Word learning and executive functions in preschool children: Bridging the gap between vocabulary acquisition and domain-general cognitive processes

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A thesis submitted for the degree of

Doctor of Philosophy

The MARCS Institute for Brain, Behaviour and Development

ARC Centre of Excellence for the Dynamics of Language

Western Sydney University

July, 2021

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Acknowledgments

I express my heartfelt gratitude to my supervisory panel and external advisors for their guidance, support and advice throughout my candidature. I thank my Principal Supervisor, Professor Paola Escudero, for providing me with holistic mentorship and advice throughout my studies since 2015 and invaluable learning opportunities throughout my candidature. My appreciation to Associate Professor Mark Antoniou for his advice and technical coaching on tasks’ programming. Huge thanks to Dr Laurence Bruggeman for her invaluable help that got me through the last writing stage.

All my gratitude to Dr Alba Tuninetti for her guidance and support from day one and for providing fundamental initial help on statistical analyses. I am deeply grateful to Dr Marina Kalashnikova for her advice and for hosting me in the Basque Centre on Cognition, Brain and Language (BCBL), providing me the opportunity to present my project and obtain feedback from international researchers.

I express my deep gratitude to each member of The MARCS Institute for Brain, Behaviour & Development for making me feel valued with their continued support. I am immensely grateful to the early childhood centres, families and all the children that took part in my research study; I definitely could not have done this study without their essential support.

I thank the Australian Government Research Training Program for awarding me a 3-year RTP Stipend Scholarship. I express my gratitude the ARC Centre of Excellence for the Dynamics for funding my research expenses and for awarding me a Mobility Grant to fund travel expenses to San Sebastian, Spain for a laboratory visit to the Basque Centre on Cognition, Brain and Language (BCBL).

Finally, I would like to dedicate this thesis to my family. I thank my beloved children Gloria Andrea and Adrian once again for being my life's engine and motive, and to my husband Alejandro for being supportive and understanding throughout my studies. I thank my parents for their trust in my abilities and their continuous love and appreciation.

Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

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Table of Contents

List of Tables

List of Figures

Abstract

Language development in children depends on domain-specific language mechanisms, biases and domain-general cognitive development (i.e., executive functions [EFs]). Additionally, both language proficiency and EFs underpin new learning and predict academic success and lifelong wellbeing. However, despite the intuitive assumption that EFs are involved in the development of language, the relationship between word-learning abilities and EFs is not fully understood. Therefore, the present thesis addresses this gap by examining novel word learning under three different scenarios integrating three main EF components.

The current thesis investigated 1) whether children learn and retain words differently depending on the word-learning scenario, and 2) whether EFs in the non-linguistic domain predict word learning in children. More specifically, the present study assessed the impact of three different word-learning scenarios and EF measurements on novel word learning outcomes in 4-year-old children in Greater Sydney, Australia. Participants were 47 children from diverse language backgrounds, including monolinguals (n= 28) and heterogeneous bilinguals (n=19).

Chapter 1 introduces the thesis and the literature review. Chapter 2 presents the thesis' motivation, research gap and design. This chapter also explains challenges that arose amid the COVID-19 pandemic and how these challenges were addressed. Chapter 3 provides an overview of common scenarios for word learning during childhood, paying special attention to disambiguation via Mutual Exclusivity (ME), Cross Situational Word Learning (CSWL) and word learning from audiovisual stories via eBook (eBook). In this thesis, these three scenarios were used in experimental settings and implicitly prompted children to associate novel words with their corresponding novel referents under different exposure conditions: i) ME - target novel word-referent pair presented with a familiar referent prompting fast-

mapping via disambiguation, ii) CSWL - target novel word-referent pair presented next to an unfamiliar referent prompting statistical tracking of target pairs across trials and iii) eBook - target word-referent pairs presented within an audio-visual electronic storybook prompting inference of meaning incidentally. Children succeeded at learning the new words above chance in all three conditions; however, performance was higher in the eBook and ME conditions compared to the CSWL condition.

