evinced as early as 18 months of age, but only in English monolingual children with large vocabularies. By 24 months, vocabulary size influences the timing of lexical-semantic priming, such that children with large vocabularies show a priming effect faster than children with small vocabularies. Similarly, in Spanish monolinguals, lexical-semantic priming effects emerged by 24 months, but once again only in children with large vocabularies. In bilinguals, vocabulary size predicted lexical-semantic processing at 18 but not 24 months of age. What conclusions can be drawn from this seemingly disparate pattern of results? Within each group, word knowledge seems to be most predictive at the age of first *emergence* of lexical-semantic priming. That is, word knowledge reliably predicts lexical associations at the age at which lexical-semantic priming first emerges across English and Spanish monolinguals and English-Spanish

bilinguals. Put another way, lexical-semantic priming was evinced at 18 months with English monolinguals and English-Spanish bilinguals, whereas priming was evinced at 24 months within Spanish monolinguals. Critically, these were the ages at which vocabulary size was predictive of lexical-semantic priming effects. It is possible that a there is a threshold of vocabulary size that is necessary to instantiate lexical-semantic associations. Indeed, as reviewed in Chapter 4, English monolinguals seemed to show a threshold effect on the CCT. These findings are consistent with Mayor and Plunkett's (2014) TRACE simulations which illustrate the importance of vocabulary size and composition in word recognition in the phonological domain. According to Mayor and Plunkett (2014), "increasing vocabulary size leads to greater competition motivating the need for inhibitory processes" and "enhanced competition leads to speedier elimination of inappropriate lexical items, and, therefore, faster target recognition" (p. 116). Competition and inhibition are a result of a *network* of lexical connections; increasing vocabulary size leads to greater lexical associations which give rise to competitive and inhibitory connections. The present empirical findings provide support for a similar model of lexical development within the semantic domain, such that lexical-semantic networks emerge when a sufficiently large vocabulary size has been acquired across monolingual and bilingual acquisition.

The effect of vocabulary size examines *how* lexical-semantic networks organize. The present set of studies also investigated *when* lexical-semantic associations emerge in development. Here, Mayor and Plunkett's (2014) TRACE model posits that lexical networks may emerge "sometime during the second half of the second year" (p. 114) through remarkable "*continuity* in the processes and

representations underlying these changes" (p. 117). The results from Chapter 4 and 5 are consistent with this interpretation. For example, lexical-semantic priming effects in the English monolingual and English-Spanish bilingual groups demonstrated a fragile emergence at 18 months of age, with more robust priming effects appearing by 24 months in both groups. This demonstrates a continuous pattern of development from 18 to 24 months of age that extends to the semantic domain just as in TRACE's simulation of phonological development. The present studies also extend these findings further by demonstrating that this developmental process is relatively consistent within monolingual and bilingual development. That is, children learning two languages evince lexical-semantic priming effects as early as 18 months of age similar to the English monolingual group. Indeed, Chapter 3 showed that speed of auditory word retrieval is similar between monolingual and bilingual children at 16 and 22 months of age. Thus, although bilingual children are tasked with forming language representations across two languages, they follow a course of development that mirrors monolinguals. This is not to say that the *structure* of lexical-semantic representations is similar across monolinguals and bilinguals. Instead, it suggests similar developmental *processes*. As we reviewed previously, it may be that vocabulary size leads to the emergence of lexical networks by forming competition and inhibitory processes. Indeed, bilingual and monolingual children demonstrate similar vocabulary sizes when both languages are considered (e.g., Pearson, Fernandez, & Oller, 1993). A prediction that follows from these findings is the existence a shared lexical-semantic space across languages that is sufficiently large to support a developmental timeline similar to monolinguals. Indeed, this interconnected

but separable language system is corroborated by the findings from Chapter 3, in which cross-language associations between vocabulary size and lexical access were found from the dominant to the non-dominant language.

An important direction for future research concerns the nature of such an interconnected system in early development and the role of cultural differences. For example, Dev-Lex II models differences between translation equivalents and semantic primes in forming cross-language associations. Further, Chapter 4 suggested differences in monolingual development between English and Spanish groups, such that Spanish-learning children showed lexical semantic priming at 24 rather than 18 months of age. Recent findings in similar group of Spanish learners in San Diego suggest a different pattern of vocabulary development between 16 and 22 months of age relative to English learners (DeAnda, Arias-Trejo, Zesiger, Poulin-Dubois, & Friend, 2016; Friend, DeAnda, Arias-Trejo, Zesiger, & Poulin-Dubois, in press). Indeed, the large majority of research investigating lexical-semantic development examines English learners in the U.S., Canada, or the U.K. The lack of replication within the Spanish speaking population across several studies suggests that there are other sources of variability that are yet to be established. Thus, future research should consider extending findings from English learners to other linguistic communities. This effort will serve to refine our understanding of language acquisition, just as examining bilingual language development has informed our understanding of lexical-semantic development by testing predictions from the monolingual domain.

Early language learning provides a window into understanding the way children organize the world around them. The set of studies presented here suggest

that there are remarkable similarities between children learning one or two languages early in development. Importantly, these studies highlight a complex language system that accommodates dual language exposure by forming an interconnected semantic system. In a similar way, the process of lexical-semantic development demonstrates continuity from early toddlerhood to adulthood such that adult language representation models in many ways can be extended to early development. Further, the present studies highlight the use of parent reports, haptic assessments, and gaze responses in examining lexical acquisition across English and Spanish learners as early as 16 months of age. Together these findings open new lines of inquiry investigating the nature of bilingual first language acquisition across development.

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