ABSTRACT

Title of Document: **INTERACTIONS BETWEEN LANGUAGE EXPERIENCE AND COGNITIVE ABILITIES IN WORD LEARNING AND WORD RECOGNITION**

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There has been much recent interest in the finding of a "bilingual advantage". That is, bilingualism confers benefits on various non-linguistic cognitive measures, particularly executive control. Yet bilingual children often face a different situation when it comes to language: their profile often negatively diverges from that of monolinguals, potentially leading to classification as language-disordered. This, in turn, contributes to public policies that discourage bilingualism. Most studies have examined ways in which bilinguals are better or worse than monolinguals. However, it is possible that bilinguals simply approach tasks differently, or weight information sources differently. This leads to advantages in some tasks and disadvantages in others. This dissertation seeks a principled understanding of this conflict by testing the hypothesis that differences in linguistic exposure and age alter how individuals approach the problem space for learning and comprehending language. To become proficient in a language, learners must process complex acoustic information, while relying on cognition to accomplish higher thought processes like working memory and attention. Over the course of development, individuals rely on these skills to acquire an impressive vocabulary, and to recognize words even in adverse listening conditions (e.g., when speech is heard in the presence of noise).

I present findings from four experiments with monolingual and bilingual adults and toddlers. In adulthood, despite showing advantages in cognitive control, bilinguals appear to be less accurate than monolinguals at identifying familiar words in the presence of white noise. However, the bilingual "disadvantage" identified during word recognition was not present when listeners were asked to acquire novel word-object relations that were trained either in noise or in quiet. Similar group differences were identified with 30-month-olds during word recognition. Bilingual children performed significantly worse than monolinguals, particularly when asked to identify words that were accompanied by white noise. Unlike the pattern shown by adults, when presented with a word-learning task, monolingual but not bilingual toddlers were able to acquire novel word-object associations. Data from this work thus suggest that age, linguistic experience, and the demands associated with the type of task all play a role in the ability of listeners to process speech in noise.

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By

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Overview

In the last ten to twenty years, there has been a significant increase in the number of studies examining how bilingualism might affect human cognition. Much excitement has resulted from the reported finding of a “bilingual advantage”. This refers to the notion that bilingualism confers benefits on a number of non-linguistic cognitive measures, particularly in areas associated with attention and inhibitory control (review in Hilchey & Klein, 2011). Furthermore, this bilingual advantage has been reported not only in adults, but also in infants and toddlers (Kovács & Mehler, 2009; Poulin–Dubois, Blaye, Coutya, & Bialystok, 2011). Yet when it comes to language, bilingual children often face a rather different situation. Their linguistic profiles (as measured by scores from standardized language assessments) often diverge negatively from those of monolingual children; these differences are frequently interpreted as “atypical”, and so bilingual children are frequently classified as language disordered (Kester & Peña, 2002; Peña, Gillman, Bedore, & Bohman, 2011).

This paradox can be seen throughout the literature on bilinguals’ language processing, much of which has focused on characterizing overarching advantages (or disadvantages) associated with different types of linguistic exposure. Much of the literature seems to presume that if monolinguals show better performance than bilinguals during a linguistic task, then this must mean that experience with two languages is associated with a disadvantage in the linguistic domain. However, it is possible that linguistic experience simply influences the way in which individuals approach the task at hand. Under this view, depending on the cognitive demands associated with the task, monolinguals and bilinguals might rely on different strategies, or weight information sources differently. This might lead to advantages in some areas and disadvantages in others (as opposed to a "global" benefit resulting from one type of linguistic experience). These strategies are not ones that are deliberately used by the individual, but instead result from the development of certain skills.

This dissertation seeks to test the hypothesis that differences in linguistic exposure and age alter how individuals approach critical linguistic tasks. Becoming a proficient language user involves not only acquiring new words, but also making use of the acquired knowledge for comprehension. In order to increase their vocabulary size, learners must be able to establish accurate associations between word-forms and meaning in environments that are rich in auditory and visual cues (i.e., multiple sounds and objects). Furthermore, in order to understand different messages, individuals must process the incoming speech input and rely on previously acquired linguistic knowledge in order to interpret the information that is being conveyed. Hence, when faced with a particular challenge (e.g., having to selectively attend to a sound source during word learning or during language comprehension) learners may perform differently on a given task, depending on the available information, the ways in which the task is approached, and the cognitive abilities that they have developed as a result of their linguistic experience.

1.2 Lifestyle factors and their influence on cognition

A long-lasting question in Psychology and Cognitive Science has been the extent to which expertise in a particular area and frequent use of a skill leads to broad cognitive gains that are generalizable to other tasks. For decades, models of learning have argued that there are localized pathways in the brain that are responsible for the learning and execution of particular tasks. Therefore, it is unlikely that skills necessary to succeed in one activity are transferable to other areas (review in Poggio & Bizzi, 2004). Evidence in support of this account has come from work examining skill learning. Ball, Berch, Helmers, Jobe, Leveck, Marisiske et al. (2002) found that training and learning in a visual search task did not lead to better performance in reasoning or memory tasks. Similar findings were obtained in a study conducted by Saffell and Matthews (2003), where participants were extensively trained to perform either a direction discrimination task or a speed discrimination task and were later tested in the skill that they did not receive training for. Participants showed poorer performance in the task that they were not trained in compared to the trained task, suggesting that the skills were not fully transferred across the two domains.

Conversely, several lines of evidence support the notion that experiences and acquired skills do in fact influence an individual's cognitive and perhaps even biological make-up, and can thus have more global impacts on language processing. According to the "cognitive enrichment hypothesis", different lifestyle factors have beneficial effects when it comes to cognitive abilities, and these are transferrable to other domains (Hebb, 1947, 1949). Support for this side of the argument comes from work examining a wide variety of lifestyle factors and from all stages across the life span. This work suggests that engaging in long-term activities such as high levels of physical exercise, cognitive-intensive hobbies such as crossword puzzles, or careers such as taxi-driving or architecture, not only leads to a slower decline in cognitive faculties with aging, but also result in overall improvement in a variety of cognitive skills (Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001; Salthouse & Mitchell, 1990; Maguire et al., 2000; Hertzog, Kramer, Wilson, & Lindenberger, 2009; Hambrick, Salthouse, & Meinz, 1999). Even short intensive tasks such as video-game playing or juggling have been associated with dramatic changes in neural activity and improvement in cognitive outcomes (Draganski et al., 2004; Gopher, Weil, & Bareket, 1994; Green & Bavelier, 2003; Green & Bavelier, 2008).

Another factor that has been examined in this literature is the experience of growing up with two languages. Bilinguals are required to “manage” two linguistic systems; this means monitoring (and switching between) the two languages on a regular basis. To become proficient language users, bilingual children must acquire distinct linguistic systems for each of their languages, and they must typically do so from multilinguistic input. This process must be carried out while avoiding any interference that may result from the two emerging systems. Bialystok (2011) argues that bilingualism is both intense (like playing video-games and juggling) as well as typically maintained across the life span (like a demanding career). Given the complexity of the task at hand, starting at a very early age, individuals in bilingual environments might develop strategies and specific mechanisms that help them achieve proficiency in both languages.

1.3 Growing up with one versus two languages

Even though the input that monolingual and bilingual children receive while acquiring a language is different (i.e., bilinguals receive mixed linguistic input, while monolinguals are exposed to a more homogenous linguistic system), for the most part, early language development and the initial acquisition of words and sentences is very similar across the two groups (Yip & Matthews, 2007; Werker & Byers-Heinlein, 2008). For example, irrespective of whether children are acquiring one versus two languages, they start to produce their first words by the age of one. The number of words that bilingual children know in each language appears to be on average smaller than the number of words that monolingual children know in their single language (Pearson, Fernandez, & Oller, 1993; Pearson, Fernandez, Lewedeg, & Oller, 1997; Hoff, Core, Place, Rumiche, Señor, & Parra, 2012). For this reason, when bilingual children are asked to complete language assessments that are normed and administered in only one language, they often fall in the impairment range (Peña et al., 2011). However, when vocabulary scores are calculated across the two languages, both monolinguals and bilinguals appear to have vocabularies of approximately 50 words by the same point in time, when they reach 18 months (Pearson et al., 1993; Petitto, 1987; Petitto et al., 2001; Hoff et al., 2012).

Despite similarities in early lexical development, differences in performance between monolinguals and bilinguals on language-related tasks seem to suggest that the way in which words and concepts are acquired, represented, and activated is different across the two groups. For example, some work has suggested that bilingual infants do not begin using phonetic detail to guide learning of minimally different words until 20 months; this is a later age than their monolingual peers (Fennell, Byers-Heinlein & Werker, 2007). Yet, there is no evidence suggesting that older bilingual children (beyond this age) are worse at the process of word learning. They may, however, be worse at accessing words they already know. Previous studies examining the frequency of occurrence of tip-of-the-tongue (TOT) states (i.e., the frustrating feeling of being certain that you know a word, but not being able to retrieve it at a particular point in time) show that bilinguals experience TOTs more often than monolinguals (Ecke, 2004; Gollan, Montoya, Fennema-Notestine & Morris, 2005). Furthermore, during naming tasks (such as the Boston Naming Task and timed picture naming), bilingual adults are less accurate (Roberts, Garcia, Desrochers, & Hernandez, 2002; Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007) and take longer to generate responses (Gollan et al., 2005). The implications of these results are that even though monolinguals and bilinguals appear to have comparable vocabularies and good speaking skills during everyday conversations, the latter group has more word-finding problems during lexical production tasks (even when they are highly fluent bilinguals). In other words, splitting lexical access across two languages results in the lexical representations themselves being weaker for bilinguals and/or the access pathways being less automatic.

A number of theories have provided explanations for these differences in word retrieval. The most widely-supported accounts attribute the performance of bilinguals to factors such as reduced word recency (the amount of time since a word was used) and frequency (the number of times a word has been used), as well as cross-linguistic competition (resulting from joint activation of the two languages). Gollan and colleagues propose that less exposure and frequency of use in each language results in "weaker links" between words and their representations (Gollan, Montoya, Cera, & Sandoval, 2008). In other words, since bilinguals can only produce one language at a time, the amount of practice using representations in each language will be less compared to monolinguals (for whom lexical entries in their sole language are used 100% of the time). In addition to having overall weaker word representations, bilinguals must also deal with simultaneous activation of words in their two languages. This account is discussed in the section below.

1.4 Bilingual language processing and its effect on cognition

According to Green (1986, 1998) bilinguals perform lexical selection through inhibition. Green's "inhibitory control theory" states that there are lexical nodes for each language that are simultaneously activated by a single concept (e.g., when a Spanish-English bilingual sees a cat, both the lexical entry in English "cat" and in Spanish "gato" are activated). In order to then retrieve the desired word (in the target language) bilinguals must suppress the lexical nodes in the non-target language. Based on this view, bilinguals may be slowed during lexical retrieval because of the time it takes to inhibit the lexical nodes in the non-target language. An important assumption under this theory is that the monitoring mechanism in charge of resolving the competition between the two languages (what Green called the "supervisory attentional system") is not necessarily language-specific (Hilchey & Klein, 2011). In other words, there may be a brain mechanism that is more globally responsible for dealing with various instances of cognitive conflict, not just those in language.

This mechanism has been described as the executive function (EF) system, and is presumably localized in the frontal lobes of the brain (Goldman-Rakic, 1996). This system is thought to start developing early in childhood (Diamond, 2002), and according to work by Bialystok (2010) is responsible for cognitive processes such as working memory (involved in tasks such as holding a phone number in mind long enough to dial it) and attention (necessary for selection, inhibition, and switching between stimuli). Previous studies examining cognitive abilities associated with bilingualism have relied on EF tasks that involve dealing with conflicting stimuli (e.g., Simon task, Stroop task, flanker task) or inhibiting a learned/habituated response (e.g., dimensional change card sort task, day-night task). For example, in the Simon task, participants are seated in front of a screen where sometimes a green square and sometimes a red square will appear. There are two response keys (one for each colored square) located below the sides of the screen. During the task, the squares can appear either directly above its corresponding key (congruent trials) or above the opposite key (incongruent trials), and participants are asked to press the correct/matching key. Accuracy and response latencies are measured based on key-presses. Assuming that participants are able to inhibit the misleading information during incongruent trials, latencies (and accuracy) should be similar across the two conditions. However, several studies have found that participants are typically slower in the incongruent trials (as described in review by Lu & Proctor, 1995). Studies with adults have found that bilinguals not only show general speed facilitation in this type of task compared to monolinguals, but they also show an advantage in inhibitory control; bilingual participants show less interference during incongruent trials and are quicker than monolinguals to press the correct key (Bialystok, et al., 2004; Costa et al., 2008; Hilchey & Klein, 2011). Furthermore, beyond the specific advantages in inhibitory control, there is some evidence suggesting that bilingualism leads to advantages in performance even during congruent trials when there is frequent switching between conflict and non-conflict types of trials (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009).

Similar studies have been carried out with children using more age-appropriate paradigms, such as the dimensional change card sort task (DCCS). In this task, participants are presented with cards that contain images of objects that vary on two dimensions (e.g., shape: circles vs. squares and color: blue vs. red). There are also two containers that are marked by a particular image (e.g., a red square or a blue circle). Children are initially asked to sort all the cards into the containers based on one dimension (e.g., reds in this container, blues in the other container). Then they are asked to switch the rule (e.g., squares in this container, circles in the other). Original studies with 3-year-old monolingual children using this task had found that, while participants could state the new rule aloud, they would continue to sort the cards based on the initial rule (Zelazo, Frye, & Rapus, 1996). However, follow-up studies with children between 4 and 5 years revealed that bilinguals were consistently better than monolinguals at switching their sorting to match the new rule (Bialystok, 1999;

Bialystok & Martin, 2004). These results suggested that even preschoolers had already developed cognitive control advantages associated with bilingualism.

Most of the early studies examining this topic were carried out with individuals who were able to produce speech (i.e., older children and adults, as opposed to pre-verbal infants). Given the assumption that it is mostly when attempting to speak that bilinguals must regulate their two linguistic systems (Green, 1998), cognitive advantages were originally attributed to the repeated need to inhibit one system in order to produce utterances in the correct/target language (Meuter & Allport, 1999). Nevertheless, even before infants can produce their first word, they can already process an impressive array of linguistic information, based on the input that they receive. Newborns are able to differentiate between languages belonging to different rhythmical categories (Nazzi, Bertoncini, & Mehler, 1998), and by 5 months can discriminate between their own dialect and other dialects of the same rhythmic class (Nazzi, Jusczyk, & Johnson, 2000). Additionally, by the end of the first year, infants' phonetic discrimination abilities change as a function of their linguistic experience, to mainly include phonetic contrasts that are relevant in their particular language (Werker & Tees, 1984; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). This might suggest that even preverbal infants being raised in bilingual environments must monitor information in their two languages, and that the effect of bilingualism on the cognitive control system could be present even earlier than previously reported.

To evaluate this hypothesis, Kovács and Mehler (2009) conducted a series of experiments comparing monolingual infants to bilinguals of the same age. In the first experiment, infants completed an eye-tracking task in which they were taught to associate an auditory speech cue (in this case a trisyllabic novel word - e.g., le-mo-ve) with a puppet appearing on one side of the screen. During a “pre-switch” phase, the puppet would always appear on a specific side (e.g., on the right), but then in a “post-switch” phase (which followed directly after), the puppet appeared on the opposite side (e.g., on the left). Data were obtained from a group of 7-month-old monolinguals and a group of English-Italian crib-bilinguals. Examination of anticipatory eye-movements revealed that both groups learned to accurately predict the location of the puppet during the pre-switch phase. However, only the bilingual group was able to then learn the new association presented in the post-switch portion of the study, while performance for the monolingual group was at chance. Furthermore, the amount of time that it took for the bilinguals to learn the new association was not any longer than the amount of time that they required to learn the initial rule during the pre-switch phase. In a second experiment, the authors investigated whether an index to signal the switch would help monolinguals succeed in the post-switch phase. The task closely resembled that of the first experiment, with the exception that the structure of the words heard in the pre-switch and post-switch phase was different (e.g., Initial-repeated syllables {AAB} in the pre-switch phase; Final-repeated syllables {ABB} in the post-switch phase). Similarly to the first experiment, only the bilingual group succeeded in the post-switch phase. These findings suggest that simply being exposed to (and having to process) two languages during the first few months of life appears to be enough to develop at least some of the previously reported bilingual cognitive advantages.

Most studies have investigated the effects of linguistic experience on cognitive abilities (i.e., how bilinguals have a cognitive advantage by virtue of having to constantly inhibit their other language). Far less work has been conducted exploring how these cognitive advantages might feed back to different language tasks and whether the bilingual advantage facilitates performance in language-related areas such as word learning and/or word comprehension.

1.5 Listener-specific versus task-related factors that influence performance on linguistic tasks

There are several factors that play a role in how individuals perform language-related tasks. These include a) abilities that are specific to the listener, and b) factors that are associated with what the task requires the listener to do. Listener-specific features refer to elements such as having the necessary cognitive and linguistic skills to perform the task, and may include both abilities that are present at birth, as well as those that are acquired across development (and hence may differ from infancy to adulthood). The second aspect refers to the demands that are associated with the particular task - that is, the differences in the resources and approach that may need to be implemented in order to successfully process that information necessary to complete the task.

Word learning and word recognition are fundamental linguistic tasks. On the surface, the two may appear to be similar, in that they both involve processing the speech signal to extract a message that is being conveyed. However, there is presumably more potential for access to stored information to play a role in word recognition compared to word learning. In other words, understanding spoken language requires mainly being able to combine stored lexical (top-down) knowledge with the acoustic information that is being received almost simultaneously. For language learning, on the other hand, the individual must primarily focus on generating connections between novel words that are heard and their corresponding meaning, and storing this newly acquired information.

Previous work with monolingual children and adults has suggested that during comprehension, listeners are able to rely on their existing knowledge of the language in order to process speech incrementally (e.g., Connine, Blasko & Titone, 1993; Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998). This means that listeners are constantly formulating and rejecting hypotheses regarding possible lexical items, based on the information that has been heard up to that moment. This results in listeners being able to rapidly identify spoken words based on initial phonetic information (Marslen-Wilson & Zwitserlood, 1989). Under this account, the initial sounds of a word (e.g., per-) activate multiple entries that share that same word onset (e.g., peruse, perimeter, periphery, etc.). Once more information is received and the listener hears per-IM the candidates can be narrowed down to the word "perimeter" even before the final syllable is heard. Assuming that bilingual listeners also formulate hypotheses based on their stored lexical knowledge, they may face processing costs resulting from the additional word candidates that must be considered and discarded (i.e., the initial phonetic information will activate entries in the two languages, whereas monolinguals must only consider words in one linguistic system). Alternatively, bilinguals may also have lexical-access paths that are weaker or less “automatic”, as a result of them encountering and retrieving words in each language less frequently, compared to monolinguals. These differences in how words are retrieved may lead to group variations in the patterns of performance.

Word learning, on the other hand, relies initially on a different set of processes that presumably make use of mostly (even though not entirely) bottom-up information. From the input that can be perceived in the environment (i.e., the objects/referents and the labels) the listener must learn a particular phonological form, link it to a meaning (such as mapping the sound /kæt/ to the concept of *cat*), and then add representing characteristics to the word-object pair in the mental lexicon (e.g., grammatical class, category) (Werker & Byers-Heinlein, 2008). When it comes to how monolinguals and bilinguals learn new words, there are presumably some differences in how each group reaches that goal. Truly balanced bilinguals will likely be exposed to two ways of referring to the same concept (one for each language), while for the most part, monolinguals will only learn one label per referent. This may result in young learners developing different word-learning heuristics (e.g., monolinguals but not bilinguals limiting the number of plausible referents that can be assigned to a novel object, the “mutual exclusivity constraint” - Merriman & Bowman, 1989). Nevertheless, both groups must similarly establish connections between visual (or conceptual) and auditory elements that are present in their environment in order to increase their vocabulary. Since bilinguals are exposed to each individual word label less frequently, one might expect them to be disadvantaged by having to establish these referent-word pairings with fewer repetitions or “chances” to establish and store the connection.

However, word-learning abilities are not solely linked to the number of repetitions of a word that the child hears. The initial stage of word learning (referred to as “fast-mapping”) actually depends on the first (single) exposure to a word and its referent (Woodward & Markman, 1998; Wilkinson & Mazzietelli, 2003; Spiegel & Halberda, 2011). After fast mapping has occurred, children must consolidate the new information based on multiple exposures over some period of time. That consolidation process presumably differs in monolinguals and bilinguals, given that bilingual children may hear any given new word fewer times, and the fact that the fast-map that a bilingual assigns during the first exposure may not receive verification/support on the next exposure when the object is referred to using another label (in the other language). The fast mapping, however, is not likely to differ in the same way, since the individual first exposure to a word is presumably comparable regardless of linguistic experience. Additionally, in real-world contexts, these steps must be accomplished by the learner in an environment that is rich in perceptual information. In other words, children are often in situations where there are multiple novel objects present at once, as well as different family members producing speech and pointing to different items. In order to correctly fast-map a new word to its meaning, children must ignore all the competing information that is irrelevant, and focus their attention on the specific association that they are trying to learn. Input quality is also of particular importance for the initial stages of word learning, namely the extent to which a good word-learning opportunity exists by virtue of whether the learner can readily infer the meaning of a word from the visual context (Cartmill et al., 2013). If bilingual children are in fact better at selectively attending to particular sources of information, then they might actually have an advantage in that respect during word learning, compared to monolinguals. Additionally, it is possible that bilingual children's prior history of not hearing the same word repeated as often in each language might lead them to adjust their word-learning strategies in a way that allows them to make the most of the input that they receive. Some of these strategies may include making use of different cues or contextual information that monolingual children might not focus on. This account is further discussed in Chapters 5 and 6.

1.6 Stream-segregation as a way of examining executive functions

Listeners are regularly faced with the task of segregating different auditory streams, as a result of the vast amount of acoustic information that is usually present in the environment. This means that during tasks such as word learning and word comprehension, language users must not only accomplish the necessary steps described in the previous section, but they must also simultaneously process competing sounds. Even young children find themselves in settings where they are spoken to in the context of background noise. Some examples include high levels of ambient noise found in hospitals and preschools (Busch-Vishniac et al., 2005; Frank & Golden, 1999), as well as background speech (produced by family members) that is typically present along with speech addressed to young children in homes (Barker & Newman, 2004).

Stream-segregation tasks not only provide a way of examining a situation that listeners encounter on a regular basis, but they also provide a way of examining cognitive abilities. When presented with competing auditory signals, listeners must separate the two sound streams into the specific components that make up each stream. They must then selectively attend to the target signal (by suppressing the background/competing noise). This process results in reduced attentional capacity since the listener must rely on attention to focus on the target speech and simultaneously inhibit the competing signal (Mattys, Davis, Bradlow, & Scott, 2012). Hence, in order for speech to be perceived in the presence of noise, listeners must rely on a number of cognitive skills such as selective attention and inhibition.

As I have discussed in the earlier sections, the explanation given for why bilinguals show advantages in executive function tasks has generally been that bilinguals develop cognitive control abilities early on, in order to monitor and select among their different linguistic representations (Bialystok et al., 2009). Extensive practice at doing so enhances their ability to process competing information. Furthermore, these theories propose that the "bilingual advantage" appears to be strongest during tasks that involve selecting one source of information over another and suppressing a potential source of interference (Hilchey & Klein, 2011). This, of course, is also what is required when there are competing sound sources in the environment. For this reason, examining word learning and recognition in noise with bilinguals is of particular interest.