Chapter 4 explored the structure of EFs in 4-year-old children by examining correlations between inhibition, flexibility and visuospatial working memory, as well as receptive vocabulary. Correlation analyses revealed that inhibition correlated with flexibility, but neither correlated with visuospatial working memory. This suggested that, at 4 years, the EF structure is bidimensional, with one dimension comprising flexibility and inhibition and the other dimension comprising visuospatial working memory. To assess the relationship between word learning and domain-general cognitive processes, Chapter 5 investigated the involvement of the EFs studied in Chapter 4 in the three word-learning scenarios examined in Chapter 3. This study did not reveal visuospatial memory, inhibition or flexibility as significant predictors of word learning in any of the word-learning scenarios. Finally, Chapter 6 provides a summary, discussion of the findings and limitations of the present thesis, and current and future research directions.

CHAPTER 1

INTRODUCTION

Vocabulary size is a crucial factor during early childhood as children's readiness for school largely depends on it (August et al., 2005; Oakhill & Cain, 2018). Vocabulary size is also a strong predictor of school outcomes (Asaridou et al., 2017; Whitehurst & Lonigan, 1998). School success is, in turn, one of the main indicators of positive achievement and future earnings (Karoly et al., 2006). A child's vocabulary greatly depends on their ability to learn new words (Carey & Bartlett, 1978; Samuelson & McMurray, 2017; Sénéchal et al., 1995). During development, children's accumulated early vocabulary knowledge and strengthening of their domain-general cognitive skills (i.e., executive functions, a set of processes that manage cognition and behaviour) provide stronger underlying tools for learning new words (Diamond, 2013; Korkman et al., 2001; Sénéchal et al., 1995).

However, growing up exposed to more than one language may be a more challenging word-learning situation than growing up with only one language. Bilingual children are concurrently exposed to words in two languages and receive less input in either language compared to what monolinguals receive (DeAnda et al., 2016; DeAnda et al., 2018; Pearson et al., 1993). Consequently, monolingual and bilingual vocabulary growth is likely to differ before starting formal schooling, with bilingual children often exhibiting smaller receptive vocabularies (Bialystok et al., 2010) and expressive vocabularies (Hoff et al., 2014) than their age-matched monolingual peers (Pearson et al., 1993; Poulin-Dubois et al., 2013). This may result in a striking disadvantage that often persists throughout life (Bialystok & Luk, 2012). This has implications for bilingual children from migrant backgrounds as the schooling system is likely to value proficiency in the community dominant language (i.e., English in Australia) over the bilingual's home language (August et al., 2005).

Despite the aforementioned vocabulary differences, some studies have found bilingual 7- to 8-year-olds may reach monolingual receptive vocabulary thresholds (Friesen et al., 2015; Jia et al., 2014; Pino Escobar et al., 2018). However, it is not well understood how bilinguals achieve such rapid word-learning progress despite starting schooling with lower vocabulary sizes and naturally less exposure to each of their languages. It has been suggested that it may be due to bilinguals' high efficiency in some cognitive aspects (see review in section 1.2.1). Therefore, it is important to investigate the specific word learning and cognitive skills of young populations with the ultimate goal to find out which abilities are likely to promote efficient lexical acquisition, and how children's individual linguistic experiences impact on word-learning outcomes. However, each word-learning situation is unique, providing different learning experiences and outcomes to learners. Therefore, in order to achieve a rigorous analysis of the cognitive processes involved in word-learning, it is crucial to examine the most common word-learning conditions to which pre-school children are exposed. These conditions vary on the amount of referential and contextual information available to support the new word learning.

The present thesis examined the involvement of both cognitive skills and vocabulary knowledge in the word-learning abilities of 4- to 5-year-old children as at this age, children in Australia get prepared to start school. During this preschool period, both vocabulary size and executive functions are critical for school readiness as they predict academic (Storch & Whitehurst, 2002) and cognitive (Asaridou et al., 2017) outcomes during the school years. Word learning is examined under three common word-learning conditions of different complexity, where complexity relates to the context and referential information available during word learning.

This chapter reviews the literature relevant for the remain of the thesis, starting with word learning during early childhood in different contexts, exposure situations and outcomes (Section 1.1.); exploring the suggestion that different word-learning conditions may fundamentally impact on the learning outcome. Then, a review of the main Executive Functions (EFs) in children (Section 1.2.) is presented, followed by the integration of EFs with word learning in children (Section 1.3).