Studies examining the ability to recognize words in noisy conditions have indicated that there are clear differences in how infants and adults process speech in noise (Newman & Jusczyk, 1996; Newman, 2005; Newman, 2009). For example, young children are better at segregating speech signals when there are multiple voices in the background than when there is a single voice (Newman, 2009), while adults show the opposite pattern (performing better with a single voice). These age-related differences in performance have been associated with selective attention (i.e., focusing on those time periods or portions of the signal that are likely to be most beneficial), a cognitive ability that does not appear to be fully developed in young children (Bargones & Werner, 1994).

Little is known about how bilinguals of different ages perform in tasks that involve stream segregation. Prior work has mainly been carried out with monolinguals and second language (L2) learners, who acquired their second language later in life. These studies suggest that both monolingual and L2 speakers show comparable speech recognition abilities in quiet listening conditions, but that the later group performs significantly worse than the monolinguals when there is noise in the background (Florentine, 1985a, 1985b; Florentine, Buus, Scharf, & Canévet, 1984). However, L2 learners are typically not balanced in their two languages and hence are not likely to have developed the same cognitive abilities as individuals acquiring two languages simultaneously. Only a few studies have examined bilinguals' ability to attend to speech in the presence of competing noise (e.g., Mayo, Florentine, & Buus, 1997; Meador, Flege, & Mackay, 2000; Rogers, Lister, Febo, Besing, & Abrams, 2006), and these studies have mainly: (i) examined comprehension abilities in adults, (ii) been carried out with relatively small number of participants, and (iii) included a measure of the participants' perception abilities, but no cognitive measures. Therefore, there is a need for additional work with balanced bilinguals in order to address some of the limitations of the prior studies with this population, and fill the current gaps in the literature.

1.7 Outline of dissertation

This dissertation includes four different experiments that examine monolinguals' and bilinguals' performance during two crucial linguistic tasks (word learning and word recognition). The main theoretical motivation behind the approach implemented in this thesis is that word learning and word recognition presumably require different weighting between information sources (i.e., stored lexical information should play a greater role in recognition, but less of a role in learning). In the current work, these tasks were carried out in the presence of competing background noise (where stream segregation is required), because this is a situation that is commonly encountered by individuals of different ages, and one that requires the listener to make use of specific cognitive abilities that may differ across individuals with different linguistic experience.

Furthermore, there are marked differences in how monolinguals and bilinguals acquire and identify words. Unlike their monolingual peers, bilinguals must not only acquire labels for objects and concepts in each of their languages, but they also encounter each word less frequently (since each word is heard and activated less often in each language). As a result, bilinguals might have weaker representations for each word, and more lexical competitors that are activated when trying to identify and retrieve a word. Given these differences, bilinguals might be more skilled at tasks that rely more heavily on perceptual information, and less-skilled when the challenge requires a focus on stored knowledge.

In Chapter 2, I explore in more depth the prior literature on adult stream segregation and evaluate whether differences in linguistic experience and cognitive abilities influence performance during word comprehension in noise in adulthood (Experiment 1). In other words, I evaluate the notion that bilinguals have weaker stored lexical knowledge than monolinguals, resulting in bilinguals' comprehension of known words in noise being poorer compared to monolinguals'. In Chapter 3, I expand this investigation to examine word learning in noise (Experiment 2) as a way of determining whether the patterns of performance obtained in the first experiments generalize to a different task. I test the hypothesis that bilinguals weigh bottom-up perceptual information more heavily (compared to stored lexical knowledge) and have better selective attention skills, resulting in bilingual adults being more skilled than monolinguals at learning new words in the presence of background noise.

In Chapters 4 and 5, I shift the focus of my investigation to early childhood and provide a more in-depth discussion of how monolingual and bilingual children perform on child versions of word recognition (Experiment 3) and word learning (Experiment 4) in noise tasks. This approach allows me to evaluate the notion that there might be a maturational trajectory of the interaction between cognitive abilities and performance on word learning and word recognition (in monolinguals and bilinguals), resulting in differences in performance between young children and adults. In other words, there might be skills necessary to succeed in these tasks that are not fully developed in early childhood (by the 2nd year of life) but that are present by the time individuals reach adulthood.

In the final chapter, I synthesize and compare the overall empirical findings included in this dissertation. I also provide a discussion of the effect that (i) the type of task (and the demands associated with it) and (ii) age appear to have on performance, and how this relates to the linguistic experience of the individual. Finally, I provide theoretical implications, general conclusions, and future directions.

Chapter 2: Adult language comprehension in noise and the effect of linguistic experience

2.1 Overview

As discussed in the first chapter, language processing involves a constant interaction between bottom-up information (that can be perceived from the environment) and top-down knowledge (which has been previously acquired). Nevertheless, the weighting between sources may change depending on factors such as the type of task and the linguistic experience of the individual. Furthermore, there are factors that can make speech perception more challenging: one common example is the presence of a competing signal or background noise. Such additional challenges could cause listeners to rely on (or weight) skills differently. Hence, in order to complete all the steps necessary for a spoken message to be processed, listeners must rely on a number of cognitive abilities that may be influenced by the individual's linguistic experience.

In this chapter, I discuss previous work examining how adults process competing auditory signals, the effect that this has on language comprehension, and the group differences that have been reported with adult listeners who have knowledge of one versus more languages. In addition, I conduct an examination to expand our understanding of how linguistic experience (in this case early-bilingualism compared to monolingualism) influences language comprehension in noise. During a task in which participants must segregate competing sounds, focus their attention on the target speech, and in addition rely on stored lexical knowledge for comprehension, there might be group differences associated with the number of languages that the listener grew up with. If language comprehension in fact relies partially on hypotheses that are narrowed down based on previously acquired knowledge, the double activation of lexical candidates in the two languages will result in a processing cost for bilinguals, given that they will have more competitors to evaluate.

2.2 Adult Processing of speech in noise

There is extensive work examining how adult listeners overcome what has been referred to as the "cocktail party effect" (Cherry, 1953), where listeners must be able to follow speech that is addressed to them in the midst of competing voices and sounds. When there is competing noise present in the environment, the segments of the speech signal can be covered (or masked) by the competing noise; this leads to a reduction in the linguistic and acoustic cues that are available to the listener, making it harder to understand the message (Helfer & Wilbur, 1990). This "energetic masking" effect appears to be more and more pronounced as the signal-to-noise ratio (SNR) decreases and the target signal becomes too weak to be reliably understood amidst the competing noise (Miller, Heise, & Lichten, 1951).

Prior work has examined how different acoustic cues influence listeners' ability to separate competing auditory streams during language comprehension tasks. One consistent finding is that differences in location in space of the competing signal facilitate stream-segregation. In other words, listeners' ability to understand speech in noise improves when the masker and the target speech have different spatial localization (e.g., Hirsh, 1950; Broadbent, 1992; Cherry, 1953; Poulton, 1953; Spieth, Curtis, & Webster, 1954; Freyman, Balakrishnan, & Helfer, 2001; Arbogast, & Kidd, 2001). This is due to the fact that listeners can rely on the additional spatial cue to separate the competing auditory signals, and focus their attention on the location where the target speech is originating. Additionally, adult listeners appear to benefit from fluctuating amplitude in the background noise signal. Competing signals that have modulating (as opposed to constant) amplitude lead to there being "glimpses" of the target speech coming through and aiding the comprehension of the target auditory information (Festen & Plomp, 1990; Cooke, 2006).

In addition, background noise that contains meaningful information (e.g., speech in a known language as opposed to, say, white noise) leads to what is known as "information masking" (review in Kidd, Mason, Richards, Gallun, & Durlach, 2007). Previous findings suggest that competing signals that contain familiar lexical information such as a native speaker in the background (Van Engen & Bradlow, 2007; Cooke, Garcia Lecumberri, & Barker, 2008) or babble that is produced by intelligible voices (Simpson & Cooke, 2005) result in greater interference during stream-segregation tasks. This appears to be associated with processing difficulties at a higher level of language processing than the type of masking described earlier in this section (i.e., energetic masking).

Beyond the characteristics of the background noise, factors directly related to the listener will also play a role in the comprehension of speech in noisy environments. Theories of speech perception (e.g., Lindblom, 1990) argue that comprehension of the spoken message is not strictly driven by the signal, but that knowledge of the language and experience with it influence what listeners hear. Under this view, listeners are constantly combining information that they obtain from the spoken message with signal-independent information such as previously stored lexical, phonetic, and syntactic knowledge of the language (Lindblom, 1996). The two sources complement one another and are thought to impact performance not only when processing speech in quiet conditions, but also in listening situations that require stream-segregation. One important speaker-related variable that will influence the stored lexical knowledge that listeners have is their linguistic experience and background. In the case of individuals who have experience with more than one language, factors such as the age of acquisition of each language, the frequency of usage, language competency, and the context of language usage will all play a role in speech comprehension (Grosjean, 1997; von Hapsburg & Peña, 2002).

2.3 The effect of linguistic experience on adult stream-segregation

The findings discussed in the previous section come primarily from research with monolingual listeners. Fewer studies have examined stream segregation in individuals who are fluent in more than one language. Mayo et al. (1997) examined English sentence comprehension in noise with monolingual English speakers and Spanish-English bilinguals who acquired English as their L2 at different points in life. Bilingual participants were divided into three groups based on their age of acquisition of English (at birth or during infancy, during toddlerhood - before the age of six, or after the age of 14). Mayo et al.'s data indicated that while participants in the two bilingual groups who acquired English earlier in life showed better performance than the bilingual participants who acquired English post-puberty, none of the bilinguals performed as well as the monolingual participants on the task. However, this work had a number of limitations, including the lack of an assessment of language proficiency in the bilingual participants, and very small sample sizes (e.g., only *n*=3 in the group of bilinguals who acquired English in infancy).

In another study, native speakers of Italian who had moved to Canada at different ages were asked to complete a word-identification-in-noise task presented in English (Meador et al., 2000). These were participants who had not had exposure to English prior to moving to Canada and who were grouped based on their age of arrival. Participants in the group that corresponded to the earliest age of arrival (in this case an average age of 7 years) obtained significantly higher word recognition scores compared to the L2 speakers who arrived in an English-speaking environment later in life. Nevertheless, when scores from the early-arrival group were compared to scores from a monolingual group, performance of the former group was significantly worse. These findings have led to the conclusion that even when a second language is acquired early in life, listeners are still at a disadvantage when it comes to the comprehension of speech in noise. It remains unclear, however, whether the same pattern would be observed with bilinguals who acquired their two languages even earlier in life (i.e., even earlier than 7 years, which was the average age at which the youngest group had started receiving exposure to their L2).

A more recent study examined this question with Spanish-English bilinguals who had been exposed to Spanish since birth and English before the age of 6 (Rogers et al., 2006). Once again bilingual participants had poorer word recognition scores compared to monolinguals when the speech was presented in noise. However, this study once again included a relatively small number of participants (*n*=12), and included a measure of the participants' perception abilities but no measures of cognition. Given that differences in executive functions between bilinguals and monolinguals have been previously reported, having a cognitive measure that can then be compared with performance on the stream-segregation task would be beneficial. This would make it possible to explore (i) whether the bilinguals in the sample being tested in fact show the cognitive advantages previously identified in the literature, and (ii) whether despite these cognitive differences, early bilinguals still have more difficulty compared to their monolingual peers segregating competing auditory streams during comprehension.

2.4 Experiment 1

The first experiment was designed to investigate the relationship between language experience and adults' ability to rely on selective attention and previously acquired knowledge to achieve language comprehension in the presence of noise. The test utilized a modified version of the word identification paradigm introduced by Rogers et al. (2006) to test monolingual and bilingual young adults' ability to identify familiar words both in quiet and in the presence of competing background noise.

Additionally, participants completed forward and backward digit span tests to measure working memory, and the Attentional Network Task (ANT) (developed by Fan, McCandliss, Sommer, Raz, & Posner, 2002), which combines the Flanker task

(Eriksen & Eriksen, 1974) with a cue reaction time task (Posner, 1980) to measure cognitive skills. This cognitive measure was used instead of the classic Flanker task because it taps not only into executive function abilities (associated with conflict resolution), but also into attention skills (related to orienting to a spatial cue). The bilingual advantage in cognitive tasks has been found to be stronger in older adults (review in Craik & Bialystok, 2006), while the magnitude of the effect is reportedly smaller in young adults (Bialystok, Craik, & Ryan, 2006). Given the smaller effect sizes found with young bilingual adults, experimenters have resorted to including extremely large numbers of participants to increase experimental power, or to relying on tasks that measure cognitive abilities in more than one dimension (i.e., not just conflict resolution), in hopes of having more opportunities to capture cognitive differences in one of the measures. The ANT is designed to take advantage of the latter approach and has been implemented by several recent studies comparing monolingual and bilingual young adults (e.g., Costa et al., 2008; Costa et al., 2009).

In addition to the tasks just mentioned, participants completed a general questionnaire (regarding demographic characteristics, a brief health history, speech and hearing history), and a Language History Questionnaire, which asked detailed information about language exposure, experience, and usage.

The goal of this experiment was to expand on the limited work that has been conducted comparing monolingual and bilingual comprehension of speech in noise. Furthermore, it addressed some of the main limitations present in the prior bilingual stream-segregation literature by including larger sample sizes, an exhaustive self-report of language experience, as well as a combination of linguistic and cognitive measures to ensure that the bilingual group was well-matched the cognitive characteristics that have been previously reported with balanced bilinguals.

Method

Participants: A total of 64 participants (32 monolinguals and 32 bilinguals) between the ages of 18 and 24 (*M* = 20.2 years, *SD* = 1.55) recruited from the University of Maryland (*n*=55) and from the University of Toronto Mississauga (*n*=9) participated in the study. Participants were all right-handed and had no history of attention, speech or hearing problems. The monolingual group was comprised of 10 males and 22 females who were born and raised in the United States or in Canada, who grew up in a monolingual English-speaking household, and who were fluent in English. While 97 percent of the monolingual participants reported having studied a foreign language for at least one year (*M* = 3.9, *SD* = 2.45), none of them reported being fluent in it (i.e., they were not able to read it, write it, or speak it).

The bilingual group included nine males and 23 females who had acquired English as well as one other language before the age of five, and who still used both languages on a regular basis (i.e., each language was used at least 30% of the time). Based on the information provided by the participants in the questionnaires, 18 of the bilingual participants were born and raised in the United States, four were born and raised in the Toronto area in Canada, and 10 were born in a foreign country (five in India, one in China, one in the Philippines, two in Iran, and one in Russia) but had grown up speaking both languages. The language distribution for the language other than English is summarized in Table 2.1 and the distribution for the age at which

Language Background	Number of Participants
Bangla	1
Cantonese	3
Farsi	2
French	3
Greek	1
Gujarati	1
Hebrew	1
Hindi	2
Korean	1
Mandarin	4
Polish	1
Russian	1
Sinhala	1
Spanish	4
Tagalog	1
Tamil	3
Telugu	1
Urdu	1

Table 2.1: Language background distribution for bilingual participants in Experiment 1.

exposure to both languages began is shown in Table 2.2. Additionally, 65 percent of the bilingual participants reported having studied a third language after the age of five for at least one year (M = 3.2, SD = 2.4), but none of them reported fluency in the third language. While all of the participants had acquired English before the age of 5 years and were fluent in it, some of the participants spoke different varieties of English (e.g., Indian-accented English). Given that speech produced by these participants sounded different than the one produced by speakers of standard American or Canadian English, there was some concern that this might lead to difficulty transcribing and coding verbal responses. Nevertheless, since coding was done offline using recordings, coders were able to listen to the speech as many times as necessary, so as to generate transcriptions that were as accurate as possible.

Furthermore, recordings from 12 percent of the participants are currently being coded by a second coder in order to ensure reliability.

Age of 1st Exposure	Number of Participants
Birth	4
By 1 yr.	3
By 2 yrs.	5
By 3 yrs.	10
By 4 yrs.	8
By 5 yrs.	2

Table 2.2: Age at which exposure to both languages began for bilingual participants in Experiment 1.

Stimuli: The auditory stimuli for the speech-perception task consisted of a target speech stream and a competing noise signal. As in the study by Rogers et al., (2006), the target speech stimuli were words from the Central Institute for the Deaf (CID) W-22. This is a test that is commonly used to assess word recognition in adults, where items are organized into phonetically-balanced lists (Hirsch, Davis, Silverman, Reynolds, Eldert, & Benson, 1952). All words were monosyllabic and in consonant-vowel, vowel-consonant, or consonant-vowel-consonant format. Some examples were "*knee*, *send*, *young*" (the full set is included in Appendix A). All words were presented at the end of a carrier phrase "repeat the word ______" and recorded in a sound-attenuating booth by a female native speaker of English. Recordings were made at a sampling rate of 44.1 kHz and were digitalized using a 16-bit analog-to-digital converter. Excess silence at the start and ends of sentences were removed (with cuts occurring at zero crossings). Additionally, the individual sentences were edited to have the same root mean square (RMS) amplitude, and were then stored on computer disk. The competing signal was white noise presented with a steady-state amplitude envelope delivered at approximately 70-75 dB sound pressure level (SPL) via headphones. This type of noise was chosen because it is one that has been previously used during speech-perception tasks, and because it does not contain language-specific features that would share similarity with speech in a particular language. Furthermore, this type of noise does not involve informational masking (a factor that could be investigated in future work).

Trials in the noise condition were presented in one of three possible SNRs (0 dB, -4 dB, & -8 dB). This meant that the target speech and the competing noise were heard at the same intensity level, or the background noise was 4 dB or 8 dB more intense than then target speech. These noise-levels were selected based on pilot work. Ultimately, however, the true goal was to include a level of noise that caused additional difficulty without being too hard to process; using multiple SNRs helped to ensure that a noise level that led to ceiling (e.g., the same level as in quiet) or floor performance was not inadvertently included. The background signal always began 500ms prior to the target speech and continued until the end of the trial.

<u>Apparatus and Procedure:</u> Testing sessions were conducted in a quiet room where participants were seated in front of a computer monitor. All participants completed the digit span tests of working memory first, since this was a quick task that could be used as a “warm-up” and that was not likely to lead to fatigue that would affect performance in the other tasks. Half of the participants completed the word recognition task second, and the ANT third; for the other half the order of the

second and third task was reversed. Audio recordings of the test sessions were digitally generated using the built-in microphone in the computer and Audacity audio recording software (2008). Recordings of the speech-perception task were later transcribed and analyzed by trained coders.

COGNITIVE MEASURES

The forward and reversed/backward digit-span test of working memory was administered verbally by the experimenter. The digit-span task has been used in prior work as a measure of abilities associated with the maintenance of phonological information (e.g., Groeger, Field, & Hammond, 1999). Participants heard sequences of numbers and were asked to repeat them aloud. The task started with short sequences (three digits for the forward test, two digits for the backward test) and the length increased by one digit at a time, when the participant correctly recalled all the numbers in the sequence. If the participant gave two incorrect responses in a row for a particular sequence-length, the test ended.

The ANT was administered using a modified version of the Java script implemented by Weaver, Bédard, and McAuliffe (2013). The task consisted of one practice block (where participants received feedback from the computer indicating whether their response was correct or incorrect), followed by nine test blocks (each containing 16 trials), where no feedback was provided. Participants saw strings of five black arrows appear on a white background and were asked to indicate whether the central arrow was pointing right or left by pressing the right/left arrows on the keyboard. On half of the trials, all arrows pointed in the same direction (these are referred to as *congruent* trials), while in the other half, the central arrow pointed in one direction and the side arrows pointed in the opposite direction (*incongruent* trials). There was a fixation cross located in the center of the screen; the arrows appeared above the fixation cross on half of the trials, and below the cross on the other half. Additionally, on some of the trials the arrows were preceded by a "cue" (one or two asterisks * that flashed on the screen 400 ms before the target stimulus). Participants were told that if only one asterisk appeared, and it was above or below the fixation cross, it also indicated the location in which the arrows would be displayed. There were four possibilities for the cues (see bottom of Figure 2.1): no cue, center cue (where the asterisk appeared on top of the cross), double cue (where

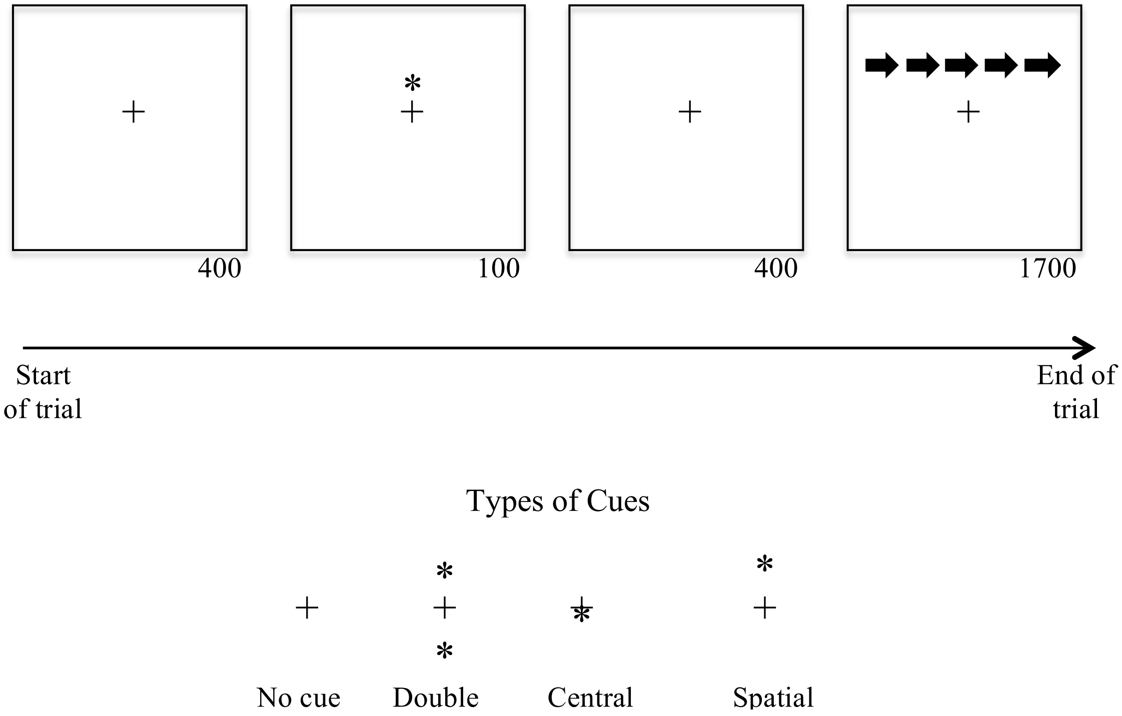

Figure 2.1: Representation of the events that would take place in a trial of the ANT, and examples of the different types of cues.

two asterisks – one above & one below the cross would appear), and spatial cue (where a single asterisk appeared either above or below the cross). Each type of cue appeared the same number of times within a block, but only the last type provided an informative clue. Participants had to provide their response within 1700 ms of visual onset of the target stimulus; otherwise, the trial would time-out and continue to the next. Figure 2.1 depicts an example of the events that would take place during one trial. The type of trial (i.e., whether it was congruent or incongruent), the location of the arrows, and the type of cue were all randomly selected by the computer. Thus, the conditions were intermixed.

LANGUAGE TASK

During the speech-perception task, listeners were asked to wear headphones and to repeat aloud familiar words heard at the end of a carrier phrase (e.g., repeat the word *young*). A list of 50 target words was presented at each of the three SNRs for the Noisy Trials, as well as in the Quiet Condition (for a total of four word-lists and 200 words – See Appendix A for complete set). The list-to-SNR level was counterbalanced across participants so that each list was heard in each of the four conditions. Words were randomly selected from the different lists by the computer using the PsyScope experiment control system (Cohen, MacWhinney, Flatt, & Provost, 1993). This resulted in trials from different conditions being intermixed. At the beginning of each trial, a black fixation cross flashed in the center of the screen for 500ms. Immediately after, participants heard the auditory stimuli presented through the headphones. A 100ms beep was played through external speakers (so that it would be captured by the computer's microphone but not heard through the participants' headphones) at the offset of the target word. Participants were instructed to repeat the target word as quickly and as accurately as possible. As a reminder, participants also saw a message that said: "say the word, THEN press [space]" appear on the screen. Once participants had produced the target word and pressed the space-bar on the keyboard, the next trial began. Participants' verbal responses were recorded and later transcribed in order to be analyzed.