1.1. Word learning in childhood: different contexts and outcomes

Children’s language exposure varies on many dimensions including the language (or languages spoken), number of talkers, quantity and quality of speech (Kuhl, 2004). Each particular experience will determine the number of languages a child is to become proficient in and more importantly, the level of language proficiency a child will achieve by the time they start their education (Byers-Heinlein & Lew-Williams, 2013; Hollich et al., 2000; Levine et al., 2020). Word learning plays a crucial role in child language acquisition (Golinkoff et al., 2000). It involves the ability to associate a spoken label to its meaning, helping children make sense of word sounds surrounding them (Carey & Bartlett, 1978; Markman, 1990). However, to learn a word, children first have to overcome several instances of word ambiguity, under different situations and contexts (Beck et al., 1983; Smith et al., 2014; Yu & Smith, 2007). This ambiguity can be illustrated with Quine’s (1960) well-known “gavagai” dilemma: imagine a scenario where a foreigner, naive to the local language, goes hunting with a group of tribesmen; when a rabbit hops by, one of the tribesmen shouts “gavagai”. At this moment the foreigner imagines a series of possible referents to link to the word “gavagai”, but is unsuccessful among the confusion. With this example, Quine presents the challenges that a naive learner faces in determining the meaning of this unknown newly heard word. This new word “gavagai” could refer to “rabbit”, “hopping”, “get it” or many other referents including superordinate and subordinate words of those possibilities or even something completely different.

In the case of children going through the word-learning process, this challenge meets with other developmental challenges such as the acquisition and strengthening of their cognitive and sensory abilities (Samuelson & McMurray, 2017). Furthermore, this same word-learning process also interacts with social environmental challenges such as exposure to two or more languages and the amount of language input received (Grosjean & Byers-Heinlein, 2018). However, children are typically capable of overcoming these challenges and learn to quickly extract meaning from new words and then recognise and use them in successive opportunities; incorporating them into their vocabularies (Byers-Heinlein, 2018; Kuhl, 2004).

A child’s first realisation of the link of a label and its referent, also known as fast-mapping, is the initial stage of the word-learning process (Horst & Samuelson, 2008). After this initial stage, children have to retain the word in memory, recognise it and use the word when needed. As such, fast-mapping and the ability to retain the word through time have long been studied as two fundamental and complementary phases of the word-learning process (Carey, 2010; Carey & Bartlett, 1978; Markson & Bloom, 1997; Waxman & Booth, 2000).

However, given that learning contexts in past word-learning studies have differed, these studies have observed different effects of fast-mapping on word retention. Carey and Bartlett (1978), in a seminal study, found that 3- and 4-year-old monolingual children were able to fast-map the word “chromium” as a label for the olive green colour after two exposure sessions to the novel word that occurred two days apart. Children recognised the word 7-to-

10 days after the first exposure session, and after a subsequent session they retained the novel association of “chromium” to the olive green colour for up to 6 to 10 weeks. Other studies have reported that 3-year-old children retain representations after fast-mapping for one week (Waxman & Booth, 2000) and up to six weeks (Markson & Bloom, 1997). In contrast, other studies have found that 3-year-old children and adults could not retain fast-mapped words for one week without mediating memory scaffolds (Vlach & Sandhofer, 2012), and that 2-year-old children could not retain fast-mapped words for even five minutes (Horst & Samuelson, 2008; Samuelson & McMurray, 2017). It appears that age and, by association, developing memory and cognitive skills may relate to children’s retention ability as well as the diverse complexity in terms of the context and the referential information available across studies.

1.1.1 Mutual exclusivity

If a learner is exposed to a novel label-referent association without conflicting information, the novel pair can be fast-mapped effortlessly (i.e., fast-mapping one label to one referent). However, if faced with ambiguous information, appropriate linguistic and cognitive mechanisms can help reduce the number of possible referents for a word (Halberda, 2003; Merriman & Bowman, 1989). One of these mechanisms is the Mutual Exclusivity (ME) assumption, which postulates that a referent is supposed to have a single label, helping the learner to establish one-to-one referent-label pairs (Liittschwager & Markman, 1994; Markman & Wachtel, 1988; Markman et al., 2003). ME can facilitate disambiguation, as children tend to assign an unfamiliar label to an unfamiliar referent rather than to a familiar referent (Markman, 1992; Markman & Wachtel, 1988; Merriman & Bowman, 1989). For instance, consider the situation whereby a child hears a novel label (e.g., where is the ***wug***?) and sees a visual stimulus of a novel referent (e.g., colourful rare object) along with one or more familiar referents (e.g., a ball). To resolve the ambiguity, the child may apply the ME assumption by inferring that *wug* is not the label that corresponds to the referent *ball* and therefore corresponds to the colourful rare object.

Early manifestations of ME are found in 10-month-old monolingual infants (Pruden et al., 2006); however stronger ME effects emerge at 16-to-24-months of age (Markman et al., 2003). Exposure to two or more languages influences the use of ME and retention outcomes during child development. As bilingual children are aware that one object can have two or more translational equivalents (i.e., at least one label per language), they commonly accept overlapping labels for a single referent, relying less on ME than do monolingual children (Byers-Heinlein, 2018; Byers-Heinlein & Werker, 2009; Kalashnikova et al., 2015). For instance, after seeing a familiar and a novel referent within a context of an interactive puppet show, 4- and 5-year-old bilingual and monolingual children were asked to choose one of the two objects using a novel label (e.g., "Can I have the kiv?"). The 4-year-old monolingual and bilingual children were similarly likely to choose the novel object and did not differ in ME performance. However, in the 5-year-old group, bilingual children relied less on ME but more on lexical overlap than their aged matched monolingual counterparts to disambiguate novel words (Kalashnikova et al., 2015). This study indicates differences in the use of ME under rich contextual cues (i.e., the puppet show); however, it is still unknown whether the isolated use of ME in a low complexity scenario and without contextual support would produce the same effects.

1.1.2 Cross-situational word learning

ME focuses on how children can resolve label-to-referent ambiguity in a single moment in time. However, when novel words are encountered in the context of several possible novel referents without contextual cues to indicate the word-referent pairing, children from early infancy can learn new words via cross-situational word learning (CSWL).

CSWL allows children to detect and learn new words by statistically tracking co-occurrences across situations and moments in time (Kuhl, 2004; Saffran, 2001; Yu & Smith, 2007). Studies have revealed that infants as young as 8 months use statistical tracking to detect and segment words from speech (Saffran et al., 1996), and at 12 months are able to associate a novel label with its referent (Smith & Yu, 2008). Recent studies have tested CSWL in preschool children (Hartley et al., 2020; Vlach & DeBrock, 2017, 2019). Although there is no comparison of novel word-learning outcomes between bilingual and monolingual children at this age, a study comparing statistical learning of non-linguistic sounds found no learning differences between monolingual and bilingual children (Yim & Rudoy, 2013). However, studies with adults point out evidence in two different directions. On the one hand there are findings that the bilingual experience improves abilities in word segmentation and learning from tonal Morse code and; on the other, there is no evidence for differences in CSWL outcomes between bilingual and monolingual adults for one-label-to-one-referent representations (Bartolotti & Marian, 2012; Poepsel & Weiss, 2016).

It has been shown that phonological short term and working memory play an important role in 2- to 5-year-old children's performance on CSWL tasks, but other cognitive abilities, such as inhibition and flexibility, may also have a role to play (Vlach & DeBrock, 2017). Children's linguistic background and social learning contexts are also likely to contribute to CSWL outcomes. Although the above factors have been investigated in isolation, no study to date has investigated the involvement of EF in bilingual and monolingual pre-schoolers when using the CSWL strategy to learn new words isolated from context.

1.1.3 Incidental learning from storybooks

While empirical research on ME exposes the learner to limited context (i.e., one or more familiar referents) and CSWL to no context (i.e., only novel referents are available), a child's natural experiences are full of context. Life situations are naturally dynamic and therefore an unknown label-referent pair is usually surrounded with familiar and unfamiliar labels and contextual information. Most laboratory tasks are somewhat artificial because they lack this contextual information that is present when a child learns label-object associations in the real world. A storybook paradigm may better approximate real life by providing context that ME and CSWL tasks do not.