Coding & Measures: Audio recordings from the word comprehension in noise task and keyboard presses from the ANT were coded for *accuracy* as well as *RT,* and compared across the two groups in order to identify any differences in performance between bilinguals and monolinguals. For the cognitive measure, the number of errors that were generated during *congruent* versus *incongruent* trials, as well as the amount of time that it took for participants to enter a correct response in each of the two conditions were calculated. In the speech-perception task, accuracy was calculated based on the number of words that participants repeated correctly. Responses were grouped based on listening condition (i.e., Quiet, 0 dB SNR, -4 dB SNR, & -8 dB SNR) in order to calculate the proportion of trials in which the correct target word was produced for each condition. RT was defined as the amount of time from the offset of the auditory cue (i.e., the beginning of the beep, which was also the end of the target word) to the onset of the participant's verbal response during trials where a correct response was produced. Verbal responses were hand-coded (rather than analyzed using a voice key) so as to avoid potentially wrong RTs that could result from participants producing disfluencies or other noises prior to their response.

Results:

COGNITIVE MEASURES

The descriptive statistics for the forward and backward digit-spans are shown in Table 2.3. Examination of the participants' responses during this task indicated that there was no difference in working memory between monolinguals and bilinguals (forward span: *t*(62)=.33, *p*=.75; backward: *t*(62)=.22, *p*=.83).

	Forward	Backward
Monolinguals	7.3 (1.3)	4.9 (.91)
Bilinguals	7.2 (1.7)	4.9 (1.3)

Table 2.3: Mean scores and standard deviations (in parentheses) on working memory task for monolinguals and bilinguals in Experiment 1.

Mean reaction times and error rates for the ANT are summarize in Table 2.4. ANT data from four of the bilingual participants were lost due to experimenter error, and hence were not included in any of the ANT analyses. Overall, bilinguals produced fewer errors compared to monolinguals during this task in both congruent and incongruent trials. However, a two-way mixed analysis of variance (ANOVA) with "flanker type" (congruent vs. incongruent) as the within-subject factor, and

	% Errors		RTs (in ms)	
	Monolinguals	Bilinguals	Monolinguals	Bilinguals
Congruent	1.8 (7.4)	0.8 (1.1)	565.8 (81.9)	558.3 (65.5)
Incongruent	7.9 (9.1)	5.3 (4.7)	672.1 (82.0)	646.6 (73.4)

Table 2.4: Mean scores and standard deviations (in parentheses) on ANT task for monolinguals and bilinguals in Experiment 1.

"group" (monolingual vs. bilingual) as the between-subject factor revealed that there was only a significant main effect of flanker type ($F(1, 58)=61.5$, $p<.001$, $\eta_p^2 = .5$), but no main effect of group ($F(1, 58)=1.3$, $p=.26$), and no interaction ($F(1, 58)=1.28$, $p=.26$). This pattern of results is at odds with previous findings with bilingual adults during similar cognitive tasks (e.g., Costa et al., 2009; Hilchey & Klein, 2011), where a main effect of group and a main effect of flanker type, as well as a global advantage, not specific to the presence of conflict, have been identified. Nevertheless, these more global effects have primarily been recorded with considerably larger sample sizes (e.g., $N \geq 60$) and have not been consistently identified across studies with smaller samples.

Follow-up t-tests comparing error rates across the two flanker types within each group showed that, as expected (based on previous work), accuracy was significantly higher for congruent trials compared to incongruent ones both for monolinguals ($t(31)= 6.28$, $p<.001$) and bilinguals ($t(27)=5.43$, $p<.001$).

Prior literature has suggested that one way to calculate the relative cost of the flanker condition, and hence the efficiency of executive control, is to calculate the difference in RTs between congruent and incongruent trials (Luk, De Sa, & Bialystok, 2011). As seen in Figure 2.2, monolinguals had greater RT costs ($M=106.6$ ms, $SD=34.7$) compared to bilinguals ($M=88.3$ ms, $SD=21$), and based on an independent samples t-test, this difference was statistically significant ($t(58)= 2.08$, $p<.05$). This flanker effect suggests that monolinguals require additional time to achieve conflict resolution, while bilinguals reach the same goal with less processing time.

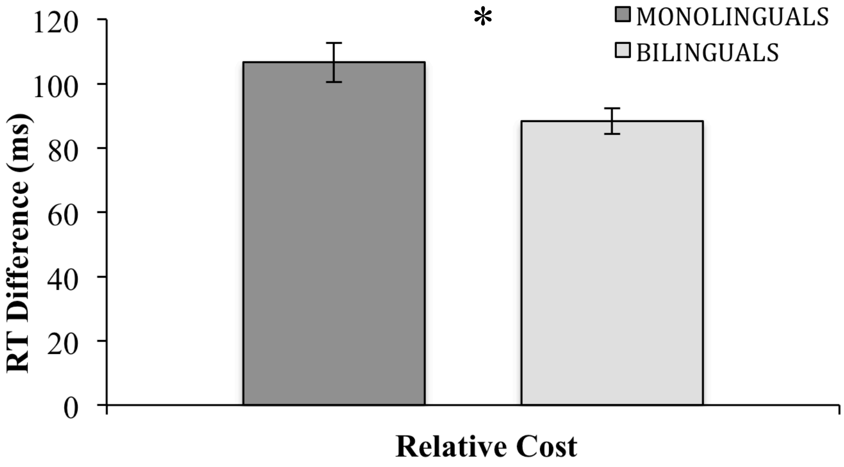

Figure 2.2: Average difference in RTs between congruent and incongruent trials for monolinguals and bilinguals during ANT task in Experiment 1. Error bars represent the standard error.

As described in the "Procedure" section, the ANT included one additional variable, which was the inclusion (or lack) of a visual cue that preceded the target stimulus. This manipulation was included in case the flanker measure alone was not sensitive enough to identify cognitive differences between the two groups. Furthermore, this was the same method implemented in prior studies (e.g., Costa et al., 2009) and so in order to be able to make comparisons it was important to keep the design as similar as possible. However, given that examination of the RT differences (regardless of cue type) revealed a significant difference in executive control between monolinguals and bilinguals, and because the purpose of including this task was simply to ensure that such a difference was in fact present, the analyses only focused on the effect of linguistic experience on the overall accuracy and differences in RTs. The four types of cues were evenly distributed across congruent and incongruent trials; therefore, averaging across all trials of the same flanker type results in the same number of cue-type trials in each flanker condition (as opposed one of the flanker types having more trials of a particular cue type than the other). This same approach was taken in the Costa et al. (2009) paper for the sake of brevity and clarity in the presentation on the results.

LANGUAGE TASK

Initial inspection of the speech-perception data revealed that there was a gradual effect of noise level on accuracy, and that listeners were still able to process speech even in the most difficult background noise condition, as indicated by relatively high accuracy (note that "chance" performance is essentially zero in this open-set task). This was the case for both language groups (see Figure 2.3). Given this pattern, I decided to focus my analysis on the two conditions at each end of the gradient (i.e., Quiet and -8dB SNR). A two-way mixed ANOVA with group as the between-subjects factor and listening condition as the within-subjects factor revealed significant main effects of listening condition ($F(1, 62)=710.6$, $p<.001$, $\eta_p^2 = .9$) and

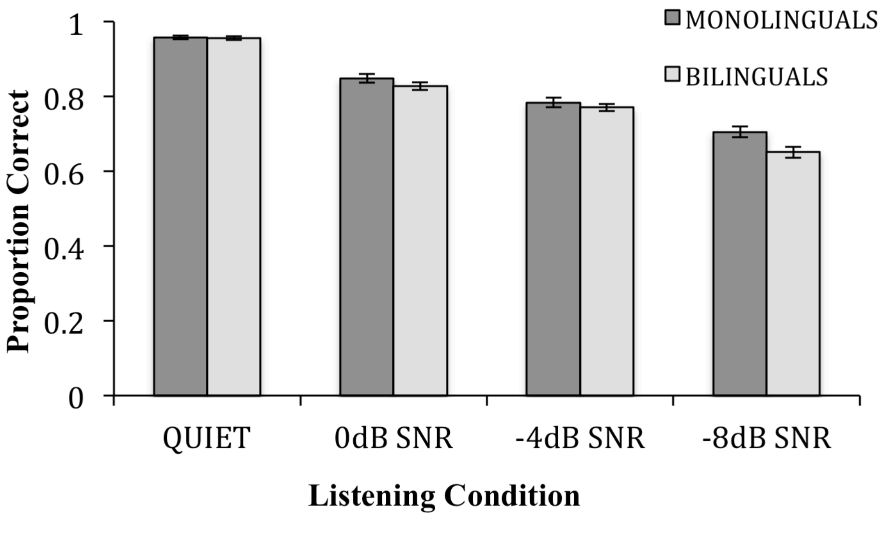

Figure 2.3: Proportion of correct responses produced by monolinguals and bilinguals in the speech-perception task during quiet and noisy trials in Experiment 1. Error bars indicate standard error.

group (*F*(1, 62)=6.77, $p<.05$, η_p^2 = .1), as well as a significant interaction (*F*(1, 62)=6.14, $p<.05$, η_p^2 = .1). Follow-up t-tests comparing group performance in the two listening conditions revealed that there was no difference in accuracy between monolinguals and bilinguals when there was no noise in the background (*t*(62)=.37, *p*=.72). On the other hand, the two groups did differ in their performance during trials presented in the -8dB noise condition (*t*(62)= 2.68, $p<.05$), with monolinguals being significantly more accurate than bilinguals (*M*=.71, *SD*=.08 & *M*=.65, *SD*=.08 respectively). This pattern suggests that bilinguals are not worse overall at the task (since there was no difference between groups in the quiet condition), but rather, that it is the noise that is driving the effect and leading them to make more mistakes.

Examination of the RT data (see Figure 2.4 for summary) revealed that there was a significant main effect of listening condition (*F*(1, 62)=39.1, $p<.001$, η_p^2 = .4), but no main effect of group (*F*(1, 62)=.20, *p*=.65), and no interaction (*F*(1, 62)=2.07, *p*=.15). This meant that while language background did not affect the amount of time

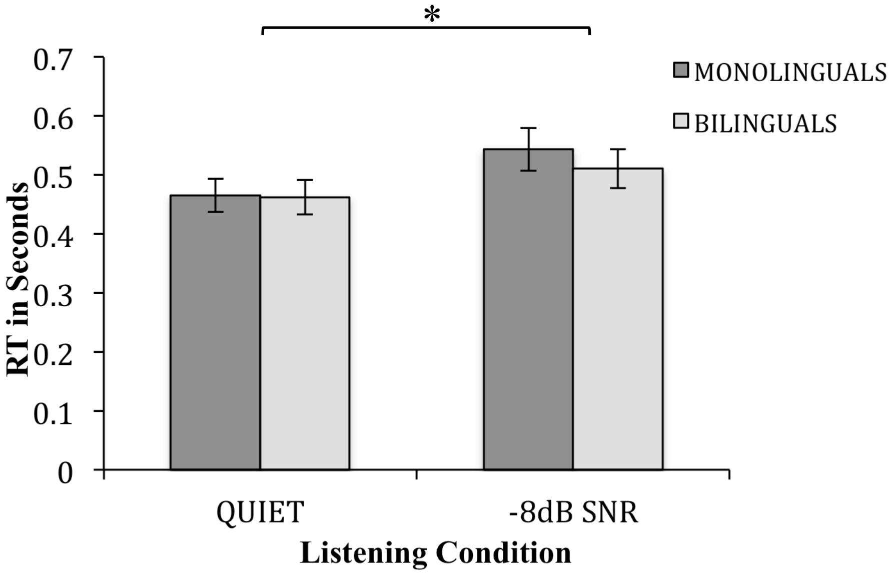

Figure 2.4: Response times for monolinguals and bilinguals during speech-perception task in Experiment 1. Error bars indicate the standard error.

necessary to produce a correct response during the task, the listening condition did. In general, participants took longer to produce a correct response when there was white noise present in the background (*M*=.53 sec, *SD*=.18) than when the target word was heard in quiet (*M*=.46 sec, *SD*=.15), and this difference was significant (*t*(62)= 6.39, *p*<.001).

2.5 Discussion

The goal of this experiment was to examine the effect that linguistic experience (i.e., growing up monolingual vs. bilingual) might have on listeners' ability to understand speech in the presence of background noise. Given that prior work with bilinguals has mostly been conducted with L2 learners (who acquired one of their languages later in life) or with very small groups of early bilinguals, the goal was also to expand on this work by including a larger sample size, as well as a combination of linguistic and cognitive measures. Data from the cognitive measures indicated that while the monolingual and bilingual participants in this study did not differ in their working memory capacity, there was a difference between the two groups when it came to the amount of time necessary to achieve conflict resolution during the cognitive measure. Bilingual participants had smaller RT costs for incongruent trials (flanker effect) in the ANT compared to monolinguals, suggesting that they require less time to achieve conflict resolution. This finding replicates prior work with early bilinguals (e.g., Luk et al., 2011; Costa et al., 2009) and suggests that the bilinguals in this sample possessed some of the cognitive benefits that have been previously associated with acquiring two languages early in life.

Despite showing an advantage in cognitive control, bilinguals were less accurate than monolinguals during the stream-segregation task and made more mistakes when asked to identify words that were accompanied by white noise. In fact, there was no correlation between bilingual processing efficiency in the ANT and accuracy scores in the noise condition (r=.04). Both groups performed equally well when there was no noise in the background. This suggests that while bilinguals do not have difficulty understanding speech in quiet conditions, they are less able than monolinguals to process speech that is presented in noise during a comprehension task. These results confirm the previous findings obtained with studies with smaller sample sizes (e.g., Mayo et al., 1997; Meador et al., 2000) and suggest that the bilingual disadvantage during speech comprehension in noise is, indeed, a robust effect. Furthermore, it is interesting that this finding has been identified with different kinds of competing noises, including babble (Mayo et al., 1997), reverberation and speech-spectrum noise (Rogers et al., 2006), and now white noise, once again demonstrating the strength of the effect.

One of the theoretical motivations for the work included in this thesis was to examine whether the same cognitive skills (those that lead to an advantage during conflict resolution tasks) previously associated with bilingualism might also play a role in the processing of competing auditory input (i.e., one of the skills that listeners rely on when listening to speech in the presence of background noise). Findings from the current experiment suggest that the two skills might not be necessarily related. The lack of a correlation between performance in the ANT and performance during the language task suggests that these might be independent factors. One possibility is that the specific dependent measures that were contrasted were not the correct ones for capturing a relationship between the two skills. There are various ways to measure cognitive abilities and it is possible that on a different task (one that does share processing mechanisms with language comprehension in noise), a correlation would have been present for the bilingual group. It is unclear, however, what the "correct" combination of tasks might be. Another possibility is that word comprehension in noise does not involve selective attention in the way that one might think (i.e., in the same way that the ANT does when competing information appears on the screen), and that instead, it is a task that is more closely related to filling in missing information from the speech input – given that the target signal is "covered up" by the competing noise. This topic is further explore in the following chapters.

Additionally, within the bilingual group, differences in the age at which both languages were acquired might have led to variations in the patterns of performance (e.g., 12 participants in this group acquired both languages by the age of two, while the other 20 acquired their two languages after two but before five years of age). A comparison of accuracy scores between the 12 bilinguals who acquired both languages by the second year of life and the 20 bilinguals who acquired both languages slightly later revealed that there was no significant main effect of group (*F*(1, 29)=3.44, *p*=.07), and no interaction (*F*(1, 29)=1.74, *p*=.20). There was only a main effect of listening condition (*F*(1, 29)=327.5, *p*<.001). Nevertheless, mean accuracy scores in the noise condition suggested that there might be a trend in the bilingual data associated with the age of acquisition of the two languages. Accuracy was highest for the monolingual group (*M*=.71, *SD*=.08), followed by the "earlier bilinguals” (*M*=.69, *SD*=.07), and finally the “later bilinguals” (*M*=.63, *SD*=.09). Furthermore, a comparison of mean accuracy for the 12 early bilinguals and the 32 monolinguals revealed no main effect of group (*F*(1, 42)=.47, *p*=.50), and no interaction (*F*(1, 42)=.62, *p*=.43). This could suggest that the bilingual disadvantage discussed in this chapter could have been driven by the age at which listeners became bilingual (with participants who acquired both languages earlier showing no difference in performance compared to monolinguals, and only bilinguals who acquired their languages slightly later experiencing greater processing costs). While this possibility should be considered, these later analyses included a much smaller sample size and must therefore be interpreted with caution. Future work could examine this account by including a larger sample size of earlier bilinguals.

Results from Experiment 1 support the initial hypothesis suggesting that bilinguals will show greater difficulty (compared to monolinguals) in a task that relies heavily on accessing top-down knowledge to determine the meaning of a word in a situation where the target information is masked by a competing auditory signal. According to the literature examining bilingual language production (Ecke, 2004; Gollan et al., 2005), bilinguals have weaker stored word knowledge and more lexical competitors; this splitting of lexical information across two languages potentially leads to the “access pathways” being less automatic. In the language-comprehension-in-noise task participants were not only asked to identify words with a signal quality that was reduced by the overlapping white noise, but they were asked to do so as quickly as possible. One possibility is that when there is high task demand (such as the one caused by segregating competing auditory signals or providing a response quickly – within a small amount of time), and in particular when the demand is related to accessing previously acquired lexical information, the weaker stored knowledge in bilinguals may lead to lower response accuracy compared to monolinguals. On the other hand, when the task demand is lower (as in the quiet condition, where the signal quality is higher) bilinguals can dedicate more attentional resources to accessing the stored information and compensate for the weaker representations. Similar hypotheses have been provided by other researchers (e.g., Rogers et al., 2006 and Pichora-Fuller, Scheider, & Daneman, 1995) and could explain the pattern of results obtained in this experiment. It is unclear whether the same group difference would be observed in other stream segregation tasks that rely less on stored lexical knowledge (e.g., during word learning); this question will be explored in Chapter 3.

Given that similar decrements in performance during listening-in-noise tasks have been reported with other populations, it is necessary to consider other possible explanations - beyond those associated with having weaker lexical representations. For example, older adults often show equivalent performance to young monolingual adults during word recognition in quiet, but poorer performance in noise (e.g., Pichora-Fuller et al., 1995). For this particular population, the differences in group performance have been typically attributed to poorer temporal or auditory processing and to the effects of aging, which lead to there being fewer resources available to comprehend speech when processing demands are high (e.g., when there is noise in the background). It is possible that the bilinguals' performance in noise is the result of this group similarly having fewer resources available to process speech in one language, since they must simultaneously inhibit the competing linguistic system.

Another possibility is that there were group differences between monolinguals and bilinguals in areas other than cognitive control that could have influenced performance in the noise condition. Two possibilities might have been differences in vocabulary size and differences in how familiar the two groups were with the variety of English that was heard during the task. In other words, it is possible that bilinguals had a smaller English vocabulary and were possibly less familiar with the American English dialect that was heard during the study. Even though all bilingual participants had grown up hearing English since early childhood, some of them had lived in other countries where they might have been exposed to other varieties of English, making it harder to identify the target words. These are interesting variables that could be explored in future work.

Taken together, findings from this experiment suggest that bilingual listeners are less able than monolinguals to process acoustic degradation that may result from a competing noise signal during language comprehension. Furthermore, this is the case even for extremely balanced bilingual adults who acquired both their languages before the age of 5 and who throughout their lifetime have continued to actively use both languages. This is an important finding given that there is a high (and rapidly growing) rate of bilingualism both in the United States and around the world, and given the fact that it is not uncommon for listeners to find themselves in noisy environments. This pattern of results will be further explored in the following chapters of this dissertation.

Chapter 3: Adult word learning in noise and the effect of linguistic experience

3.1 Overview

Findings from Experiment 1 in the previous chapter suggest that during language comprehension, early-bilingual adults show greater difficulty than monolinguals understanding speech in the presence of background noise. One possibility is that this group difference is related to task demands, and the bilingual disadvantage is specific to tasks that rely primarily on accessing previously stored lexical knowledge. Other tasks (such as learning new words in the presence of noise) rely more heavily on processing information that is being perceived from the environment and may lead to bilinguals not experiencing the same processing costs that were identified in the word comprehension task.

Even though word learning is a phenomenon that is mainly associated with young children who are acquiring their vocabulary or with individuals who are acquiring a foreign language, adults (both monolingual and bilingual) are learning new words all the time. In this chapter, I summarize prior work exploring word learning in adulthood, as well as how this process might differ as a function of the linguistic experience of the individual. Additionally, I discuss an experiment designed to evaluate monolingual and early-bilingual adults' ability to learn new words in noise. Assuming that during word learning the task-demands are in fact different than during comprehension, bilingual adults might show better or equal performance compared to monolinguals during a task where listeners are required to rely on selective attention skills to segregate competing auditory signals, focus their attention on the target speech, and learn novel word-object associations in the presence of noise.

3.2 Word learning in adults

The great majority of the adult literature exploring language processing has focused on comprehension and not on word learning. However, the process of acquiring new words does not end in childhood; instead, it is something that adults continue to do throughout their lifetime. Prior work examining this topic suggests that monolingual adults actually follow some of the same word learning heuristics that have been observed in young children. One common lexical principle that individuals appear to rely on during word learning is the "mutual exclusivity constraint", which limits the number of plausible referents that can be assigned to a novel word (Merriman & Bowman, 1989; Au & Glusman, 1990). When presented with two referents (one that has already been assigned a label and one that has not been named), adults will consistently assign a novel label to the unnamed object (Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992). Furthermore, this study by Golinkoff also demonstrated that adults (like children) will extend the newly-acquired term to other objects that share similar taxonomic characteristics, supporting the notion that adults are relying on categorical scope principles.

In addition to these lexical and categorical rules, adult word learning is guided by sensitivity to the statistical patterns of the language. Prior work has suggested that after only a couple of minutes of exposure to continuous auditory streams of an artificial lexicon, adults are able to identify patterns of syllable co-occurrence to segment novel “words” (i.e., the fact that there is a higher occurrence of within-word syllable sequences compared to lower occurrence of between-word syllable sequences) from a continuous syllable stream (Saffran, Newport, & Aslin, 1996). Furthermore, during a task that required adults to rely on statistical information about the language to learn novel word-object pairings, listeners learned the relationships faster when words contained high-probability syllable sequences (Mirman, Magnuson, Graf Ester, & Dixon, 2008).

A study by Storkel, Armbrüster, and Hogan (2006) examined how (a) the likelihood of occurrence of specific sound sequences in the language (i.e., the phonotactic probability) and (b) the number of similarly-sounding lexical items (i.e., the neighborhood density) would influence word learning in adults. Findings from this work suggested that these two elements influence the acquisition of new lexical entries in different ways. Adult participants learned more words when the lexical items had low phonotactic probability compared to when the phonotactic probability was high. The authors explain this finding by suggesting that phonotactic probability may influence the initial process through which words are acquired. Novel words with low phonotactic probability will “stand out” more easily, triggering the learning process, while novel words that are more “word-like” may be perceived as possibly already being stored in memory and might require additional exposure to the particular item in order for the word-learning process to be initiated. On the other hand, neighborhood density had a different effect; adults in the study more easily learned novel words that had high neighborhood density, compared to those with low density. Storkel and colleagues argued that while phonotactic probabilities might be more closely linked to the initiation of the learning process, neighborhood density might play more of a role in the integration of newly-encoded terms with existing lexical items. Therefore, having a novel word with high neighborhood density will lead to additional connections with pre-existing items that get activated, and hence to better permanent storage of the newly acquired information.

There are a number of additional elements that contribute to adult performance during word-learning tasks. Some of these include factors such as the phonological familiarity of the novel words that are being acquired, as well as the rehearsal strategies (e.g., vocally repeating new words) that are implemented by the individual during the learning process (Kaushanskaya & Yoo, 2010). Furthermore, there appears to be a strong link between non-word repetition abilities and the rate of novel word learning in adulthood, with individuals who are better at repeating novel words also being more efficient language learners (Atkins & Baddeley, 1998; Gupta, 2003; Gathercole, 2006). Some researchers have attributed this last finding to individual differences in phonological short-term (or working) memory[1], which in turn lead to having either better or worse abilities to encode new lexical entries (Papagno & Vallar, 1992; Gupta, 2003). In the next section, I will discuss the role that linguistic experience plays in this account.

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[1] Short-term memory (STM) and working memory (WM) are sometimes defined as separate terms with STM being primarily associated with the recalling of information (without doing any kind of manipulation), while WM involves additional manipulations. However, for the purpose of my discussion I am treating the two as similar concepts.

3.3 The effect of linguistic experience on adult word learning

Several lines of work support the notion that linguistic experience will influence the strategies that individuals rely on during word learning. In the case of adults, prior findings have suggested that the use of principles (such as the ones described in the previous section) to achieve novel-word learning might differ depending on whether the learner is fluent in one versus more languages. For example, bilingual adults do not show mutual exclusivity biases and are willing to accept more than one label for the same referent in situations where it is clear that the different novel words correspond to different languages (Au & Glusman, 1990). This is presumably due to the fact that bilinguals (and multilinguals) acquire cross-language synonyms and hence break away from a strategy that relies on a one-to-one mapping between label and referent.

Some researchers have actually suggested that knowledge of multiple languages facilitates performance during word-learning tasks in adulthood. In a study by Kaushanskaya and Marian (2009) English-Mandarin bilinguals, English-Spanish bilinguals, and English monolinguals were asked to learn novel words in a foreign language. During this task, non-words that contained phonological information that was unfamiliar to all groups were trained in association with their English translation. Accuracy was higher for the English-Mandarin and English-Spanish bilingual groups compared to the monolingual group. The main explanation for this finding had been that bilingualism and multilingualism leads to the development of a phonological memory system that is more “efficient”, and hence allows listeners to better remember new terms, even when the phonological information is not familiar

(Papagno & Vallar, 1995). Nevertheless, a more recent word-learning study in which monolingual and bilingual adults were matched in their phonological memory capacity still revealed the same group differences in performance (Kaushanskaya, 2012).

Kaushanskaya and Rechtzigel (2012) examined the possibility that bilinguals and monolinguals might differ in how they process the semantic information associated with novel terms. Data from this study revealed that the bilingual advantage was greater for novel words that corresponded to concrete (compared to abstract) referents. Words that have concrete meanings are not only thought to lead to a richer activation of stored lexical representations (Grondin, Lupker, & McRae, 2009), but in the case of bilinguals also share a greater semantic-overlap across the two languages compared to words that correspond to abstract referents (Van Hell & De Groot, 1998). Therefore, Kaushanskaya and Rechtzigel introduce the possibility that the concreteness of the word leads to a stronger activation of the semantic system during encoding, particularly when the meaning of the novel term is activated across the two linguistic systems.

Nevertheless, all of the above findings were gathered using word-learning tasks that relied on paired-associates-learning methods, where the novel terms were trained through associations with previously acquired translation equivalents. While this type of approach is relevant to how adults might learn a second language (after having acquired a first language), learning words through translations is not necessarily how early-bilinguals acquire their two language systems early in life, and hence might not be how this population approaches word learning outside of the laboratory.

3.4 Experiment 2

This second experiment explored the relationship between language experience and adult listeners' ability to selectively attend to a particular sound source in the environment, in order to learn entirely novel word-object relations. This experiment used a modified version of the word-learning task introduced by Gupta (2003) and tested monolingual and bilingual young adults' word-learning skills both in quiet and in the presence of background noise. In addition to the word-learning task, participants also completed the same cognitive measures (i.e., digit-span tasks and ANT) and questionnaires (i.e., general questionnaire and Language History questionnaire) described in the first experiment in Chapter 2.

The goal of this experiment was to examine the hypothesis that monolingual and early-bilingual adults weigh information sources differently depending on the task and the demands associated with it. Therefore, performance across the two groups might be different during word learning compared to word comprehension in the presence of noise. Additionally, this experiment aimed to expand the knowledge we have regarding adult language processing during situations that require the listener to generate and store new lexical representations, and in particular, whether these abilities vary as a function of the type of linguistic experience that the individual has had.

Method

Participants: Data from 64 participants (32 monolinguals and 32 bilinguals) between the ages of 18 and 33 (*M* = 20.4, *SD* = 2.3) recruited from the University of Maryland (*n*=48) and from the University of Toronto Mississauga (*n*=16) were included in this experiment. Participants were all right-handed and had no history of attention, speech or hearing problems. There were 14 monolingual males and 18 monolingual females who were born and raised in the United States or in Canada, had grown up in a monolingual English-speaking household, and were only fluent in English. While 90 percent of the monolingual participants reported having studied a foreign language for at least one year (*M* = 3.5, *SD* = 2.20), none of them reported being fluent in it (i.e., they were not able to read it, write it, or speak it).

In the case of the bilingual group, a total of nine males and 23 females were included in the study. All bilingual participants had acquired English as well as one other language before the age of five, and reported that they still used both languages on a regular basis (i.e., each language was used at least 30% of the time). Within the bilingual group, 14 participants were born and raised in the United States, six were born and raised in the Toronto area in Canada, and 12 were born in a foreign country (two in Hong Kong, one in Ghana, one in Saudi Arabia, one in Nigeria, five in India, one in Zimbabwe, and one in Brazil) but had grown up speaking both languages. Furthermore, of the 12 participants that were born abroad, six had moved to the US or Canada while they were infants. The language distribution for the language other than English is summarized in Table 3.1 and the distribution for the age at which exposure to both languages began is shown in Table 3.2. Additionally, 71 percent of the bilingual participants reported having studied a third language after the age of five for at least one year (M = 3.4, SD = 2.6), but none of them reported being fluent in the third language. None of the participants in this experiment had completed Experiment 1.

Language Background	Number of Participants
Albanian	1
Arabic	1
Bangla	1
Cantonese	4
Czech	1
French	1
Hindi	2
Macedonian	1
Mandarin	1
Portuguese	2
Shona	1
Spanish	6
Tamil	4
Twi	2
Urdu	1
Vietnamese	1
Wolof	1
Yoruba	1

Table 3.1: Language background distribution for bilingual participants in Experiment 2.

Age of 1st Exposure	Number of Participants
Birth	7
By 1 yr.	1
By 2 yrs.	11
By 3 yrs.	4
By 4 yrs.	8
By 5 yrs.	1

Table 3.2: Age at which exposure to both languages began for bilingual participants in Experiment 2.

Stimuli: The auditory stimuli for the word-learning task consisted of 78 four syllable non-words (six target and 72 foils) that were generated following the constraints in Figure 3.1, which followed English phonotactics (these were the same rules used by Gupta, 2003). All novel words had second syllable stress and were recorded by the same female speaker from Experiment 1. Some examples of the target non-words were "*che-CHE-pa-tile, ta-BE-to-gobe, bi-BU-ka-dir*" (a complete list of the non-words is included in Appendix B). All non-words were presented in isolation (as opposed to being included in a sentence) and were recorded and edited using exactly the same procedure described in Chapter 2.

The competing signal was once again white noise presented with a steady-state amplitude envelope delivered at approximately 70-75 dB sound pressure level (SPL) via headphones. Trials in the noise condition were presented using a -2dB SNR. This meant that the background noise was 2 dB more intense than the target speech. This noise level was selected based on pilot work. The background signal always began 500ms prior to the target speech and continued until the end of the trial.

Nonword → syll$_{\#1}$ + syll$_{\#2}$ + syll$_{\#3}$ + syll$_{\#4}$
syll$_{\#1}$ → Consonant + Vowel
syll$_{\#2}$ → Consonant + Vowel
syll$_{\#3}$ → Consonant + Vowel
syll$_{\#4}$ → Consonant + Vowel + Coda

Consonant: b, ch, d, g, j, k, p, t
Vowel: a, e, i, o ,u
Coda: b, be, c, ce, d, de, f, fe, g, ge, l, le, m, me, n, ne, nt, p, pe, r, re, rt, s, st, t, te, th, ve, x, ze

Figure 3.1: Spelling constraints on non-word construction for Experiment 2.

The visual stimuli consisted of six colored pictures of novel "creatures from another planet" created using SPORE(TM) Creature Creator software. All objects had different features and colors and were presented on a white background (see Figure 3.2). These objects were selected because they were easily distinguishable from one another and because they would not have any previously existing names.

Apparatus and Procedure: Testing sessions were conducted in a quiet room with participants seated in front of a computer monitor. As in Experiment 1, all participants were administered the digit span test of working memory first, followed by either the ANT second, and the word-learning task third (for half of the participants) or the word-learning task second, and the ANT third (for the other half). Audio recordings of the entire test sessions were digitally generated using the built-in microphone in the computer. Participants' verbal responses during the word-learning task were later transcribed and analyzed by trained coders.

Figure 3.2: Novel objects used during word-learning task in Experiment 2.

COGNITIVE MEASURES

The digit-span measures and the ANT were identical to the ones described in the first experiment (see Chapter 2 for detailed description).

LANGUAGE TASK

During the word-learning task, participants were asked to wear headphones and to repeat aloud non-words that in some situations corresponded to a particular novel object that appeared on the screen. The paradigm for this experiment was set up in a way that minimized proactive and retroactive interference, while at the same time avoiding making the task trivially easy. An outline of the experimental design is included in Table 3.3. Participants completed a total of 9 blocks (each containing 22 trials). There were five main steps/trials within each block (Trials 1-5 in Table 3.3) that were cycled four times per block. During the first four trials of each block, participants heard a non-word and repeated it aloud. Two of these were Foil Trials (where "distractor" non-words were presented auditorily without a referent) and the other two were Training Trials (where the target label was presented once,

STEP/TRIAL	STIMULUS	PARTICIPANT'S RESPONSE	
1.	**Nonword foil**	**Repeat non-word**	1 block = 22 trials
2. Training 1	**Nonword target 1 + Picture of creature 1**	**Repeat non-word**	
3. Training 2	**Nonword target 1 + Picture of creature 1**	**Repeat non-word**	
4.	**Nonword foil**	**Repeat non-word**	
5. Early Test	**Cue: Picture of single creature 1**	**Name creature**	
6.	[Repeat trials 1-5 with creature 1, Target 1]		
7.	[Repeat trials 1-6 with creature 2, Target 2]		
8. Joint Test	**Cue:** Picture of single creature	Name creature	
9. Joint Test	**Cue:** Picture of single creature	Name creature	
10.	[Repeat trials 1-9 two more times]		
11.	[Repeat trials 1-10 with creature & Target 3, 4]		
12.	[Repeat trials 1-10 with creature & Target 5, 6]		

Table 3.3: Structure of word learning task in Experiment 2.

accompanied by a picture on the screen of the corresponding referent). Within those 5 main steps, the two Training Trials were identical (i.e., same non-word and referent), and always successive (e.g., 1st & 2nd trials or 2nd & 3rd trials in each block). The two Foil Trials, on the other hand, had different non-words so as to add greater difficulty to the task (rather than hearing the same labels being repeated). The fifth trial in each block was the Test Trial, where participants were cued with an image on the screen and were asked to correctly produce the corresponding label that they learned. There was always at least one Foil Trial in between Training Trials and the Test Trial. This pattern was followed in order to require participants to encode the word-object representations and prevent them from simply relying on verbal short-term memory to repeat what they had just heard. After these five steps had been completed twice for the first word-object pairing, they were repeated twice more (within the same block) for the second word-object pair (for a total of 20 trials).

These 20 trials were then followed by two Joint-Test trials (one for each word) in which participants were asked to provide responses based on the training of the two referents they had just seen. The order of presentation of the picture cues was randomized by the computer using the PsyScope experiment control system (Cohen, MacWhinney, Flatt, & Provost, 1993). This basic structure was repeated three times using the same pair of words, before going on to the subsequent pair of words; a total of six word-object combinations (three pairs of words) were trained and tested throughout the experiment. Hence, each participant received a total of three blocks of training and testing for each of the six Target words. Different non-word foils were used within and across blocks. Training Trials for half of the pairs (e.g., Target 1 but not 2) were presented in the -2dB SNR noise condition, while the other half were presented in quiet. This resulted in trials from the two conditions being intermixed (i.e., within each block one target was trained in noise and one target was trained in quiet, and the computer randomly selected which condition was presented first). Which target word occurred in noise vs. silence, and which label was associated with which object were counterbalanced across participants so that each target word was heard in noise and in quiet, and each referent was paired with the 6 different target words.

At the beginning of each Training Trial, participants saw a message that said: "repeat the word, THEN press [space]" appear on the screen for 2000ms. Immediately after, participants heard the non-word presented via headphones and saw the corresponding object appear on the screen. Trials during which a foil word was presented were identical, except for the fact that no object was seen. Participants were given 4500ms to provide a response and press the space bar, at which point the current trial ended and the following one began. If no response was provided during this time-window, the trial timed-out and the next one began. Test Trials began with the message "say the name of the object, THEN press [space]" flashing on the screen for 2000ms. This event was followed by a picture of the trained referent appearing on the screen and a 100ms beep being played through external speakers (so as to be captured by the computer's microphone but not heard through the participants' headphones) at the onset of the image. The image of the object remained on the screen until participants provided a verbal response and pressed the space-bar. At that point, the Test Trial ended and the following trial began. At the beginning of the study, participants were instructed to repeat all the words that they heard, but to particularly focus on learning the words that corresponded to an object on the screen. In addition, participants were asked to produce words as quickly and as accurately as they could. Participants' verbal responses were recorded and later transcribed in order to be analyzed.

Coding & Measures: Audio recordings from the word-learning task and keyboard presses from the ANT were coded for *accuracy* as well as *RT,* and compared across the two groups in order to identify any differences in performance between bilinguals and monolinguals. The ANT data were analyzed in the exact same way described in Experiment 1. In the word-learning task, accuracy was calculated based on the number of words that participants produced correctly on the later joint test trials (at the end of each block). Responses were counted as correct when at least three out of the four syllables in the word were accurately produced.[2] Responses were grouped based on listening condition (i.e., Quiet compared to -2dB SNR Noise) in order to calculate the percentage of correct responses for each condition. RT was defined as the amount of time from the onset of the visual cue (i.e., the beginning of the beep, which corresponded to the moment when the object appeared on the screen), to the onset of the participant's verbal response during the later joint test trials where a correct response was produced. As in the first experiment, verbal

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[2] Several other studies examining word learning in adults have implemented accuracy measures that rely on partial word-form knowledge (e.g., Meara & Ingle, 1986; Schmitt, 1998; Storkel et al., 2006; Barcroft, 2008). The reasoning behind this approach is that whole word forms are not necessarily acquired automatically, and instead the process of learning new labels might take place gradually as the different parts of the word are processed and stored "bit-by-bit" (Barcroft & Rott, 2010). Given the length of the words and the difficulty of the listening in noise task in the current experiment, I felt that it was important to rely on a measure that would be sensitive to the partial learning of information, rather than an all-or-nothing accuracy score.

responses were hand-coded to avoid potentially inaccurate RTs that could result from noise or disfluencies produced prior to providing the correct response.

Results:

COGNITIVE MEASURES

Scores from the working memory task are displayed in Table 3.4. Analysis of the participants' responses during the forward and backward tasks indicated that there were no significant differences in performance across the two language groups (forward span: *t*(62)= 1.04, *p*=.30; backward: *t*(62)= .42, *p*=.68).

	Forward	Backward
Monolinguals	6.9 (1.4)	4.7 (1.5)
Bilinguals	7.3 (1.5)	4.8 (1.5)

Table 3.4: Mean scores and standard deviations (in parentheses) on working memory task for monolinguals and bilinguals in Experiment 2.

Mean reaction times and error rates for the ANT are summarized in Table 3.5. ANT data from three of the monolingual participants and three of the bilingual participants were lost due to experimenter error, and hence were not included in any

	% Errors		RTs (in ms)	
	Monolinguals	Bilinguals	Monolinguals	Bilinguals
Congruent	.65 (.91)	0.72 (1.3)	530.2 (57.1)	529.0 (60.0)
Incongruent	6.44 (7.5)	6.1 (6.0)	632.5 (67.5)	618.8 (70.0)

Table 3.5: Mean scores and standard deviations (in parentheses) on ANT task for monolinguals and bilinguals in Experiment 2.

of the ANT analyses. Data were analyzed using a two-way mixed analysis of variance (ANOVA) with "flanker type" (congruent vs. incongruent) as the within-subject factor, and "group" (monolingual vs. bilingual) as the between-subject factor to compare the percentage of errors produced by both groups across conditions. This analysis revealed that there was a significant main effect of flanker type ($F(1, 56)=42$, $p<.001$, $\eta_p^2 = .4$), but no main effect of group ($F(1, 56)=.02$, $p=.89$), and no interaction ($F(1, 56)=.06$, $p=.81$). Follow-up t-tests comparing error rates across the two flanker types within each group showed that, as in Experiment 1, accuracy was significantly higher for congruent trials compared to incongruent ones, both for monolinguals ($t(28)= 4.42$, $p<.001$) and bilinguals ($t(28)=5.53$, $p<.001$).

In order to calculate the efficiency of executive control, The difference in RTs between congruent and incongruent trials was computed (Luk, De Sa, & Bialystok, 2011). As seen in Figure 3.4, monolinguals had greater RT costs ($M=102.3$ ms,

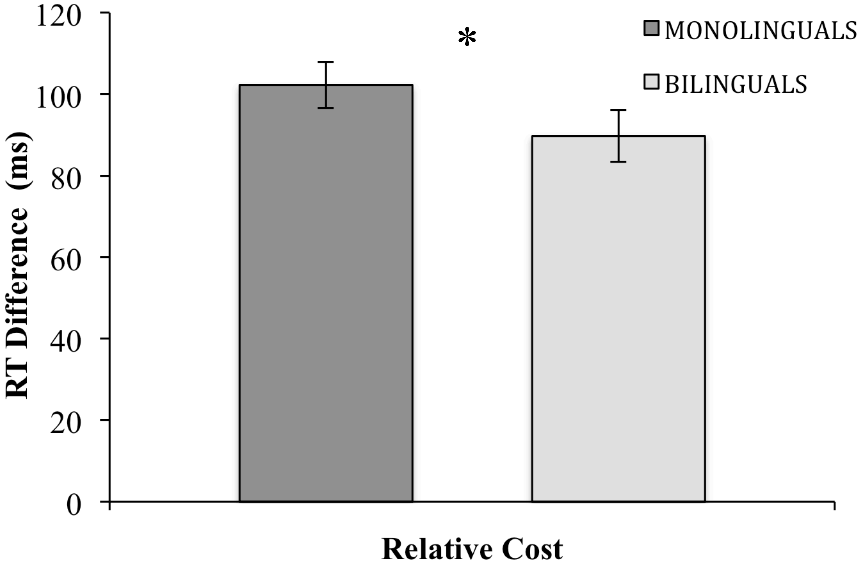

Figure 3.4: Average difference in RTs between congruent and incongruent trials for monolinguals and bilinguals during ANT task in Experiment 2. Error bars represent the standard error.

SD=25.4) compared to bilinguals (*M*=89.8 ms, *SD*=25.6), and based on an independent samples t-test, this difference was statistically significant (*t*(56)= 2.18, *p*<.05). This flanker effect suggests that monolingual participants required additional time to achieve conflict resolution, while bilinguals were able to succeed in the task with less processing time.

LANGUAGE TASK

Accuracy performance during the word-learning task is summarized in Figure 3.5. A two-way mixed ANOVA with group as the between-subjects factor and listening condition as the within-subjects factor revealed a significant main effect of listening condition ($F(1, 62)=77.5$, $p<.001$, $\eta_p^2 = .6$), but no main effect of group ($F(1, 62)=.10$, $p=.76$), and no significant interaction ($F(1, 62)=.05$, $p=.82$). This meant that the listening condition in which novel words were trained influenced accuracy later on during test trials. However, the language background did not affect this measure.

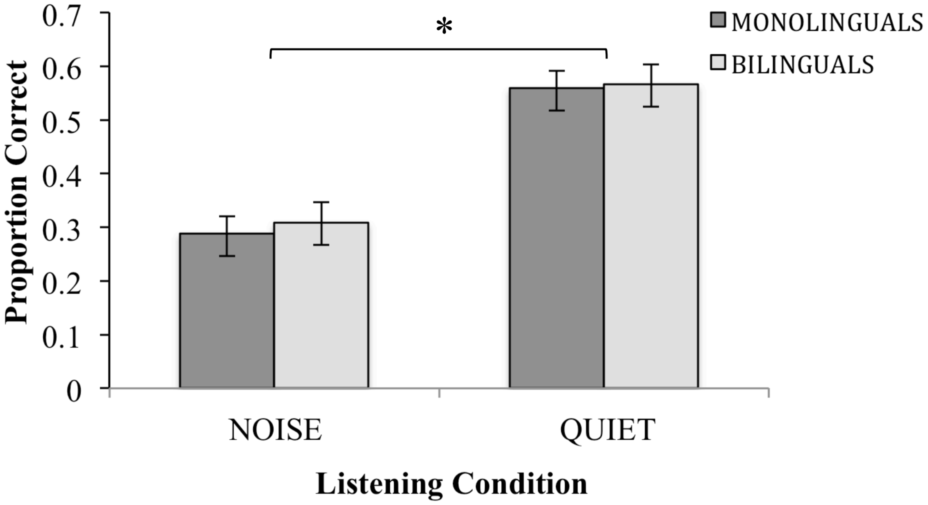

Figure 3.5: Proportion of correct responses produced by monolinguals and bilinguals in the word-learning task during quiet and noisy trials in Experiment 2. Error bars indicate standard error.

In general, participants in both groups were less accurate at learning new words when there was white noise present in the background during training (*M*=30% accuracy, *SD*=.19) than when the non-words were trained in the quiet condition (*M*=56% accuracy, *SD*=.23), and this difference was significant (*t*(62)= 9.08, *p*<.001).