Children most commonly acquire new words by inferring them from natural experiences and pedagogical settings (Beck et al., 1983; Broadbent et al., 2018; Joseph & Nation, 2018). In pedagogical settings, incidental learning through book reading is a powerful tool to learn new vocabulary in second and foreign language learning in classroom settings (Joseph & Nation, 2018; Joseph et al., 2014). Pre-literate children also benefit from picture storybooks to learn new words. Storybooks accompanied with narrations mimic real life experiences, providing clues that support children's word learning (Abel & Schuele, 2014; Flack et al., 2018; Ramachandra et al., 2011; Sénéchal et al., 1995; Whitehurst et al., 1988). An immediate retention test showed that 4-to-5-year-old children successfully associated novel labels with their referents incidentally from audio-visual narratives (Abel & Schuele, 2014; Ramachandra et al., 2011). This word-learning process is similarly experienced by groups of children who are read to during shared storybook reading time in day care settings (Flack, 2018; Flack et al., 2018; Flack & Horst, 2018; Horst et al., 2011; Sénéchal et al., 1995).

Despite the apparent successful learning effects of storybook reading, a comprehensive meta-analysis of studies of word learning from storybooks in 2- to 10-year-old children concluded that word-learning success was variable across studies, and suggested a possible publication bias favouring studies with significant effects (Flack et al., 2018). Across studies, children learned around 45% of the words presented to them, and learners' age did not significantly moderate learning effects, likely because researchers already considered participants' age when designing each experiment. Unfortunately, language background of participants was not considered within the analysed studies. Therefore, it is unknown whether storybook reading would have a differential word-learning and retention effect among monolingual and bilingual populations. Toub et al. (2018) studied the role of play in vocabulary growth in 258 preschoolers from different language backgrounds, including monolingual English, English second language learners and dual language learners. All children experienced vocabulary gains in the guided-play and story-reading conditions; however, results revealed no effects of language background. Although this study did not focus on incidental learning, results suggest that language experience may not significantly influence word learning.

Each of the three aforementioned word-learning strategies has a different level of complexity depending on the degree of ambiguity posed by the new word exposure scenario. Ambiguity and complexity of word-learning scenarios impact the word-learning outcome and also determine the child's capacity to maintain later retention of newly learned words (Vlach & Sandhofer, 2012).

Vlach and Sandhofer (2012) also showed that the quality and quantity of memory scaffolds provided in the word-learning experience influence fast-mapping and retention outcomes in 3-year-olds. Children were provided with one, two or three scaffolds to support memory as follows: i) saliency of the novel referent, ii) additional repetitions of the new label, and iii) productive generation of the label. Results showed that the more scaffolds children received, the better word retention they achieved. However, the scaffolds provided seem to be a way to reduce ambiguity in the word-learning situation. Therefore, integrating findings in a variety of learning scenarios is crucial to fully understand the mechanisms involved in handling ambiguity and contextual information when identifying and retaining newly learned words.

Furthermore, it is argued that domain-general cognitive processes, such as EFs, are crucial during the fast-mapping of new words and their subsequent word retention (e.g., Gathercole & Baddeley, 2014; Samuelson et al., 2017). Indeed, children's domain-general EF skills appear to be related to their language development. However, in studies assessing the relationship between EF's and language development have often tested receptive or productive vocabulary knowledge treating it as a measure of language development (e.g., Kaushanskaya et al., 2017; Weiland et al., 2014). Particularly, EF could relate to word learning as both constructs develop with age and appear to support each other throughout childhood development (White et al., 2017). The following section therefore reviews EF in children.

1.2. Executive functions in children

EFs are crucial for adapting efficiently to changes in the environment, and to manage basic daily tasks, such as planning, decision making, and problem-solving (Miyake et al., 2000; Zelazo et al., 2003). Different lines of research have classified EFs independently and therefore, the number and scope of EF components commonly differ across studies. Some include several components, such as strategic planning, attention, working memory, switching between mental sets, organised search, flexibility of action, suppression of impulsive responses, task monitoring and updating working memory (Costa & Sebastian-Galles, 2014; Hernández et al., 2013; Zelazo et al., 1997). Contrastingly, a prominent EF model by Miyake and Friedman (1998) classifies only three core EF components, namely inhibition (i.e., attentional control), shifting (i.e., flexibility) and updating (i.e., working memory). It is suggested that these three EF components overlap and they are used in conjunction when facing cognitively challenging tasks (Miyake & Friedman, 2012).