RT data are shown in Figure 3.6. Four of the monolingual participants and 4 of the bilinguals had to be excluded from the RT analysis since they did not have an RT score for the two experimental conditions (since RT was only calculated for trials where a correct response was provided, if a participant produced a correct response during trials corresponding to one training condition, but no trials in the other condition, they were excluded from the analysis). Examination of these data revealed that, surprisingly, there was no main effect of listening condition (*F*(1, 54)=3.6, *p*=.06), although the trend was for items learned in noise to later be responded to more slowly. There was, however, a significant main effect of group (*F*(1, 54)=4.1,

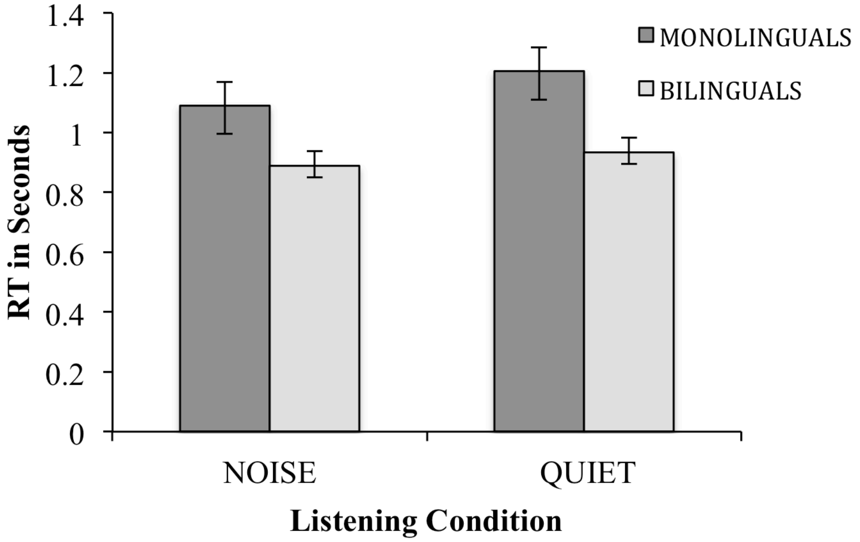

Figure 3.6: Response times for monolinguals and bilinguals during word-learning task in Experiment 2. Error bars indicate the standard error.

$p<.05$). The interaction between these two factors was not significant ($F(1, 54)=.27$, $p=.61$). This meant that while the listening condition in which the non-word was trained did not affect the amount of time necessary to produce a correct response during later test trials, the linguistic experience of the listeners did. In general, bilingual participants were quicker at providing correct responses during test trials ($M=.91$ sec, $SD=.25$) compared to monolinguals ($M=1.15$ sec, $SD=.49$), and this difference was significant ($t(54)= 3.34$, $p<.01$).

3.5 Discussion

The goal of this second experiment was to evaluate the notion that differences between monolingual and early-bilingual adults during speech processing in noise tasks might be associated with task demands. Findings from the word comprehension paradigm in Experiment 1 had suggested that bilinguals experienced more processing costs compared to monolinguals when there was noise in the background, and were therefore less accurate at comprehending speech that was presented in this condition. In the current experiment, monolinguals and bilinguals were asked to complete a language task that relied less on accessing previously stored lexical knowledge to identify words, and more on processing perceptual information to acquire new lexical terms. Data from the ANT indicated that the group of early-bilinguals in this experiment in fact possessed the cognitive advantages that have been previously associated with bilingualism. This was indicated by the fact that bilinguals had smaller RT costs (they required less time to achieve conflict resolution) during incongruent trials compared to monolinguals. Nevertheless, there was no correlation between bilingual processing efficiency in the ANT and accuracy (r=.19) nor RT (r=.24) scores in the noise condition of this word-learning-in-noise task. Some researchers have claimed that bilingualism is linked to having a greater working memory capacity and that this, in turn, leads to better non-word repetition abilities and word-learning skills in bilinguals compared to monolinguals (Papagno & Vallar, 1995). There were not, however, any differences in working memory; performance in the forward and backward digit span tasks was comparable across the two groups.

Analyses of the participants' performance during the word learning in noise task revealed that, not surprisingly, it was considerably more difficult for listeners to learn new words in the presence of noise than in quiet. However, this was equally the case both for monolinguals and bilinguals; differences in linguistic experience did not lead to greater (or lesser) accuracy during the task. Bilinguals were not only just as accurate as monolinguals across conditions, but in fact were overall faster at providing correct responses during test trials. This pattern of results differs from what was observed in the word comprehension task discussed earlier, where bilingualism was associated with lower proportions of correct word identification during noisy trials.

Taken together, these findings support the idea that depending on the language experience of the individual and the demands associated with the linguistic task, participants might weight information sources differently. To succeed in the present experiment, participants were mainly required to focus on the visual and auditory stimuli during training, store this information, and later recall it. Additionally, for non-words that were taught in the presence of noise, participants would have had to selectively attend to the target signal during training as an additional step. Given that all non-words followed phonotactic rules of English and corresponded to referents that would not have had a lexical equivalent in the bilinguals' other language, this task likely did not lead to the same lexical competition during word production that bilinguals experienced in the word recognition task (which relied more on stored lexical knowledge). The differences in the approaches that were necessary to succeed in each of the tasks would explain why bilinguals would experience processing costs in Experiment 1, but not in the current study.

Given that there were differences in cognitive abilities between the two groups, and that one of the original hypothesis was that this task might primarily rely on processing perceptual information and the use of selective attention skills, it was somewhat surprising that bilinguals were not more accurate than monolinguals in the noise condition. The assumption was that the cognitive control advantages previously associated with bilingualism - that are necessary to succeed at conflict-resolution tasks (e.g., focusing on a correct source of information while at the same time suppressing a potential source of interference), would be related to the selective attention skills needed for processing speech in noise. As discussed in the previous chapter, it is not clear what the links (if any) are between the skills necessary to complete the ANT and the skills necessary to process speech in noise. Since in the second experiment there was, once again, no correlation between performance in the two tasks, it is necessary to consider the possibility that the two mechanisms are independent from one another. It is also possible that the difficulty level in the noise condition was too high for a group difference to be observable. While participants in both groups did manage to learn novel words when there was white noise that was 2dB louder than the target speech (as indicated by the fact that accuracy performance was not at floor for either group in this condition), performance levels suggest that this was a very difficult task, and the cognitive advantages associated with bilingualism might not have been enough to generate a significant group difference at this noise level. Adjusting the degree of difficulty (e.g., using an easier SNR, providing additional training) could potentially lead to more drastic differences in accuracy across groups in this type of listening condition.

Given the pattern observed in the accuracy data, it was unexpected to find that bilinguals had overall faster RT scores compared to monolinguals. It is possible that bilingualism did lead to a facilitatory effect during word learning and that the accuracy measure was not sensitive enough to capture the effect. Additionally, while this word-learning task relied primarily on processing new perceptual information, it is possible that to some extent, retrieving the newly-acquired words during test trials involved accessing stored knowledge (even if it was information that was recently encoded); this process may have been subject to some level of interference (even more so for individuals with two linguistic systems). Under this account, while a bilingual advantage in cognitive skills (selective attention being one of them) may have facilitated their ability to learn words in noise, the greater degree of interferences in this group compared to monolinguals might have reduced this advantage - leading to similar accuracy scores across group.

But why were bilinguals faster than monolinguals to produce correct responses? One possibility is that bilingual individuals experience greater interference compared to monolinguals but only for items that are already part of an integrated lexical network. Newly-acquired terms that have not yet been permanently stored might not be subject to the same amount of interference. Previous findings (e.g., Gaskell & Dumay, 2003; Storkel et al., 2006) support this account and suggest that the integration of newly acquired lexical information requires additional time. For example, in the Gaskell & Dumay (2003) study it was only after 3-7 days that monolingual adults showed evidence of competition when they were asked to complete a lexical-decision task for recently-acquired words. Under this account, bilingualism might have facilitated the encoding of new words allowing participants in this group to then "hesitate" less when asked to recall the terms during testing. Additionally, since not enough time had gone by to allow the new words to be integrated into permanent storage, lexical competition would not have played as much of a role during this task. One way to test this hypothesis would be to add an additional testing session a week later and compare RT scores during the later and earlier sessions to see if response times increase for the bilinguals when there has been a longer delay.

Findings from the current study expand our understanding of bilingual word learning in a number of ways. First, prior work examining word learning in adults had suggested that bilingualism led to advantages during word learning (e.g., Kaushanskaya & Marian, 2009; Kaushanskaya, 2012). However, these findings came from studies that relied on paradigms that required participants to connect novel words with previously stored translation equivalents. Findings from the current study, which instead relied on the encoding of completely novel word-object associations, suggest that while bilingualism was not associated with higher accuracy scores, it did lead to faster correct responses. One could argue that the task implemented in the present experiment might more closely resemble the learning process that early-bilinguals (who are acquiring both languages simultaneously – as opposed to establishing one linguistic system first, and mapping a second one onto the existing one) undergo when expanding their lexicon. Therefore, it is informative to know how bilingual performance compares across different types of word-learning tasks.

Second, this work provides some of the first data associated with bilingual word learning in noise. Prior work examining stream-segregation abilities in bilingual adults has focused on speech comprehension, and has led to claims regarding an overarching bilingual disadvantage when processing of speech in noise. The current findings not only suggest that bilingual adults are able to acquire words in difficult listening conditions, but that they are not worse than monolinguals at doing so – that is, that the previously reported bilingual disadvantage does not extend to word learning in noise tasks.

Last, this study also contributes to the existing knowledge regarding monolingual adults' ability to learn words in noisy settings. As stated earlier in this chapter, there is a limited amount of work examining word learning in adulthood and even fewer studies that investigate the effect that noise might have on this ability. Given that monolinguals have been thought to lack some of the executive function advantages that have been associated with bilingualism (and that might facilitate processing competing information), one initial prediction was that monolinguals would show poorer performance than bilinguals during the present task. However, this was not the case. Monolingual adults were just as successful as bilinguals at acquiring novel word-object relations, even when there was competing noise in the background. One interesting aspect that should be further explored is whether there are differences in performance across noisy and quiet blocks during the immediate repetition of words (i.e., when participants were asked to repeat the word that they heard during training trials). One possibility is that noise simply makes it harder to hear the word during training (and this is why it hampers learning). If so, one would expect to see the difference between training trials in noise and in quiet in the immediate repetitions. On the other hand, if the presence of competing noise is instead associated with greater processing costs that make it more difficult to store the new lexical items, then one would expect to see a larger drop in performance between immediate repetition and later testing accuracy in noise versus in silence.

It is unclear whether the same patterns of performance across groups and across tasks would be present in young monolingual and bilingual children who are much less experienced with the language. In Chapters 3 and 4 I expand this work to examine whether or not there are age differences in how individuals with different linguistic exposures approach the problem space for learning and comprehending language.

Chapter 4: Early language comprehension in noise and the effect of linguistic experience

4.1 Overview

As discussed in the previous chapters, there are high task demands associated with processing speech in noise. Given that even adult listeners (who have had many years of experience across their lifespan using their native language) still find it difficult to process competing acoustic information, an interesting question to consider is how young listeners who are just starting to acquire their language(s) might approach stream-segregation tasks. Furthermore, it is unclear whether differences in cognitive abilities and linguistic organization associated with bilingualism in adulthood (that might influence performance on stream-segregation tasks) are already present in the same way during early childhood.

Chapters 2 and 3 provided an in depth examination of the patterns of performance displayed by monolingual and bilingual adults during word-recognition and word-learning in noise tasks. In this chapter, the focus is on the child literature and the exploration of age-related differences in performance during stream-segregation tasks, as well the role that linguistic experience might play on language comprehension in young children. Evidence is presented from a study designed to expand the findings obtained in Experiment 1 (examining comprehension in noise in adults) to monolingual and bilingual toddlers. This work is meant to provide a developmental perspective in the exploration of stream-segregation abilities in balanced bilinguals (and monolinguals) by examining whether patterns of performance identified in adulthood are present earlier in life.

4.2 Age-related differences in stream-segregation

Over the years, there has been a growing interest in examining stream-segregation abilities in young children. This area of investigation has been motivated by the fact that different research sources, including parental reports (Barker & Newman, 2004), measurements from infant rooms in hospital settings (Busch-Vishniac et al., 2005; Falk & Woods, 1973), and recordings of the auditory input received by a young child in different environments – including at daycare and during shopping trips (van de Weijer, 1998), suggest that young children often find themselves in noisy settings. One of the first sets of experiments to examine infants' word recognition in the context of background speech was carried out with 7.5-month-olds (Newman & Jusczyk, 1996). Infants were tested on their ability to recognize words that were produced by a female speaker, when the voice of a male talker was simultaneously heard in the background. During the task, participants heard the target voice repeating words in isolation, while the competing speech played either at the same intensity level (0 dB condition) or at softer levels (5 dB softer and 10 dB softer). Subsequently, passages were heard in the target voice and either contained the familiarized words or contained words that were not previously heard. Infants were able to identify words in the presence of noise (and listened longer to the passages that included the familiar words), but only with the softer noise levels; in the 0 dB condition children were not able to segregate the two streams of speech.

Follow-up studies with infants ranging from 4-13 months (Newman, 2005; Newman, 2009, Newman, Morini, & Chatterjee, under revision) have tested children's ability to recognize their own name (one of the first words that children acquire – Mandel, Jusczyk, & Pisoni, 1995) in the presence of different types of background noise (e.g., a single talker, multitalker babble, a single talker played backward, white noise that is modulated in amplitude or constant). Findings from these various experiments have indicated that there are in fact age-related differences associated with the processing of speech in noise. For example, young infants are better at segregating speech signals when there are multiple voices in the background than when there is a single voice (Newman, 2009), while adults show the opposite pattern (performing better with a single voice). A possible explanation is that a single talker's voice varies in amplitude over time, and adults are able to take advantage of such fluctuations by "listening in the dips" (Festen & Plomp, 1990; Wilson & Carhart, 1969). This is especially the case when the variation occurs in a slow, predictable manner (Gustafsson & Arlinger, 1994). Infants, on the other hand, do not appear to be able to benefit from the dips in the signal.

These age-related differences in performance have been associated with selective attention (i.e., focusing on those time periods or portions of the signal that are likely to be most beneficial), a cognitive ability that does not appear to be fully developed in young children (Bargones & Werner, 1994). However, this developmental work has mainly been carried out with monolingual infants, and hence the way in which background noise might influence word identification in young bilingual children remains greatly unknown.

4.3 Word comprehension in early childhood and the role of language experience

In order to understand spoken language, children must be able to remember and identify the patterns of sounds that make up words. Previous research with monolingual infants suggests that the ability to comprehend words starts to develop soon after birth, even before children start to produce their first words. By six months, children are able to understand words that they hear frequently, such as “mommy” and “daddy” (Tincoff & Jusczyk, 1999), as well as several other common nouns corresponding to body parts and food items (Bergelson & Swingley, 2012). Over the second year of life, there is an age-related gradual improvement in language comprehension abilities, with 24-month-old monolinguals being significantly faster than 15-month-olds at recognizing familiar words (Fernald et al., 1998; Hurtado, Marchman, & Fernald, 2007). Furthermore, individual differences in the ability to recognize words at this age appear to be associated with vocabulary development, with more “efficient” language comprehension skills being related to faster word learning (Fernald, Perfors & Marchman, 2006). Even though the rate and the timing of vocabulary growth varies considerably in monolingual children, typically by the third year of life children can understand hundreds of words (Fenson, Marchman, Thal, Dale, Reznick, & Bates, 2006).

Although prior work has examined vocabulary development in children being raised with different linguistic exposure, very few studies have documented how word-comprehension abilities in bilingual children compare to those of their monolingual peers. As I stated earlier, in order to succeed at language comprehension, the listener must store phonetic forms and their corresponding meanings. For bilinguals, these steps must be carried out for each of the two languages. Furthermore, the input that bilingual children are relying on to accomplish these processes is much more complex than what monolingual children are exposed to (i.e., bilinguals are receiving input in both languages). As a result, one might predict that early language comprehension skills would differ in monolingual and bilingual infants. Nevertheless, prior work suggests that this is not necessarily the case.

In a study examining word recognition in English monolinguals, Welsh-English bilinguals, and Welsh monolinguals, the bilingual group showed accurate recognition of familiar words in each language by 10 months, and this was comparable to the performance of the two monolingual groups who showed recognition at 9 and 11 months, respectively (Vihman, Thierry, Lum, Keren-Portnoy, & Martin, 2007). These findings were obtained both through behavioral measures, as well as neural recordings of event-related potentials (ERPs). In another study with slightly older children, ERP patterns that have been previously associated with the recognition of known words were recorded in Spanish-English bilinguals between 19-22 months (Conboy & Mills, 2006). Although there were differences in the latency and localization of the responses for word identification in the dominant compared to the less dominant language of exposure (suggesting that there might be differences in the organization of the two linguistic systems at the neural level), the overall findings can be taken as an indication that like monolinguals, bilingual children are able to recognize words in the second year of life. Last, there are some findings suggesting that there are strong within-language associations between vocabulary size and language comprehension abilities. Like monolinguals, bilingual children who have larger vocabularies in one language also show better word-recognition abilities in that particular language. Cross-language relations, however, are weak. In other words, vocabulary size and comprehension skills in one language do not appear to be associated with vocabulary size and comprehension in the other language, but the two factors are related within the same linguistic system (Marchman, Fernald, & Hurtado, 2010).

Taken together, these findings support the notion that both monolingual and bilingual children reach gross vocabulary milestones at roughly the same points in time, and that based on parental report (and contrary to claims that bilingualism leads to language delays), both groups develop receptive vocabularies that are similar in size (Pearson et al., 1993). Previous findings, however, do not answer the question of how linguistic experience might influence young children's comprehension of words in difficult listening conditions.

4.4 Experiment 3

This third experiment was designed to investigate the relationship between language experience and children's ability to rely on selective attention and stored lexical information to segregate competing auditory signals and achieve language comprehension in the context of noise. A version of the Preferential Looking Procedure (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987) was used to test monolingual and bilinguals toddlers on their ability to identify familiar words in white noise, as well as in quiet. The participants' caregivers were asked to complete the Language Development Survey (LDS; Rescorla, 1989), which relies on a checklist of words that allows parents to report the child's productive vocabulary. Caregivers also completed a general questionnaire (regarding demographic characteristics, child's health history and speech and hearing history), a Language History Questionnaire, and an SES questionnaire (which asked information about combined household income, highest education and parent-child interactions).

Method

Participants: A total of 44 children (22 monolinguals and 22 bilinguals) between the ages of 29 and 31 months (*M* = 30.1, *SD* = .65) recruited from the University of Maryland (*n*=21) and from the University of Toronto Mississauga (*n*=23) completed the study. Participants had no known developmental or physiological diagnoses. Data from an additional 22 participants were excluded for the following reasons: fussiness/crying (*n*=17), failure to meet language requirement (*n*=2), motor and language delays (*n*=1), equipment failure (*n = 1*), or experimenter error (*n*=1). The monolingual group included 11 males and 11 females who were born in the United States or in Canada, and who were being raised in monolingual households where English was spoken at least 90% of the time. Based on the LDS, monolingual children had an average of 231 words in their productive vocabulary (range: 13-309 words).

The bilingual group included 12 males and 10 females who were being exposed to a minimum of 30% and a maximum of 70% of both languages since birth (one of the two languages being English). These parameters were based on the definition of bilingualism used in previous child studies (Fennell et al., 2007). Language exposure was measured through a Language History Questionnaire, where caregivers were asked to provide estimates of the children's linguistic exposure, as well as the context in which the exposure was taking place (e.g., at home, at day-care, from television, etc.). Five of the bilingual participants had also been exposed to a third language, but only for 5% or less of the time. The language distribution for the language other than English is summarized in Table 4.1. LDS scores for the bilingual participants revealed an average English productive vocabulary of 208 words (range:

Language Background	Number of Participants
Arabic	1
Cantonese	3
Farsi	1
French	2
Greek	2
Gujarati	3
Polish	1
Punjabi	2
Spanish	5
Tamil	1
Urdu	1

Table 4.1: Language background distribution for the language other than English in the bilingual group in Experiment 3.

65-300 words). Groups were not expected to be matched in their receptive vocabulary, given that scores were only calculated in English (and not the two languages combined in the case of the bilingual group). Surprisingly though, there was no significant difference in LDS scores between monolingual and bilingual children ($t(42)=1.47$, $p=.15$), suggesting that participants in both groups had similar abilities in terms of their understanding and use of English vocabulary.

Additionally, both groups of participants were being raised in middle to high socioeconomic class homes (as determined by maternal education)[3]. On average, the monolingual children's mothers had completed 17.9 years of education, while the mothers of the bilingual children had completed 17 years. This difference was not significant ($t(42)=1.66$, $p=.10$). There is previous work suggesting that the linguistic input that children receive varies as a function of socioeconomic status (Hoff, Laursen, & Tardif, 2002), and that this in turn influences children's language development (Hoff & Naigles, 2002; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Naigles & Hoff-Ginsberg, 1998). Therefore, it was very important for the two groups to be matched in SES. This was accomplished by recruiting children from two locations, including one area where two languages are used by most members of the community (and hence where bilingualism is less correlated with SES – the Toronto area in Canada), as well as one area where most individuals speak a single language (the College Park area in Maryland).

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[3] Maternal education was used as the main measure of SES because it has been previously correlated with other indices of social class and because according to prior work it is a highly predictive component of SES when examining developmental outcomes (Noble, Norman, & Farah, 2005; Hurtado et al., 2007).

Stimuli: As in the adult experiments described in Chapters 2 and 3, the auditory stimuli for the child word-recognition in noise task consisted of a target speech stream and a competing noise signal. The speech stimuli consisted of short sentences instructing participants to look at an item on the screen, and included a familiar 2-syllable word (e.g., *apple*, *flower*) presented in sentence-final position and repeated 3 times per trial (e.g., Look at the *apple!* Can you find the *apple? Apple!*). All the speech stimuli were recorded by the same female speaker from Experiments 1 and 2 in a soundproof booth using the same procedure described in Chapter 2, but this time using child-directed-speech prosody. Target words were chosen based on English lexical norms for 30-month-olds (Dale & Fenson, 1996) to ensure that both the words and the objects that they represent were familiar to the children. Additionally, the words that were chosen were not specific to one dialect of English. Given that both American and Canadian children participated in the study, it was important to include words that did not differ across these two dialects.

The competing signal was once again white noise presented with a constant amplitude at approximately 70-75 dB sound pressure level (SPL) through speakers, in one of two possible SNRs (5 dB & 0 dB). This meant that the target speech was either 5 dB more intense than the background noise, or the same intensity as the competing noise. The two noise-levels were selected based on pilot work and were included in order to have a point of comparison and as a precaution in case the 0 dB noise-level turned out to be too hard for children to process. Audio files were edited in the same ways as in the adult studies and saved on computer disk.

The visual stimuli consisted of colored pictures of familiar objects that were comparable in size and overall shape, but differed in color (see Figure 4.1). All images were presented in pairs on a 58” TV screen. Between trials a short attention-getter (a laughing baby) appeared on the screen to provide participants with a break from the stimulus and to direct their attention to the center of the screen.

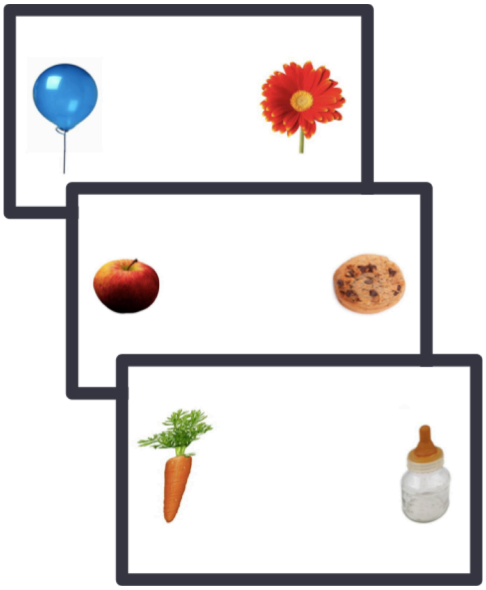

Figure 4.1: Familiar object pairings as they were presented during Experiment 3.

Apparatus and Procedure: The two testing sites had comparable child-testing facilities and equipment and had both been used to conduct Preferential Looking studies with children of the same age. Therefore, the apparatus was equivalent and the procedure was identical. Testing was conducted in a quiet room with participants seated on their caregiver’s lap four feet from the stimulus-presentation screen. A video camera positioned above (for the children tested in Maryland) or below (for the children tested in Canada) the screen recorded the child’s eyes throughout the entire test-session. An experimenter controlled the testing paradigm from a computer located right outside the testing room using E-prime stimulus presentation software (Psychology Software Tools, Inc., 2006). Each trial began with the attention-getter, which continued to play until the experimenter indicated via a mouse click that the child was looking at the screen. Participants then saw two pictures presented side-by-side on a white background. All trials were the same length (7500 ms), with the onset of the first repetition of the target word always occurring 2000 ms from the time that the images appeared on the screen. The speech itself started at least 1100 ms after trial onset, which meant that on trials presented in one of the noise conditions, the white noise was heard prior to the onset of the target signal. Speech stimuli were delivered at a maximum of 75 dB SPL though speakers in the room or though the built-in speakers in the screen. Each testing session began with the presentation of three familiarization trials (one for each object-pair), where the objects appeared on the screen and "generic" sentences were heard (*Look at that! Do you see that! How neat!*). These trials were included as a way of familiarizing participants with the images of the objects and with the general procedure that the task would follow.

A total of 21 trials were included in the experiment: three familiarization trials, and six test trials in each of three listening conditions (0 dB SNR, 5 dB SNR, and quiet). The position of the objects (left vs. right) and the target noun were counterbalanced across trials. The order in which the test trials were presented was randomly selected by the computer. During testing, caregivers were asked to wear noise-reducing headphones and to listen to masking music, in order to prevent them from inadvertently influencing the children's looking behavior.

Coding & Measures: Participant videos were coded off-line on a frame-by-frame basis using SuperCoder (Hollich, 2005). A highly trained coder recorded the durations of the participants' eye movements to the right or left object on the screen for all of the videos. A second coder coded 10% of the videos from each group. Values from the two coders were compared for reliability and resulted in correlations ranging from r =.99 to r =1.0. All coders were blind to the location of the target object. Data on the overall time course of eye movements were then linked to the auditory stimuli in order to calculate fixation duration and shifts in gaze between the objects that appeared on the screen. Data were analyzed for accuracy (based on looking times), as well as RT. Accuracy was defined as the amount of time that the participants remained fixated on the picture that corresponded to the target word, as a proportion of the total time spent fixating on either of the two pictures, averaged over a 367-1800 ms time window from the onset of the first repetition of the target word – across all trials of the same condition.[4]

RT was defined as the mean time required by the participants to shift gaze to the correct object during test-trials. Based on previous analyses of shift distributions in studies with young children (Fernald, Swingley, & Pinto, 2001), RT was only taken into account for trials in which participants were not looking at the target object at the beginning of the target word but instead shifted to look at the target picture within 367-1800ms from the onset of the first repetition of the target word. Trials in which the shift occurred prior to 367ms were not included in the analysis.

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[4] This measure has been consistently used in the child literature (e.g., Fernald & Hurtado, 2006; Fernald, Swingley, & Pinto, 2001) and is based on the notion that gaze shifts that take place before the 367 ms mark occur before the child has had enough time to process the auditory stimulus and generate a shift in gaze that is the result of lexical processing (Haith, Wentworth, & Canfield, 1993).

Results: Initial examination of the proportions of children's fixation patterns revealed that accuracy across the two noise-levels was virtually the same for both groups. Unlike the adult data in Experiment 1, there was no gradual change in looking proportions as the noise level increased (See Figure 4.2). Instead, the proportions of correct looks were comparable in the two noise conditions for both monolinguals (0 dB SNR: *M*=.70, *SD*=.14 & 5 dB SNR: *M*=.70, *SD*= .14) and bilinguals (0 dB SNR: *M*=.62, *SD*=.16 & 5 dB SNR: *M*=.63, *SD*= .16). Based on this pattern of results and given that there were only 6 trials in each condition in the child paradigm (and that some trials had to be dropped if children failed to orient to the screen), accuracy and RT data were collapsed across the two noise levels as a way of increasing the number of trials to be analyzed.

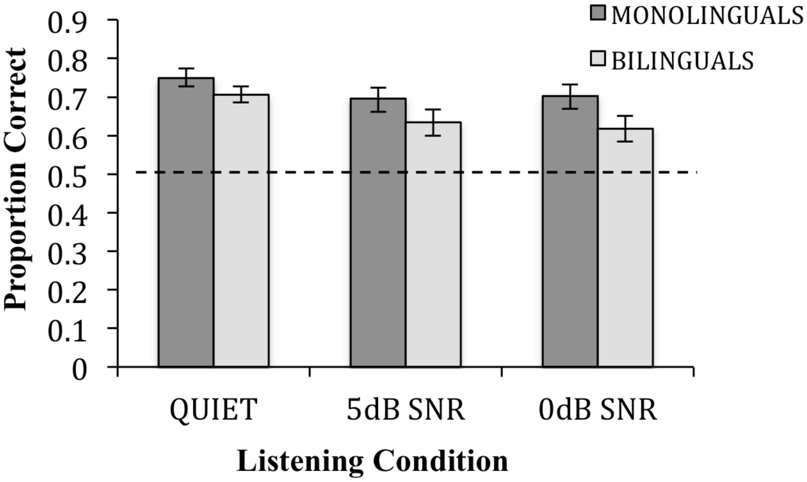

Figure 4.2: Proportion of looking time to the correct object in monolinguals and bilinguals across the three types of trials during Experiment 3. Error bars indicate standard error. Dashed-line at .5 indicates chance performance.

Accuracy scores for the combined noise condition and the quiet condition are displayed in Figure 4.3. Both groups performed significantly above chance in both the quiet trials (monolinguals: $t(21)=9.97$, $p<.001$; bilinguals: $t(21)=9.67$, $p<.001$) and the trials where there was noise in the background (monolinguals: $t(21)=8.61$, $p<.001$; bilinguals: $t(21)=4.70$, $p<.001$). A 2x2 mixed ANOVA with group as the between-subjects factor and listening condition as the within-subjects factor revealed significant main effects of listening condition ($F(1, 42)=614.2$, $p<.01$, $\eta_p^2 = .2$) and group ($F(1, 42)=4.35$, $p<.05$, $\eta_p^2 = .09$), but no significant interaction ($F(1, 42)=.62$, $p=.44$). While overall performance across conditions was above chance for both groups of children, these analyses suggest that 30-month-olds were more accurate at recognizing words in the quiet condition compared to the noise condition, and that accuracy scores for the monolingual group were higher than the ones obtained by the bilingual group in both noise and quiet. Nevertheless, the group difference was only

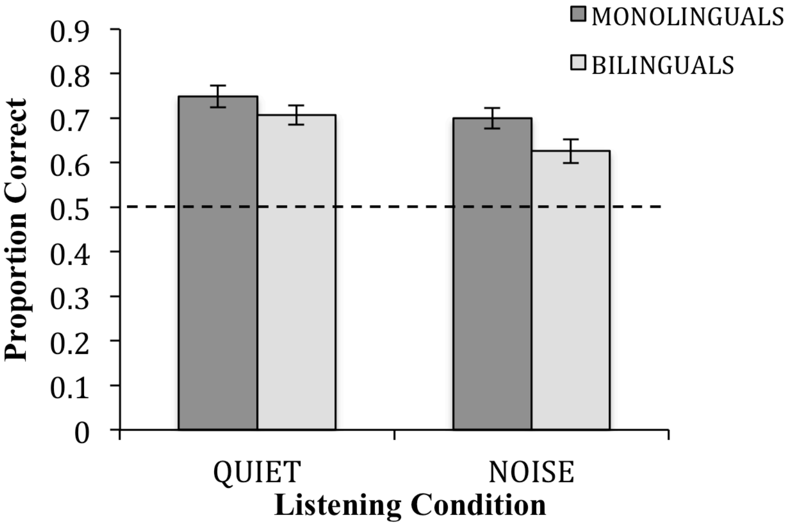

Figure 4.3: Proportion of looking time to the correct object in monolinguals and bilinguals during noise and quiet trials in Experiment 3. Error bars indicate standard error. Dashed-line at .5 indicates chance performance.

significant for the noise condition (*t*(42)=2.08, *p*<.05) and only minimal for the quiet condition (*t*(42)=1.66, *p*=.10).

The RT data is summarized in Figure 4.4. At first glance, it looks as if bilinguals were overall slower that monolinguals to recognize words both in quiet (bilinguals: *M*=.93 sec, *SD*=.19; monolinguals: *M*=.83 sec, *SD*=.2) and in noise (bilinguals: *M*=.91 sec, *SD*=.22; monolinguals: *M*=.86 sec, *SD*=.17). However, further analyses revealed that there were no major group nor condition differences in the amount of time required for infants to shift gaze to the correct picture. A 2x2 mixed ANOVA indicated that there was no main effect of listening condition (*F*(1, 38)=0.49, *p*=.83), no main effect of group (*F*(1, 38)=2.55, *p*=.11), and no significant interaction (*F*(1, 38)=.53, *p*=.47). Given that this measure can only be calculated on trials where the child shifted eye-gaze (from the distracter to the target object) during

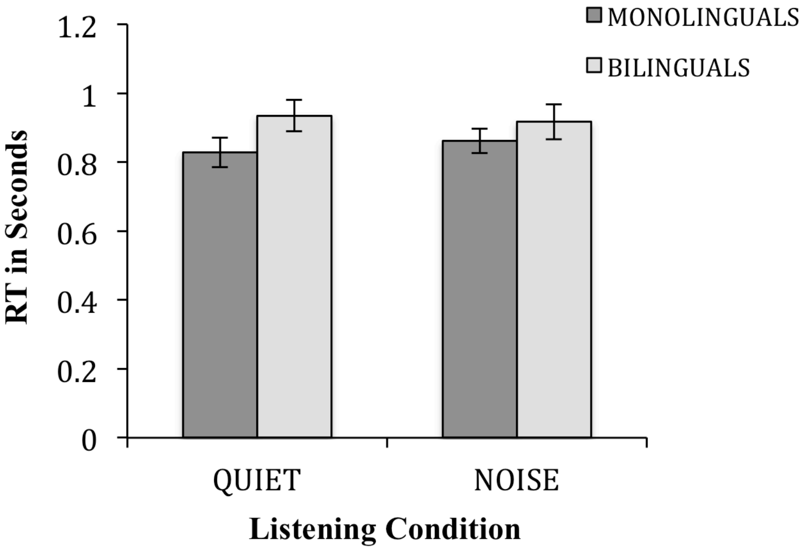

Figure 4.4: Response times for monolinguals and bilinguals during noise and quiet trials in Experiment 3. Error bars indicate standard error.

a critical period (here, 367-1800 ms after target-word onset), the analysis had to be conducted on fewer data points than the ones used to calculate accuracy. Two of the 22 bilingual participants did not have an RT measure for the two experimental conditions and were excluded from this analysis, and even among the remaining participants in each group, the reaction time data was based only on an average of three trials, compared to six trials for the accuracy data. This method of calculating response latencies, while widely used in the child literature, does lead to somewhat noisier data.

4.5 Discussion

This study was designed to examine the role of linguistic experience on the ability to understand speech in the presence of competing noise. Given the cognitive demands association with this type of task, and considering that monolingual and bilingual children are developing different executive function skills and are processing language in a different way, comparing these two groups at a critical age for language acquisition is of great interest. Furthermore, this experiment expands our knowledge of whether or not there might be developmental changes in the ability to process familiar words in noise that would lead to differences in performance between young children and adults.

Examination of the accuracy data revealed that, while performance was high for both groups during the task, bilingual children performed significantly more poorly than the monolinguals of the same age. The difference in performance across groups was larger when the listening condition contained noise, suggesting that bilingualism does not lead to better language comprehension in noise. However, given the lack of an interaction in Experiment 3, it is unclear whether the observed pattern of performance was due to the noise per se (i.e., whether group differences might be associated with bilinguals having greater difficulty perceiving the linguistic information – due to the noise being present), or whether it was a result of there being differences in the lexical system (e.g., weaker representations and/or more competition in bilinguals).

These findings are consistent with the patterns observed with adults in the work that was described in Chapter 2, as well as with findings from other adult studies (e.g., Mayo et al., 1997; Meador et al., 2000; Rogers et al., 2006). The current work provides evidence supporting the notion that, like bilingual adults, children who are growing up with two languages simultaneously have greater difficulty than monolinguals completing a task that relies heavily on accessing stored lexical knowledge to make sense of information that is difficult to understand.

Based on LDS scores it can be concluded that the observed group differences are not the result of differences in the size of the children's English vocabulary, since there was no significant difference in this respect between the two groups. Furthermore, there were no correlations between monolinguals' nor bilinguals' LDS scores and performance during the noise condition (r=.25 and r=.33 respectively). Therefore, other explanations must be considered. The input that bilingual children receive is being divided between the two languages, and so they are, in turn, exposed to each language less frequently than monolinguals are exposed to their single language. While children's productive vocabulary is still relatively small at 30 months, it also makes sense to consider the possibility that, even at this age, bilinguals already have more competitors in their lexical repertoire. The competing information between the two linguistic systems combined with the limited attentional resources (resulting from having to simultaneously rely on attention to block and access stored knowledge from both languages) likely lead to access pathways that are less automatic in bilinguals than in monolinguals. These are claims that have been introduced in the adult literature (Ecke, 2004; Gollan et al., 2005) and that are consistent with the patterns of results obtained in this experiment with bilingual children.

Given this explanation, it was surprising not to find any significant differences in RT. Nevertheless, as discussed in the results section, this measure might have been noisier; RT analyses were based on a more limited amount of data, due to the exclusion of trials that did not meet the gaze-switch parameters. Another possibility to consider is that an RT (and even accuracy) difference might have been more substantial with a higher noise level, or a type of noise that resulted in even more competition (e.g., background speech). In the present study, even the most challenging noise level yielded well-above-chance performance in both groups, suggesting that the level of difficulty could have been greater. Nevertheless, white-noise was chosen because it did not contain language-specific features that would share similarity with speech in a particular language, and the noise levels were selected based on pilot data with children of the same age, and because perceptually these noise levels appeared to be difficult to segregate.

There is a need to further explore how linguistic experience affects the mechanisms that are involved in language comprehension. Assuming that the patterns of performance observed in the present experiment are primarily due to bilinguals getting less exposure to each word, one might expect younger monolingual children (who have also had less experience with each word) to similarly show lower accuracy. This would suggest that poorer accuracy during comprehension is not associated with bilingualism per se, but rather, with the amount of experience that children have had with the lexical items. However, the fact that we find similar patterns of performance in adults leads to the question of why don't bilinguals "catch up" eventually? One possibility is that there might be more than one factor at play. The amount of experience with the words might be more critical for young children's comprehension, while the amount of lexical competition might be more critical for adults. One way to explore this account would be to examine the identification of words that are always produced the same regardless of the language (e.g., most bilingual parents probably use a single word for "mommy" or "daddy"). Assuming the issue described above is associated with reduced exposure to labels, then one would not expect to find the same pattern of results in bilingual children with words that are not language-specific. Instead, one would predict that when asked to look appropriately to mommy or daddy in the noise condition, monolingual and bilingual children would show similar performance. However, when asked to look at language-specific terms such as the ones included in the current experiment, the difference in performance between the two language groups would be present. Based on the current data, it is not possible to confirm nor disprove this claim. It is, however, possible to conclude that, as initially suspected, any cognitive advantages that result from bilingualism are not enough to outweigh the lexical disadvantages associated with activating a lexical system that includes more competition and/or weaker representations during comprehension.

Additionally, future work with bilingual children should ideally combine a cognitive measure (in addition to the language measures) that could be compared to performance on the listening in noise task. Given that children in the age group that was tested in this experiment have very limited attention spans, it was not possible to include an additional measure to assess cognitive development during the same session. This could be accomplished by testing a slightly older group. Since performance in the 30-month-olds followed the patterns observed in prior studies with adults, it would be justifiable to increase the age of the participants.

Taken together, findings from the present work support the notion that even in early childhood, the linguistic experience of the individual plays a role in the organization and accessing of stored lexical knowledge. This leads to differences in performance between monolingual and bilingual children (with bilinguals experiencing greater processing costs) during tasks that primarily require the listener to segregate competing sounds and in addition rely on top-down knowledge for comprehension. The next chapter will explore whether this group difference is task-specific and mainly attributed to the "type" of resources that a particular task demands, or whether the same differences in performance between bilingual and monolingual toddlers can be observed during word learning in noise.

Chapter 5: Early word learning in noise and the effect of linguistic experience

5.1 Overview

Findings from Experiments 1-3 suggest that linguistic experience does play a role in listeners' ability to process speech in noise. In particular, bilingual listeners have greater difficulty compared to monolinguals recognizing familiar words when there is a competing auditory signal, and this appears to be true both in toddlers as well as adults who acquired both languages early in life. However, group differences in adults appear to be linked to the type of task and the demands associated with it. When presented with a word-learning task (where training of novel word-object relations took place both in noise and in quiet), there were no group differences in accuracy between monolingual and bilingual adults, and bilinguals were overall faster than monolinguals at providing correct responses. Thus far, it is unclear whether the same task-related patterns identified in adults are also present in children – that is, whether the group differences identified with toddlers during the word recognition task will also be present during word learning that takes place either in quiet or in the presence of background noise.

This chapter provides an overview of prior literature examining the development of word-learning abilities in young children, and discusses how noisy listening conditions and linguistic experience may influence the acquisition of novel words during early childhood. Last, an investigation is designed to: (i) expand the findings obtained in Experiment 2 (examining word learning in noise in adults) to monolingual and bilingual toddlers, and (ii) explore whether the group differences in toddlers identified in the third experiment (during word recognition) are also present in a different type of task (one that relies more on processing perceptual information in the environment and less on accessing stored lexical knowledge).

5.2 Word learning in early childhood

From the time that infants start acquiring a language to the time they are fully proficient in it, a clear increase in vocabulary size takes place. Between 13 and 20 months of age, children experience a rapid growth in their lexicons (Benedict, 1979). By the time children reach the 30-month mark, they are reportedly producing approximately 500 words (Fenson et al., 1994) and likely understanding many more. In order to acquire new words, children rely on a number of specialized strategies and rules based on the linguistic input that they receive (Nazzi & Bertoncini, 2003). Even though (for the most part) the acquisition of words happens incidentally during every-day activities, it is necessary for children to complete a number of steps to ensure that new lexical entries are stored in memory and are later available to be accessed (Horst & Samuelson, 2008). To learn a word such as "apple" from the utterance "look at the apple!", children must first segment the target word from the continuous stream of speech. They must then identify the referent that corresponds to the new word. Next, they must encode the sequence of phonemes that make up the word. Last, they must store the new word-referent mapping (Capone & McGregor, 2005; Gupta, 2005; Oviatt, 1980, 1982).

On a daily basis, children encounter many familiar and unfamiliar words that they might or might not know the meaning of (Brent & Siskind, 2001). Previous work has suggested that young children develop word-learning heuristics to limit the number of plausible referents that can be assigned to a novel word. One such heuristic is the "mutual exclusivity constraint" (Merriman & Bowman, 1989). The notion is that children establish mappings between novel words and novel objects that they encounter in their environment. So if a child sees an unknown object along with a familiar item (e.g., a bottle) and hears a new word (e.g., "blicket"), the child will assume that the new label corresponds to the unfamiliar item. This particular disambiguating strategy has been observed in children as young as 17 months (Halberda, 2003; Markman, Wasow, & Hansen, 2003) and is reportedly guided by conceptual principles such as "an object should only be linked to one basic-level label" (Markman & Wachtel, 1988; Markman, 1992), and "there must be a word for every object" (Clark, 1987; Mervis & Bertrand, 1994; Mervis, Golinkoff, & Bertrand, 1994).

There are different skills associated with word learning in childhood; these include: (a) the ability for young children to learn relations between specific sound patterns and a concrete referent (e.g., Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola, & Stager, 1998; Werker, Fennell, Corcoran, & Stager, 2002), and (b) the ability to acquire word-referent relations that are more symbolic and that lead to the understanding that a label stands for a particular concept and can be used to refer to that concept in different contexts (Oviatt, 1980). Presumably, both types of word-referent associations are necessary in order for learning to occur. Furthermore, in real-world situations, these associations must be generated and stored relatively fast in order for vocabulary growth to occur at the speed that it does (i.e., children's vocabulary increases rapidly and it is not the case that children spend months or even weeks learning a single word). The amount of exposure/training that children require in order to establish word-object associations has been found to decrease as children get older. Twelve-month-old infants are able to learn word-object pairings after only 5 to 6 repetitions (Schafer & Plunkett, 1998; Woodward & Markman, 1998; Hollich, Hirsh-Pasek, & Golinkoff, 2000), but by the age of two, children rely on fast-mapping to accurately identify word-object relations after only a single exposure (Carey, 1978; Dollaghan, 1985). As discussed in an earlier chapter, fast-mapping has been described as the first stage of word learning (Woodward & Markman, 1998; Wilkinson & Mazzietelli, 2003; Spiegel & Halberda, 2011). During this stage, children benefit from environmental cues that help them to acquire partial information about the word and its referent (Dollaghan, 1985; Heibeck & Markman, 1987). This initial information then becomes more refined as children receive additional exposure to the lexical item (Carey & Bartlett, 1978).

It is important to note that fast-mapping does not necessarily lead to long-term retention of lexical entries. In a study by Horst and Samuelson (2008), 2-year-olds were only successful at retaining newly established relations between novel words and referents when the name-object mapping occurred via ostensive naming (e.g., the experimenter would hold up the target referent and say "Look, this is a *cheem*!").

When ostensive naming was not included (e.g., the child would just pick whatever referent they thought corresponded to the new label and if it was the correct one, the experimenter would then say "Yes, that's the *cheem*!"), children were initially able to successfully map novel labels onto novel referents, but after a 5-minute delay, children were no longer able to identify the connections that were earlier established. This appeared to be the case even when novel words were presented multiple times during training, and even when only a single item was trained. There are, however, several other studies supporting the notion that fast-mapping can lead to long-term learning in children of different ages (e.g., Carey & Bartlett, 1978; Dollaghan, 1985; Markson & Bloom, 1997). Taken together these findings suggest that while fast-mapping appears to be a necessary step for initial word-object associations to be established, the process of word learning is one that is influenced by a number of factors. Some examples of these include age, the amount and/or type of information that is provided during the initial encoding process, and possibly even elements associated with the linguistic experience of the learner and the listening conditions in which the fast-mapping takes place.

5.3 Acquiring new words in the presence of noise during early childhood

Even though receiving linguistic input in the presence of background noise is a situation that is not uncommon for young children who are acquiring a language (Frank & Golden, 1999; Barker & Newman, 2004; Busch-Vishniac et al., 2005), as discussed in the previous chapter, noisy listening conditions still lead to difficulties in language processing. Most studies examining children's stream-segregation abilities have relied on word or consonant identification tasks. This prior work suggests that children have greater difficulty discriminating words and sounds in noise than in quiet (Mills, 1975; Nábelek & Robinson, 1982; Elliott, 1995; Johnson, 2000; Talarico et al., 2007). This is presumably caused by the fact that the presence of a competing auditory signal results in the target signal being less audible and hence harder to understand. This increased difficulty in the ability to process the target signal is likely to affect not only the recognition of previously acquired words and sounds, but also the acquisition of new lexical entries, since it will be harder for children to encode the correct information during fast-mapping.

Furthermore, stream segregation and word learning rely heavily on the auditory and cognitive systems; these are two mechanisms that are presumably still developing during early childhood. For example, auditory thresholds are higher in younger children compared to older children and adults (Elliott & Katz, 1980; Berg & Smith, 1983; Trehub, Schneider, & Thorpe, 1988), and before the age of 5 years children have been described as having overall poorer skills associated with auditory selective attention (Bargones & Werner, 1994; Gomes, Molholm, Christodoulou, Ritter, & Cowan, 2000). The combination of immature systems and the added distraction that is generated by having a competing noise in the background are likely to make it harder for young children to focus their attention on the target information (while ignoring the background noise) while generating new word-object relations.