EFs develop early in life, and around the age of three children experience important leaps in their EF development (Carlson, 2005; Korkman et al., 2001; Petersen & Posner, 2012). Particularly, from 3 to 6 years of age children make the most dramatic gains in self-control, behaviours, and emotions (Carlson, 2005; Carlson & Meltzoff, 2008), and this development is progressive and incremental with age (Best & Miller, 2010).

Korkman et al. (2001) observed cognitive milestones and the effects of age using a battery of neuropsychological assessment tasks in 5-to-12-year-old children. The tasks included assessments for non-verbal EF, language, and verbal memory and learning. It was found that auditory attention correlated with verbal memory and learning, indicating potential relationships between non-verbal and verbal tasks. Because 5-to-8-year-old children showed more variability than 9-to-12-year-olds, EF development was deemed most sensitive to age within the 5-to-8-year window, probably due to the dynamic EF development during that time.

Typical EF development in children is related to positive progress in important social and cognitive skills such as social competence, moral conduct, school readiness and effective communication (Carlson & Meltzoff, 2008). Importantly, EF predict emergent literacy skills in pre-schoolers and reading competence throughout the school years (Bierman et al., 2008; Diamond, 2013; Diamond & Lee, 2011; Gathercole et al., 2004).

Executive functions may have a different path during early bilingual experience. Since both languages are simultaneously activated in the brain, bilinguals must constantly select the language in use while simultaneously suppressing unwanted interference from the non-target language (Bialystok, 2001; Bialystok & Werker, 2017; Costa & Sebastian-Galles, 2014). This may lead to bilingual disadvantages in some language-based tasks but is also proposed to be the basis of bilingual advantages in non-verbal tasks. Bilingual children often underperform monolinguals in receptive and productive language-based tasks. This has been attributed to bilinguals' reduced vocabulary size in each of their languages and to unwanted intrusion from the non-target language during verbal processing and retrieval. (Bialystok et al., 2008; Bialystok et al., 2010; Ivanova & Costa, 2008). However, this same linguistic intrusion is the basis of an enhanced inhibitory control. Inhibitory control is the capacity to focus on relevant information in the presence of disruptive additional information (Bialystok, 1999, 2015). As strenuous demands are placed on the inhibitory control system during bilingual language acquisition and development, it has been argued that bilinguals develop more efficient and robust attentional processes than monolinguals (Bialystok, 2015). However, not all experimental evidence supports this (Antón et al., 2014; Paap & Greenberg, 2013; Paap et al., 2015). Nevertheless, researchers ascribing for the bilingual advantage argue that bilinguals' enhanced processes are sensitive to non-linguistic tasks with a high degree of complexity (Barac et al., 2014; Barac et al., 2016; Zhou & Krott, 2018) but not to non-linguistic tasks of lower complexity and cognitive demands (Qu et al., 2016).

A non-linguistic bilingual advantage has been observed for inhibition in pre-school-aged (Barac et al., 2016; Martin-Rhee & Bialystok, 2008) and school-aged bilingual children (Park et al., 2018). This effect was revealed under conditions that place greater demands on EFs, such as interference suppression (i.e., a subcomponent of inhibition, involved in solving highly complex tasks with abundant conflicting information) (Martin-Rhee & Bialystok, 2008), and updating memory and flexibility (Carlson & Meltzoff, 2008), but not under conditions that place lower demands on monitoring resources.

Evidence from the neuroscientific literature suggests that the brain regions responsible for non-linguistic EFs considerably overlap with brain regions responsible for language control in bilinguals (Abutalebi & Green, 2008; Luk et al., 2010). Compatibly, measures of interference suppression activate linguistic EF brain areas in bilinguals (Luk et al., 2010), which may explain EF underlying mechanisms in language learning. Therefore, it is likely that word-learning scenarios of high (but not low) complexity may activate EF components enhanced by bilingual experience (e.g., interference suppression, memory and flexibility).

EFs may potentially predict the ability to learn words. However, this idea is still evolving, and so far only a few studies (conducted with monolingual participants) have suggested that this may be the case. These have found relations between memory processes and word learning via CSWL (Vlach & DeBrock, 2017) and ME (Kaushanskaya et al., 2014) and between memory and retention of newly learned words (Vlach & Johnson, 2013; Vlach & Sandhofer, 2014). However, the intervention of other components of EF (i.e., inhibition and switching) are also likely to underlie word-learning (Samuelson et al., 2017; Vlach & DeBrock, 2017).