Most of the above assumptions are based on existing findings regarding children's ability to comprehend speech in noise, and on what is known about the general developmental time course of cognitive and auditory skills. There is still much need to examine this topic in the context of word learning. Word learning in noise is likely to be much more complex than recognizing words that are already part of the mental lexicon. The reason for this is that, in addition to the abilities that are already being implemented to successfully recognize familiar words, listeners must also rely on skills that will allow them to establish novel links and subsequently store these associations in memory. In addition, the presence of noise leads to a more limited attentional capacity (compared to when speech is heard in a quiet environment), since children are essentially in a dual-task environment: they must focus on the target speech and acquiring the new information, while at the same time relying on attention skills to inhibit the competing noise signal (see Mattys et al., 2012).

5.4 The effect of linguistic experience on early word learning

Language experience plays an important role in the development of skills associated with word learning. The majority of bilingual children grow up in situations where they hear both languages on a regular basis (e.g., each parent speaks a different language to the child, or one language is spoken at home, and the other language is spoken at day-care). These situations will lead to bilingual children often being exposed to multiple labels that correspond to the same referent (i.e., one word for each language). Differences in the linguistic exposure that monolingual and bilingual children receive are thought to be associated with variations in how the two groups acquire and implement word-learning strategies.

First, there are recorded differences in the age at which monolingual and bilingual children acquire certain word-object relations. For example, monolingual infants succeed at learning and recognizing phonetically similar words such as ‘‘*bih*’’ and ‘‘*dih*’’ by 17 months (Werker, et al., 2002). Studies with bilingual infants, on the other hand, suggest that it is not until 20 months of age that they start using phonetic information to direct word learning (Fennell, Byers-Heinlein & Werker, 2007). Researchers have commonly attributed these age differences primarily to the increased cognitive load that comes along with acquiring two languages simultaneously. However, other factors such as the amount and length of exposure to each language (e.g., Peña, Bedore & Zlatic-Giunta, 2002; Hemsley, Holm & Dodd, 2010) and the test modality that is being implemented to assess the learning of new words (e.g., Kohnert & Bates, 2002; Hemsley, Holm, & Dodd, 2006) have also been suggested to influence the size of bilingual children's vocabularies and the type of words (the composition of the lexicon) at different points throughout development.

Second, there appear to be differences in the rules that guide monolingual and bilingual word learning. A study by Byers-Heinlein and Werker (2009) compared children being exposed to one, two, or three languages on their implementation of the mutual exclusivity constraint. The results showed that monolingual children displayed a stronger mutual exclusivity bias compared to children being exposed to two or more languages. Furthermore, there was a systematic decline in the implementation of this strategy associated with the number of languages of exposure (i.e., the more languages being learned the less likely the child was to rely on mutual exclusivity during word learning). These finding have been explained by the fact that bilinguals (and multilinguals) acquire cross-language synonyms and hence break away from a strategy that relies on a one-to-one mapping between label and referent (Pearson, Fernandez, & Oller, 1993; Junker & Stockman, 2002).

Little is known about the role that linguistic experience might play in the acquisition of words in difficult listening conditions. One possibility is that monolingual and bilingual children will rely on different strategies and cognitive resources and that this in turn will lead to differences in performance between the two groups. Another possibility is that when presented with a word-learning task that does not rely on the implementation of specific rules (like the mutual-exclusivity constraint), that both groups (regardless of linguistic experience) will perform similarly.

5.5 Experiment 4

This last experiment investigated the role of linguistic experience on young children's ability to segregate competing auditory signals and selectively attend to the target signal in order to learn new word-object associations. This experiment manipulated the listening condition in which novel words were trained (i.e., words were trained either in the presence of white noise or in quiet), and once again relied on a version of the Preferential Looking Procedure (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987) to measure monolingual and bilinguals toddlers' ability to learn the new word-object relations. As in Experiment 3, the participants' caregivers completed the LDS (Rescorla, 1989), as well as the questionnaires described in the previous chapter (general questionnaire, a Language History Questionnaire, and an SES questionnaire).

Method

Participants: Forty-eight children (24 monolinguals and 24 bilinguals) between the ages of 29 and 31 months (*M* = 30.0, *SD* = .53) recruited from the University of Maryland (*n*=27) and from the University of Toronto Mississauga (*n*=21) completed the study. Participants had no known developmental or physiological diagnoses. Data from an additional 20 participants were excluded for the following reasons: fussiness/crying (*n*=9), failure to meet language requirement (*n*=3), equipment failure (*n*=4), or experimenter error (*n*=4). Children in the monolingual group were born in the United States or in Canada, and were being raised in monolingual households where English was spoken at least 90% of the time. This group included 12 males and 12 females who had an average productive vocabulary (based on LDS scores) of 235 words (range: 15-305 words).

All children in the bilingual group were being exposed to a minimum of 30% and a maximum of 70% of both languages since birth, with one of the two languages being English (these were the same parameters implemented in Experiment 3, as well as in prior literature – e.g., Fennell et al., 2007). This group included 8 males and 16 females. One of the bilingual participants had also been exposed to a third language, but only for 5% of the time. The language distribution for the language other than English is summarized in Table 5.1. Bilingual children had an average English productive vocabulary of 183 words (range: 14-287 words). A comparison of the

LDS scores suggested that there was a significant difference in English productive vocabulary between monolingual and bilingual children (*t*(46)=2.11, *p*<.05). This difference in vocabulary was not present across groups in Experiment 3. However, given that scores were only calculated based on children's production of English words (and not the two languages combined in the case of the bilingual group), finding this difference in the current experiment was not surprising.

Language Background	Number of Participants
Cantonese	1
French	2
German	1
Hindi	1
Indonesian	1
Malayalam	1
Polish	1
Punjabi	1
Portuguese	2
Russian	2
Spanish	8
Telugu	1
Urdu	2

Table 5.1: Language background distribution for the language other than English in the bilingual group in Experiment 4.

As in Experiment 3, a measure of SES was obtained based on maternal education. Both groups of participants in the current experiment were being raised in middle to high socioeconomic class homes. On average, the monolingual children's mothers had completed 17.4 years of education, while the mothers of the bilingual children had completed 16.7 years. This difference was not significant (*t*(44)=.83, *p*=.41). In order for both groups to be matched in SES, testing was once again conducted at a lab in the Toronto area in Canada, as well as in the College Park area in Maryland.

Stimuli: The auditory stimuli consisted of a target speech signal and a competing white-noise signal. In this experiment, the speech stimuli consisted of four 2-syllable non-words (*dekah, cheche, cudough*, and *joopee*). These words were generated by selecting four of the target words from Experiment 2, extracting the first two syllables of the words, and changing the stress from the second to the to the first syllable (e.g., *che-CHE-pa-tile* → *CHE-che*). Words were presented three times in isolation during each training trial and at the end of a sentence during test trials (e.g., look at the *dekah*!). Additionally, there was a generic sentence (look at *that*!), which was presented during one of the trials in the familiarization phase. All non-words followed English phonotactic rules and did not have a meaning in any of the other languages that the bilingual children were exposed to[5]. Speech stimuli were recorded by the same female speaker from the previous three experiments using infant-directed-speech prosody.

The same white-noise signal from the previous experiments was used as the competing auditory stream using a 5dB SNR during half of the training trials. This meant that the target-speech signal was 5dB more intense than the white noise. Both the target and the competing signal were edited in the exact same way as in the previous experiments and delivered at approximately 70-75 dB sound pressure level (SPL) via loud-speakers.

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[5] This was assessed by producing each of the words for the caregivers and asking them whether or not they had a meaning in the child's other language.

The visual stimuli consisted of 4 pairs (1 per block) of the same colored novel "creatures from another planet" used in the adult word-learning experiment in Chapter 3, but this time they were animated to move from side-to-side as a way of better capturing children's attention. Pairs of objects were chosen so that the items were comparable in size, but differed in the color and features so as to make them more easily distinguishable from one another (see Figure 5.1). Between trials, a short attention-getter (a laughing baby) appeared on the screen to direct participants' attention to the center of the screen. Additionally, between blocks, a short filler cartoon was displayed in order to give participants a break from the stimuli and as a way of maintaining their interest.

Figure 5.1: Novel-object pairings as they were presented during Experiment 4.

Apparatus and Procedure: Testing was conducted in a quiet room while participants sat on their caregiver's lap 4 feet from the stimulus-presentation screen. A video camera positioned above (for the children tested in Maryland) or below (for the children tested in Canada) the screen recorded the child's eyes throughout the entire test-session. The testing paradigm consisted of 3 phases (see Figure 5.2). Each block consisted of three phases, and one novel word (and its referent) were trained in each block. A total of 3 trials were included in the familiarization phase. During the first two familiarization trials, participants saw animations of two novel referents, presented one at a time on a white background for a period of 7000 ms each. During the third familiarization trial, the two objects appeared on the screen side-by-side while a generic sentence was heard, simply telling the participants to "look at that!". The goal with this phase of the experiment was to familiarize participants with the two referents as well as with the task. Following the three familiarization trials,

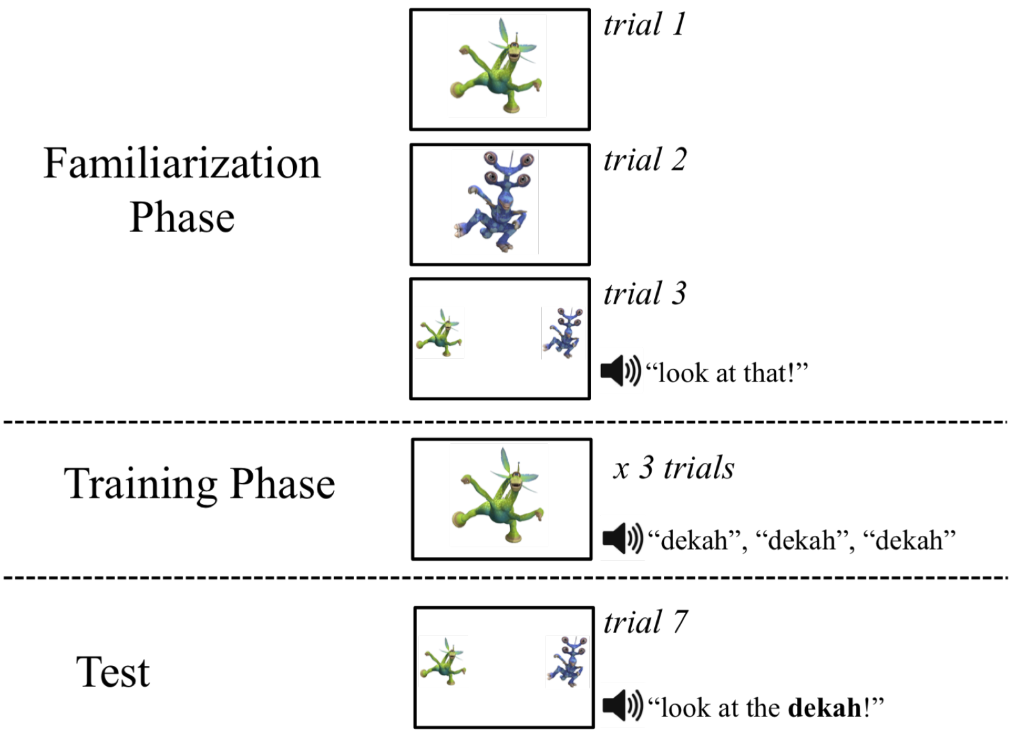

Figure 5.2: Sample of experimental design for one block in Experiment 4.

training began for one of the two referents. During each training trial, the object appeared on the screen for a total of 5000 ms, while three repetitions of the novel label were presented auditorily. Three training trials with the same referent were included in a block, for a total of nine repetitions of the target label. Immediately following training, one test trial was presented. During test trials, the two referents from the familiarization phase (one which was trained, and one untrained) appeared on the screen side-by-side for 6500 ms, while participants heard a sentence asking them to look at the target/trained object. If toddlers learned the correct word-object pairing, they should look longer at the target referent compared to the other object when instructed to do so (i.e., during target trials).

A total of four blocks following the same design but teaching different words were presented (two where training was in noise and two where training was in quiet). This meant that there were 28 trials included in a testing session. During training trials, the repetitions of the novel word were heard in isolation (as opposed to embedded in a sentence); this was because it is unclear whether or not listeners have greater difficulty dividing sentences into words in the presence of noise. In two of the four blocks, training occurred in quiet, while in the other two blocks training took place in the presence of a competing white noise. All objects were presented on a white background using a 58” TV screen. An experimenter controlled the testing paradigm from a computer located right outside the testing room using E-prime stimulus presentation software (Psychology Software Tools, Inc., 2006). The order in which the blocks (and hence listening conditions) were presented were randomly selected by the computer. The position of the target objects, the word-referent pairings, and the word-to-listening-condition selections were counterbalanced across participants. During testing, caregivers were asked to wear noise-reducing headphones and to listen to masking music, in order to prevent them from inadvertently influencing the children's looking behavior.

Coding & Measures: Videos of the participants' test sessions were coded offline in the exact same way described in Experiment 3. All videos were coded by one highly-trained coder, while a second coder coded 10% of the videos from each group. Values from the two coders were compared for reliability and resulted in correlations ranging from r =.98 to r =1.0.

Data were analyzed for accuracy, as well as RT. Accuracy was defined as the amount of time that the participants remained fixated on the picture that corresponded to the target/trained word during test trials, as a proportion of the total time spent fixating on either of the two pictures on the screen, averaged over the same time window used in Experiment 3 (367-1800 ms from the onset of the target word) across all trials of the same condition. RT was once again calculated based on the mean time required by the participants to shift gaze to the correct object during test-trials. RT was only measured for trials in which the shift to the target object took place within the 367-1800 ms window. Trials in which the shift occurred prior to 367 ms from target onset were not included in the analysis.

Results: Accuracy scores for the quiet and noise conditions are displayed in Figure 5.3. Surprisingly, initial examination of this data revealed that bilingual children's performance appeared to be better in the noise condition (*M*=.65, *SD*=.50)

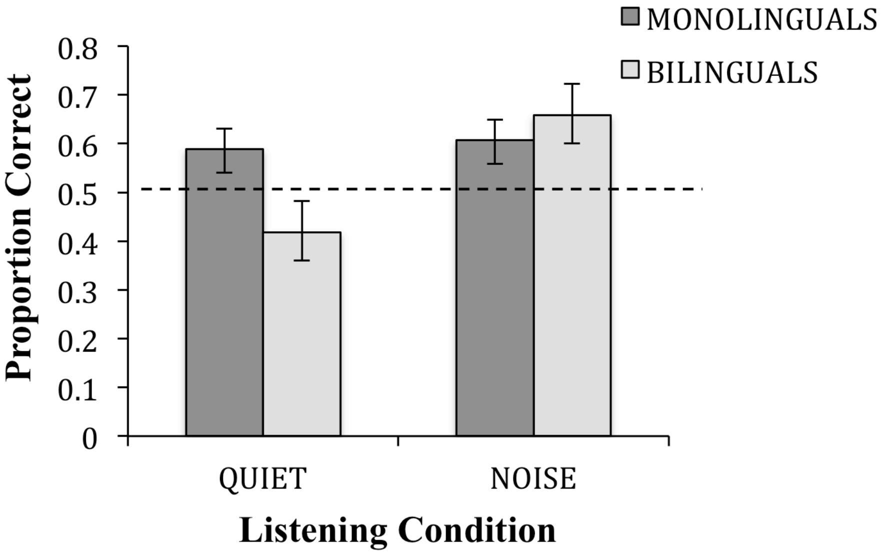

Figure 5.3: Proportion of looking time to the correct object in monolinguals and bilinguals across the two types of training trials in Experiment 4. Error bars indicate standard error. Dashed-line at .5 indicates chance performance.

compared to the quiet condition (*M*=.42, *SD*=.46), while monolingual children's performance was similar both in noise and in quiet (*M*=.60, *SD*=.40 & *M*=.59, *SD*=.37 respectively). A 2x2 mixed ANOVA with group as the between-subjects factor and listening condition as the within-subjects factor revealed a significant main effect of listening condition ($F(1, 46)=6.28$, $p<.05$, $\eta_p^2 = .1$), and a significant interaction ($F(1, 46)= 4.63$, $p<.05$, $\eta_p^2 = .09$), but no main effect of group ($F(1, 46)=1.15$, $p=.29$). This analysis suggested that, while language experience did not influence overall performance in the task, it did affect the ability for children to acquire new word-object associations depending on the listening condition. Specifically, monolingual children appeared to be significantly better than bilinguals at learning words in quiet ($t(46)=2.52$, $p<.05$), while in the noise condition the direction was inverted – with bilingual children showing slightly better performance than monolinguals; however, this latter difference was not significant ($t(46)=1.16$, $p=.25$).

However, during test trials, participants appeared to shift gaze to the target object, even before the label corresponding to that object had been heard. One possibility is that children were initially looking to the object that was "most familiar". In other words, even though both objects had been seen during the familiarization phase, the trained object had appeared on the screen three additional times (during the training phase) and when presented with the object-pair during test trials, children might have just been looking at the object that they saw more frequently. To address this possible bias, the accuracy measure was adjusted to rely on the difference in looking time to the target object before and after the target word was heard (specifically, looking proportions in the 367-1800 ms window after target onset MINUS looking proportions during the 1500 ms before the onset of the target word). This analysis yielded a "difference in looking time" measure that would more accurately reflect looking to the target object that resulted from hearing and identifying the word-object relation. The outcomes of this analysis are summarized in Figure 5.4. Monolingual children experienced an increase in looking time to the target object after hearing the corresponding label both in quiet blocks (*M*=.14, *SD*=.20) and in noisy blocks (*M*=.10, *SD*=.27) and both of these increases were significantly above chance ($t(23)=3.40$, $p<.01$ and $t(23)=1.85$, $p<.05$ respectively). Bilingual children, on the other hand, experienced only a small increase in looking time to the target object during blocks in the noise condition (*M*=.06, *SD*=.39) but this increase was not significantly above chance ($t(23)=.78$, $p>.05$). Additionally, bilingual children actually experienced a decrease in looking proportions to the target in the quiet condition (*M*=-.11, *SD*=.35). A 2x2 mixed ANOVA comparing group performance

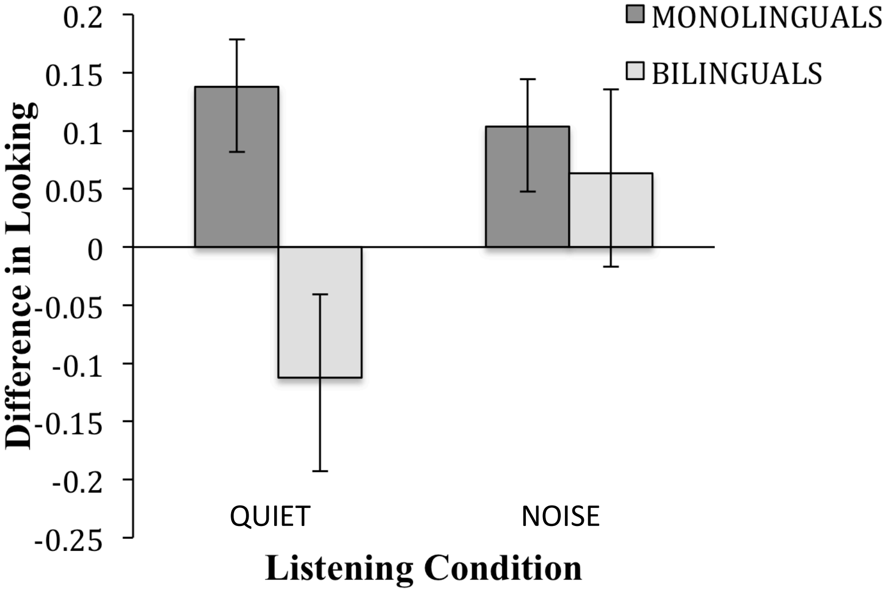

Figure 5.4: Proportion of looking time to the correct object before and after the onset of the target word in Experiment 4. Error bars indicate standard error.

across the two conditions revealed a main effect of group ($F(1, 46)= 5.52$, $p<.05$, $\eta_p^2 = .1$), but no main effect of listening condition ($F(1, 46)= 1.15$, $p=.29$) and no significant interaction ($F(1, 46)= 2.52$, $p=.12$). Monolingual children showed significantly better performance than bilingual children of the same age ($t(46)=2.28$, $p <.05$) – that is, while monolingual children successfully acquired word-object relations both in noise and in quiet, the bilingual participants were not able to do so.

The RT data are summarized in Figure 5.5. Given that (a) this measure could only be calculated on test trials where the child shifted their eye-gaze (from the distracter to the target object) during a critical period (here, 367-1800 ms after target-word onset), and (b) only participants who had an RT score for the two experimental conditions could be included in the analysis, this measure was based on considerably fewer data points. Sixteen of the monolingual participants and 17 of the bilinguals could not be included in this analysis. This high exclusion rate was due to the fact that there were only four test trials (two per condition) included per testing session, and as discussed earlier, children often tended to already be looking at the target object before it was named. A 2x2 mixed ANOVA indicated that there was no main effect of listening condition (*F*(1, 13)=2.32, *p*=.15), no main effect of group (*F*(1, 13)=.27, *p*=.61), and no significant interaction (*F*(1, 13)=1.22, *p*=.29). This pattern of results was not surprising, given the considerably smaller sample sizes that were included in the analysis.

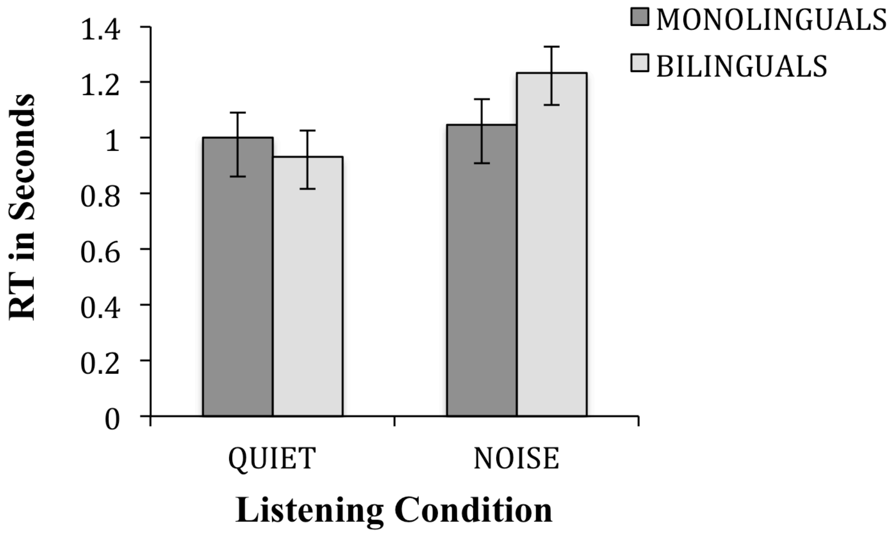

Figure 5.5: Response times for monolinguals and bilinguals during noise and quiet blocks in Experiment 4. Error bars indicate standard error.

5.6 Discussion

This fourth experiment was designed to investigate whether linguistic experience would influence children's ability to acquire new word-object relations in different listening conditions. Furthermore, it aimed to provide a better understanding of any differences in performance between monolinguals and bilinguals that might be associated with task demands and/or maturation. Data from Experiments 1 and 2 had suggested that monolingual and bilingual adults processed speech in noise differently depending on the type of task. While monolingual adults were better than bilinguals at understanding speech that was presented in a noisy environment, both groups showed comparable performance during a word learning in noise task. Data from the word-identification task in Experiment 3 suggested that at 30 months, monolingual children were overall more accurate than bilinguals of the same age at identifying familiar words, and this group-difference in performance was particularly clear when the listening condition contained noise.