It is also of interest to find out whether vocabulary proficiency supports both the development of EFs and lexical acquisition, as verbal proficiency appears to be associated with children’s performance in EF tasks (Carlson et al., 2004; Hughes & Ensor, 2007; Miller & Marcovitch, 2011). There is evidence of correlations between vocabulary size and ME (Kalashnikova et al., 2015), CSWL (Smith & Yu, 2013) and incidental word learning (Abel & Schuele, 2014; Sénéchal et al., 1995). Additionally, studies on word-learning retention with contextual familiarisation show that children with larger vocabularies retain newly learned words better than children with smaller vocabularies (Bion et al., 2013; Kucker & Samuelson, 2012; Samuelson et al., 2017).

Additionally, careful attention should be given to intersecting variables that influence both EF and lexical acquisition. Socio-economic status (SES), for instance has been shown to impact on performance in a number of behavioural studies (Costa & Sebastian-Galles, 2014; Valian, 2015). The factors comprised in the SES construct, such as parental education, income or cultural status, significantly influence children's cognitive experiences giving children from high SES an advantage (Christensen et al., 2014; Lee & Burkam, 2002). However, it is also suggested that bilingual proficiency reduces the SES gap enabling low SES bilingual children to achieve higher status later in life (de Abreu et al., 2012). Lexical acquisition is also impacted by SES in similar ways (Dwyer et al., 2019; Hoff, 2013); for instance, lexical gains are modulated by maternal education as children benefit more from play-based word learning programs when the mothers have achieved education beyond high school (Toub et al., 2018). In addition, asymmetrical gender balance across language groups could potentially impact in cognitive studies in childhood, as it has been proposed that around four to seven years of age girls display a better performance in many behavioural tests when compared with boys (Hyde, 2016; Palejwala & Fine, 2015). All these variables are considered in the present thesis.

1.3. Integrating children's EFs and word learning

To succeed at fast-mapping in real-life situations, a child needs to select and attend to the relevant information (i.e., target novel words and objects), and inhibit more salient irrelevant information. Additionally, the child will need to update memory while the situation and speech are changing from one topic/setting to another. Finally, the child will need to release current information being held in memory to allow new information. This whole process requires the three main EF components: inhibition, updating memory and shifting (Miyake & Friedman, 2012).

Therefore, the present thesis extends and elaborates on the idea that word learning is supported by domain-general cognitive processes, resulting in a more comprehensive EF model that includes inhibition, switching and memory interacting with vocabulary size. It is hypothesised that the involvement of EF components on children’s lexical acquisition depends on the specific word-learning strategies required in each learning scenario. Since non-linguistic EF performance is affected by the complexity of tasks, it is most likely that the ability to learn words is also affected by the complexity of the word-learning scenarios. The studies in this thesis therefore include word-learning scenarios of different degrees of complexity (as described below). They also include bilingual populations, because bilingualism modifies EFs, particularly those components demanded under high complex tasks (see Bialystok, 2017 for a comprehensive review).

CHAPTER 2

THE PRESENT STUDY

2.1. Introduction

The present study started in 2018 to explore bilingual and monolingual children's capacities to learn new words and the extent to which executive functions are involved in the word-learning process. In March 2020, however, the COVID-19 pandemic started. Researchers were affected in many ways, and those with parental responsibilities, like myself, were particularly affected, since home schooling increased significantly. Perhaps the worst effect of lockdowns for empirical research was the sudden closure of laboratories and the inability to collect data in setting such as schools, childcare settings, museums and public spaces. This situation also deeply affected my PhD thesis research, as I had only managed to collect a third of the data I had planned to collect based on a power analysis when I had proposed my original research questions. After finding some balance between my research duties and my familial obligations, my supervisor and I defined my options to move forward with my PhD thesis. There were only 9 months left to the end of my candidature in March 2021. We discussed the following three possible pathways: 1) wait a few months for COVID-19 to disappear, 2) assume the pandemic was here to stay and redesign my seven tasks for online delivery, and 3) reformulate my research question and study aims to work with my current data set.