In the current experiment, monolingual and bilingual toddlers completed a task that relied primarily on processing perceptual information, and selectively attending to the target speech in order to acquire new word-object associations (and relied less on accessing previously stored lexical information to identify words). Given the difference in task-demands between the word-recognition and the word-learning task, one might hypothesize that, in the current experiment, bilingual children might actually outperform monolinguals, especially in the noise condition. Nevertheless, examination of the accuracy data revealed that this was not the case. Bilingual 30-month-olds failed to acquire novel word-object mappings not only when they were trained in noise, but also when training occurred in quiet. Such word-learning failure might suggest that perhaps overall the task was too demanding, or that children did not understand what they were being asked to do. However, the pattern of performance of the monolingual children contradicts this conclusion. Monolingual 30-month-olds not only successfully acquired word-object pairings in the quiet condition, but they actually were able to do so (equally well) when there was noise in the background. The monolingual pattern would suggest (i) that this paradigm did lead to children successfully acquiring novel word-object relations, and (ii) that the noise level might not have been challenging enough to lead to observable differences across listening conditions. So why was there such a vast difference in performance across the two groups?

One possibility is that the differences in vocabulary (LDS) scores between monolingual and bilingual children could explain the group-differences in performance. Since bilinguals had significantly smaller English vocabularies compared to monolinguals (and possibly less knowledge of the language), this might have contributed to poorer performance during the task. Nevertheless, there was no correlation between bilingual LDS scores and accuracy in noise ($r=-.1$) nor in quiet ($r=.09$).

Another possibility was that monolingual children were more attentive than bilinguals during training trials and that this perhaps led the former group to being able to better acquire the word-referent relations. To examine this alternative, an independent-samples t-test comparing mean attention (defined as the total looking time in frames) during training trials was conducted across the two groups. This analysis revealed no significant difference in attention between monolingual and bilingual children ($t(46)=1.20$, $p>.05$). In other words, children in both groups were looking at the object that appeared on the screen during the training phase an equal amount of time. There was, however, one child in the bilingual group who looked at the screen during training less than 50% of the time. Prior work examining word learning with children (e.g., Puccini & Liszkowski, 2012) has suggested that participants who do not provide valid gaze (i.e., looking to the target object) for at least half of the time during training trials should be excluded. This is, of course, one consideration to keep in mind for future analyses, but it does not entirely explain the reported patterns of results.

Next, the bilingual children's linguistic and developmental profiles were examined in more depth, to identify any possible elements that may have led to poor performance on this type of task. There was a greater amount of variability in the input and linguistic development of bilingual children in this particular experiment (compared to the bilingual children in Experiment 3). For example, there was one child who had an LDS score of only 14 words. This was a considerably smaller English vocabulary compared to all the other children who completed the study, possibly suggesting that this particular child (whose performance during the task was at chance for both conditions) likely did not have enough English knowledge to successfully complete the task. Second, there was another child who, based on parental report, was receiving much more diverse linguistic input. At daycare, this child was being exposed to standard Canadian English. However, at home, the child's father spoke French most of the time, but on some occasions would speak French-accented English. The child's mother only spoke in English to the child, but she was originally from Romania and therefore spoke Romanian-accented English. Last, the child's grandfather who lived with the family was from Scotland and therefore spoke a Scottish dialect of English. Once again this child's performance was at chance for both conditions. Given that it is unclear exactly how exposure to different dialects and accents of a language (in addition to being exposed to an entirely separate linguistic system) would influence word-learning abilities, this child perhaps should not have been included in the analyses. Scenarios like these suggest that perhaps there is a need for a more strict inclusion criteria to minimize the amount of noise that may result from factors other than being exposed to one versus two languages.

Last, it is worth considering the possibility that bilingual children might rely on specific cues to help them achieve fast-mapping. Given that children who are being raised in bilingual environments hear individual words less frequently, and must therefore establish referent-word pairings with fewer repetitions, it is possible that they might develop coping mechanisms that rely on taking advantage of additional cues in the environment to help them establish these connections. Work with monolingual children has found that live social interactions as well as familiarization with novel objects facilitate learning and retention of new nouns and verbs (Roseberry, Hirsh-Pasek, Parish-Morris, & Golinkoff, 2009; Kucker & Samuelson, 2012). While these additional cues might simply make word learning in monolinguals "easier", they might be more of a requirement for bilingual children who have fewer "chances" to establish and store the new word-referent relations. During the present experiment, these additional cues would not have been available. This could explain why bilingual children were unable to succeed at the task.

Taken together, these accounts suggest that there is still a need to further explore this topic. As next steps I will run additional bilingual participants to replace data from children who either had extremely low productive vocabulary scores, those who did not accumulate enough looking during the training phase, and those who on a regular basis were exposed to linguistic variability that was not solely in the form of two languages (but also in the form of different accents and dialects). Furthermore, follow-up work with bilinguals could examine word learning using a paradigm where additional cues to facilitate word learning can be provided. One example would be to use real novel objects (as compared to cartoon images), so that it is possible to incorporate a familiarization-phase (prior to training) where participants can have the opportunity to play and interact with the objects.

Chapter 6: General discussion and conclusion

This dissertation set out to investigate whether linguistic experience and age play a role in how listeners approach basic language tasks such as word recognition and novel-word learning in different listening conditions. The motivation for this work came from the idea that depending on the task demands and on the cognitive abilities of the individual, monolingual and bilingual children and adults may weight information sources differently – leading to group differences in performance across tasks. Under this account, bilinguals, who have been shown to have stronger executive function skills but presumably have weaker lexical representations, would rely more heavily on signal processing and less on prior knowledge. This would result in advantages during tasks that rely primarily on processing perceptual information (e.g., segregating auditory signals and learning new words) while showing disadvantages in the use of previously-stored knowledge to recognize familiar words in noisy environments. Furthermore, there are presumably maturational effects associated with the development of cognitive abilities that result from bilingualism and that are necessary to perform different stream-segregation tasks. Therefore this work aimed to provide an important step forward to understanding the differences and similarities in how children and adults with different linguistic experiences approach every-day language-related challenges.

6.1 Summary of empirical findings

In this thesis, I presented findings from 4 different experiments with monolingual and bilingual adults and toddlers. Data from the language tasks across experiments are summarized in Table 6.1. In Experiment 1, I examined adult word-recognition abilities in noise and in quiet. Data from this experiment suggested that even truly balanced bilinguals (who acquired both languages before the age of 5 and who showed clear advantages in cognitive control) were less accurate than monolinguals at identifying familiar words that were heard in the presence of white noise. Previous studies examining bilingual speech comprehension in noise had

		QUIET		NOISE	
		Monolinguals	Bilinguals	Monolinguals	Bilinguals
Experiment 1 **Adult Word Rec.**	Accuracy	=		**.71 ***	.65
	RT	=		=	
Experiment 2 **Adult Word Learn.**	Accuracy	=		=	
	RT	main effect of group → Monolinguals: *M*=1.15 sec vs. Bilinguals: **_M_=.91 sec***			
Experiment 3 **Child Word Rec.**	Accuracy	=		**.70 ***	.63
	RT	=		=	
Experiment 4 **Child Word Learn.**	Accuracy (increase in looking)	**.14 ***	-.11	**.10 ***	.06
	RT	=		=	

Table 6.1: Summary of findings during language tasks across experiments. * indicates significantly more accurate/faster performance; = indicates no significant difference in performance across groups.

mainly been carried out with individuals who acquired their second language later in in life, yet findings from Experiment 1 were consistent with the prior literature suggesting that both early and late bilinguals experience greater processing costs compared to monolinguals during word-recognition-in-noise tasks.

In Experiment 2, I turned my attention to a different type of task, in order to examine whether the same group differences observed during word recognition, were present during word learning. No group differences were identified in terms of the accuracy with which monolinguals and early bilinguals acquired novel word-object associations. The only difference across groups was in RT scores, with bilinguals being significantly faster than monolinguals at producing correct responses during the task. This is one of the first experiments to examine bilingual word learning in noise, and the pattern of results suggests that the bilingual “disadvantage” identified during word recognition does not appear to be present during word learning. This finding challenges previous claims of an overarching processing cost during speech processing in noise associated with bilingualism, and suggests that on certain stream-segregation tasks, bilingual adults are not worse than monolinguals.

In Experiments 3 and 4 I implemented child versions of the word-learning and word-recognition tasks to examine 30-month-olds’ performance. Data suggested that during word recognition bilingual children performed significantly worse than monolinguals in the task. Furthermore, there was some indication that this disadvantage might be stronger when asked to identify words that were heard in the presence of white noise. Last, when presented with a word-learning task, monolingual, but not bilingual, toddlers were able to acquire novel word-object associations and this was equally the case regardless of the listening condition in which the word-object pairings were trained. In the following sections, I discuss the implications of these results.

6.2 Implications associated with task-demands

One of the main hypotheses that I set out to evaluate stated that bilingual advantages during speech processing in noise would depend on the particular task. Specifically, I predicted that **(i)** bilinguals might have weaker stored lexical knowledge and more lexical competitors compared to monolinguals, resulting in bilinguals' word comprehension in noise being poorer compared to monolinguals, and **(ii)** bilinguals might weigh bottom-up perceptual information more heavily (compared to stored/top-down knowledge) and have better selective attention skills, resulting in bilingual listeners being more skilled than monolinguals at learning new words in the presence of background noise. Findings from the different experiments included in this thesis suggest that differences in performance between monolinguals and bilinguals do vary as a function of the type of task.

In particular, the adult data support the notion that both linguistic experience and task demands influence the success with which listeners process speech in noise. Previous theories of bilingual language processing have suggested that there are different factors that are potentially at play. For example, during certain tasks (e.g., those where the individual must identify and produce lexical information in one language) bilinguals, but not monolinguals, must deactivate/inhibit the non-target language in order to successfully identify words in the linguistic system that is being targeted (Grosjean, 1997; MacKay & Flege, 2004). This extra step that bilinguals must complete leads to there being an additional demand on the attentional resources that are available for bilinguals to process speech. Researchers have suggested that this element might be particularly problematic for this group during tasks where there is an even greater processing load, as in the case of comprehension of speech in noise (e.g., Mayo et al., 1997; Meador et al., 2000). This would explain why during Experiment 1, bilinguals showed poorer accuracy compared to monolinguals when words were presented in noise, but not during the condition where there was a single signal to process (i.e., the quiet condition), and hence lower task demands.

Findings such as the one obtained in the adult language-comprehension task have led researchers to the conclusion that advantages associated with bilingualism are mainly seen for tasks that are not associated with speech-processing, since in this domain, bilinguals overall are more susceptible to processing costs compared to monolinguals (e.g., Rogers et al., 2006). Nevertheless, results from Experiment 2 suggest that this is not necessarily the case, and that in a different type of speech-processing task (one that deals with newly acquired lexical information) bilinguals might not be at a disadvantage. While the accuracy data from the word-learning task did not indicate that bilinguals were more accurate than monolinguals at acquiring word-object associations, it did reveal that bilinguals were just as accurate as their monolingual peers (even when there was noise in the background). Furthermore, when asked to recall the newly acquired terms, bilinguals were actually quicker to produce correct responses. As I discussed in Chapter 3, I believe that this could have been due to the fact that the newly-acquired words had not yet been incorporated into the permanent lexicon, and hence were not subject to the same competition/interference as the lexical items in the word recognition task.

To summarize, I had predicted that monolinguals would perform better on some tasks, and bilinguals on others. This was not, however, what was observed across the different experiments included in this thesis. Instead, I found that monolinguals showed better performance during the word-recognition-in-noise task, and the two groups were comparable during word learning in noise. I had chosen to examine these two types of linguistic tasks because they presumably differ in the degree to which listeners must rely on stored lexical knowledge in order to succeed. It is difficult to identify a language task that would rely even less (than word learning) on prior knowledge. Therefore, it is necessary to consider the possibility that a reversal in the pattern of performance (where bilinguals would outperform monolinguals) during linguistic tasks is not realistic and parity is the best outcome that can be observed.

6.3 Implications associated with age effects

Another goal of this thesis was to evaluate the hypothesis that there might be a maturational trajectory of the interaction between cognitive abilities and performance on word learning and word recognition (in monolinguals and bilinguals), resulting in differences in performance between young children and adults. Findings from Experiment 3 suggest that there are no observable age differences (between 30-month-olds and adults) during word-recognition-in-noise tasks. It is certainly possible that younger children (who are even less experienced with their language(s)) might show a different pattern of results. However, 2.5-year-old bilinguals (like adults) experienced greater difficulty compared to monolinguals when asked to access stored lexical knowledge in order to identify words that were difficult to understand due to background noise.

While these findings do not provide information regarding the exact point in the development when linguistic experience begins to play a role in the ability to comprehend speech in noisy environments, they do provide evidence suggesting that the effect of bilingualism on word identification in noise is likely present from toddlerhood and across the lifespan. As shown in Table 6.1, accuracy scores for toddlers and adults during the word recognition task are strikingly similar despite task difference (i.e., adults were asked to repeat the word that they understood, while children were asked to look at the picture that corresponded to the word that was heard). This similarity across age groups supports the notion that the ability to process familiar words in noise is already in place at a very young age and does not seem to change across development. Furthermore, these findings suggest that whatever role bilingualism plays on the acquisition of linguistic and cognitive skills, the effects appear to be in place since very early on. This would suggest that the development of these abilities are not primarily tied to elements such as vocabulary size (since this is something that changed over time), but instead might be associated with the early setup of the lexical system.

Similar results to the ones observed in this compilation of studies have been documented all the way into older adulthood, with elderly bilinguals experiencing greater processing costs compared to young adult bilinguals during word-recognition-in-noise tasks (e.g., Pichora-Fuller et al., 1995). Given the wide age-range in which this effect appears to be present, and given that individuals of different ages often find themselves in environments where there are high noise levels, this work has important real-life implications. For example, researchers have previously suggested that children who are learning English as a second language (and who have been shown to have difficulty processing speech in noise) would benefit from modifications of room acoustics (Crandell & Smaldino, 2000; Picard & Bradley, 2001). The current work suggests that these modifications would also be beneficial for bilingual children who acquired both languages early in life. Once could argue that acoustic modifications are akin to enhancing the signal-to-noise ratio. Therefore, one way to further explore this topic would be to compare speech processing in noise with an easier SNR in bilinguals and a harder SNR in monolinguals. Assuming my prediction is correct, one might expect for the two groups to perform similarly and for the bilingual "disadvantage" (during comprehension in noise tasks) to disappear.

Unfortunately, it is unclear whether the performance observed during the child word-learning task in Experiment 4 (where the bilingual group completely failed to acquire novel word-object relations) should be interpreted as being truly representative of bilingual toddlers' word-learning abilities. As I discussed in the previous chapter, it is possible that the patterns of performance that were recorded were the result of artifacts that were introduced during this particular investigation (e.g., characteristics of some of the bilingual participants that were included in the sample, or elements specific to the testing paradigm that was implemented). Therefore, before drawing general conclusions about the word learning patters of monolingual and bilingual toddlers (and how the abilities compare to those of adults) it is necessary to conduct additional testing to rule out some of the concerns that I have identified. However, assuming that this poor pattern of performance holds up, and that it is, in fact, characteristic of bilinguals' true word learning abilities in toddlerhood, some conclusions could be drawn. It might be the case that during word learning, bilingual children not only need to process the perceptual information in the environment, but that they are also being required to "inhibit" the competing linguistic system in order to store the new lexical entries in the correct lexicon (i.e., in the mental lexicon that corresponds to the target language). This process might use up some of the available resources leading bilinguals to have greater difficulty learning new words in general.

I have mentioned throughout this thesis that while (compared to monolinguals) bilinguals might have smaller vocabularies in each of their languages, overall (across the two linguistic systems) the size of the bilingual lexicon is equivalent to that of monolinguals. Nevertheless, this statement refers to words that have been successfully acquired and permanently stored. It does not, however, take into account whether or not the two groups might differ in terms of words that are "vaguely" known (i.e., words that have only been heard a couple of times and that are only starting to be learned). It is possible that in everyday life bilinguals experience slower learning than monolinguals, but that this difference is not large enough to be identified in measures (such as the LDS and other standardized vocabulary assessments) that rely on the number of words that have been "solidly" acquired by the individual.

Taken together, the data from the present set of experiments emphasize a more general finding that background noise influences the ability for listeners to successfully complete everyday language tasks. Both children and adults had greater difficulty learning and understanding words in noisy listening conditions. Given how frequently listeners encounter situations where speech is heard accompanied by noise, gaining a better understanding of the different ways in which noise influences speech processing is of great relevance not only for the study of language acquisition, but also for topics associated with learning more generally.

6.4 Future directions

Findings from this dissertation provided and initial step to better understanding the interaction between linguistic experience and performance during different speech-processing tasks. In order to expand the knowledge acquired through the present work, it is necessary to conduct additional investigations that will further examine the theories that I have proposed in this paper.

First, given the inconclusive findings in Experiment 4, it is important to further explore word-learning abilities in monolingual and bilingual toddlers. This could be done by testing additional participants in the paradigm that was used during this experiment, but also by developing other testing procedures that will make it possible to examine whether the two groups rely on different types of cues to accomplish word learning. This could include having a live familiarization-phase that would provide children with additional information about the novel referents. Given the difference in the input, and in particular the difference in the number of repetitions of specific words that monolingual and bilingual children might be exposed to, the hypothesis that bilinguals might rely on cues that are not “mandatory” for monolinguals (but that help bilinguals encode new information) to achieve the same learning appears to be worth exploring.

Second, it is necessary to further explore the role that linguistic experience plays on the mechanisms that are involved in language comprehension. One possibility is that bilinguals were less accurate at identifying familiar words in noisy conditions because they have had less exposure to each word. If this is true, it might also be the case that younger monolingual children (who have also had less experience with each word) would similarly show lower accuracy. Exploring this account would make it possible to determine whether or not poorer accuracy during comprehension is really the result of bilingualism per se, or whether it is truly about the amount of experience that individuals have had with the lexical items.

Third, in order to better understand how cognitive abilities that develop as a result of being raised in a bilingual environment play a role in performance during various linguistic tasks, it would be ideal to expand the investigation of the factors that were examined in the present work by a) combining additional cognitive and linguistic measures, b) examining the recognition and learning of other types of words, and c) investigating how different types of background noises might affect speech processing. In the current investigation it was not possible to include a cognitive task with the child participants. This could, however, be accomplished by testing slightly older children (who are likely to have longer attention spans).

Furthermore, only two specific linguistic skills were measured in this dissertation, yet language proficiency in real life involves much more than this. Individuals must not only learn and identify nouns, but they must also acquire other linguistic concepts (e.g., verbs). Given that other types of words function differently across languages, one might expect that there would be further differences in how monolinguals (who must only acquire one set of rules) and bilinguals acquire and identify words other than nouns (e.g., the use of path vs. manner verbs, which may vary across languages). Additionally, the type of noise might also play an important role in speech processing. For example, in the present investigation only white noise was used. This particular type of competing signal leads to energetic masking but not informational masking. Processing noise signals that result in information masking (e.g., a competing talker in the background) might involve relying on additional attention mechanisms. This could, in turn, lead to age-related differences in performance.

Last, another interesting area for future work would be to examine the role of linguistic experience on different types of learning. So far this investigation focused on lexical learning. However, it is possible that bilinguals and monolinguals might show a different pattern of performance in other areas (e.g., during fact-based learning which more closely resembles the type of learning that takes place in classrooms). This topic would, therefore, have important implications in the area of academic performance.

6.5 General conclusion

In conclusion, this investigation has provided evidence suggesting that linguistic experience does play a role in how individuals of different ages perform language-related tasks. However, bilingualism does not lead to overall poorer performance in linguistic tasks. While bilinguals might have greater difficulty compared to monolinguals identifying previously stored lexical knowledge in difficult listening conditions, they do not show the same disadvantage (at least in adulthood) during the encoding of new perceptual information. This might suggest that bilingualism leads to reliance on a different set of cognitive processes or on a different weighting of available cues – bilinguals seem to approach the tasks slightly differently, such that advantages/disadvantages are specific to the particular type of task.

Finally, I had initially introduced the idea that the same ability to select one source of information while suppressing a source of interference that has been associated with the "bilingual advantage" might be involved in speech processing in noise. However, the present work suggests that this is not necessarily the case – that is, it is not just that bilinguals are better at inhibiting all kinds of competing information. The pattern of bilingual performance across language tasks (at least based on the adult data) suggests that there are other elements at play. Bilingual listeners rely heavily on previously stored lexical knowledge, and so group differences are not just the results of representations being weaker, but are also associated with the system that bilinguals are relying on to access previously stored information. Therefore, it can be concluded that there are differences in the executive function abilities that listeners rely on when faced with listening-in-noise tasks versus those required to inhibit other sources of conflicting information (although on the surface they may appear to be the same).

Appendix A: Word lists from the CID W-22 used in Experiment 1

List 1	List 2	List 3	List 4
an	your	bill	all
yard	bin	add	wood
carve	way	west	at
us	chest	cute	where
day	then	start	chin
toe	ease	ears	they
felt	smart	tan	dolls
stove	gave	nest	so
hunt	pew	say	nuts
ran	ice	if	ought
knees	odd	out	in
not	knee	lie	net
mew	move	three	my
low	now	oil	leave
owl	jaw	king	of
it	one	pie	hang
she	hit	he	save
high	send	smooth	ear
there	else	farm	tea
earn	tear	this	cook
twins	does	done	tin
could	too	use	bread
what	cap	camp	why
bathe	with	wool	arm
ace	air	are	yet
you	and	aim	darn
as	young	when	art
wet	cars	book	will
chew	tree	tie	dust
see	dumb	do	toy
deaf	that	hand	aid
them	die	end	than
give	show	shove	eyes
true	hurt	have	shoe
isle	own	owes	his
or	key	jar	our
law	oak	no	men
me	new	may	near
none	live	knit	few
jam	off	on	jump
poor	ill	is	pail
him	rooms	raw	go
skin	ham	glove	stiff
east	star	ten	can
thing	eat	dull	through
dad	thin	though	clothes
up	flat	chair	who
bells	well	we	bee
wire	by	ate	yes
ache	ail	year	am

Appendix B: Nonword list used in Experiment 2

Target Words	Foil Words	
bibukadir	batibagobe	jugugochop
chechepatile	bejachubuf	jupobegif
dekabagom	bidutobom	kajibobole
jupitoduce	bopapotup	kepechepof
kutopechef	butitogot	ketijopert
tabetogobe	chabugupun	kigatachaf
	chachugokal	kijadachop
	chagakejis	kikuchepeve
	chakobekole	kobadubore
	chetagateg	kudopotire
	chetukopime	kugojochame
	chibutochid	pagijochod
	chichetitex	pebedachupe
	chobedakile	pegakebun
	chokukebare	pikicheburt
	dakujugir	popobiduce
	datipekode	puchakipin
	dijigochut	puchupipent
	dochagagize	pukabagade
	dokidutal	pukajugife
	duchipijar	tapugukot
	dudekajup	tatepagist
	gadipagale	tebukibob
	gedechobege	techibogule
	gibipagunt	titagubet
	gipabijem	tochupopabe
	gipechejel	tojachigave
	gokepetor	tojukided
	gopokebige	tokukuchive
	gugekipert	topejabot
	gujukojert	tuchichedupe
	jaguchajont	tudidojope
	jedokibile	tugukuchere
	jidakopuge	tukabagag
	jojujugif	tupadubuce
	jugatojert	tutibubith

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