Given that the pandemic was estimated to continue for quite some time, PhD candidates were strongly encouraged to think critically and come up with creative ways to produce a thesis within the originally estimated timeframe. Although the possibility of online testing was appealing, my experimental tasks could not be easily and quickly converted for online delivery, as I will explain further in the next section. Therefore, as conveyed in Chapter 1, I chose to reformulate my project based on the data that I had already collected. My revised research questions replaced the variable *bilingualism* with the variable *word-learning scenarios*, to examine a) whether children in general learn and retain words differently depending on the word-learning scenario, and b) if EFs in the non-linguistic domain predict word learning across scenarios. Below, I will detail my motivations for this choice. At the end of this chapter I will present a summary of each of my revised chapters.

2.2. Motivation of a new PhD thesis approach

When face-to-face testing restrictions were imposed I had collected face-to-face data from 47 participants of diverse language backgrounds. A power analysis conducted prior to starting data collection had shown that 150 participants were needed to perform regression analyses that included bilingualism as a variable along a continuum. Therefore, the bilingualism analysis was no longer possible due to lack of power. Fortunately, as we had assigned participants randomly to each of the three word-learning scenarios (rather than completing data collection for one scenario before moving on to the next), each scenario had been completed by a similar number of participants (ME = 15, CSWL = 17 and eBook = 15). A new power analysis (see Chapter 3) indicated that this was enough for a comparison between experiments.

An additional motivation for reformulating the research design was that it allowed me to further expand my repertoire of statistical analysis techniques. Shortly after testing had started in mid-2019, my supervisory panel and I endeavored to explore the best statistical analysis technique. This crucially allowed me to master statistical analysis in the now commonly-used program R (RStudio Team, 2020), whereas I had only used SPSS till then. Not having to collect any more data during the pandemic enabled me to consolidate and improve my ability to understand, replicate and further extend sophisticated linear mixed modelling in R (see Chapters 3 to 6).

Finally, the only way I could have maintained my original research question was through further data collection, which due to the COVID-19 restrictions would only have been possible online. Three reasons made online testing not viable: 1) the number of tasks, 2) the nature of the tasks, and 3) a direct comparison between data collected face-to-face versus online. There were seven tasks across two domains and I could not find a previous study that had used an online version of either task, which meant that programming each task from scratch was required, including a piloting period per task to ensure suitability for young children. Secondly, the nature of EF tasks requires a touch screen for ease of delivery with children. While implementing a touch screen task online is possible, it requires programming skills that I would not have been able to gain within the submission timeframe and with which our research institute's technical support team had no experience. Even if programming had been feasible, validation of each task would likely have taken at least three months per task, from implementation to participant recruitment through to data collection and analysis (nearly two years for all seven tasks).

Having explained the motivation for the choice of reformulating the aim of the thesis, I hope to have convinced the reader of the merit of each decision.

2.3. The current thesis

In Chapter 1 I have reviewed literature showing that children's ability to learn new words before entering school is crucial for academic success because vocabulary proficiency is a strong predictor of school outcomes (Whitehurst & Lonigan, 1998) and an indicator of positive achievement and future earnings (Karoly et al., 2006). We also pointed out that children rely on different mechanisms to acquire new words depending on the cues, context and linguistic information available; these may differ depending on the word-learning scenario, and the degree of reliance on certain word-learning mechanisms and strategies may also change from infancy to childhood (Hirsh-Pasek et al., 2004). To date, no study has provided a cohesive theoretical and experimental overview of the most common scenarios involved in word-learning during childhood and their implications. In Chapter 3 therefore we examine children's novel word learning in three word-learning scenarios, namely the ME assumption, a CSWL paradigm and an eBook. We suggest that linguistic information, context and different levels of ambiguity determine the extent of success on word learning.

Additionally, EFs are crucially involved in most areas of life during childhood (see Diamond, 2013 for a review). There is a growing need to determine the structure of EFs in children, as it would help to more effectively target EF training and early intervention. However, there is a lack of consensus on the structure of EFs in children. It has been mainly suggested that EFs in 3-6-year-olds are a unidimensional construct and that the regular EF components will differentiate as children's cognition develops with age, from around age 8 onwards (Akshoomoff et al., 2018; Carlson, 2005; Lehto et al., 2003). However, given that other theories suggest that children's EF structure may be either bidimensional (Monette et al., 2015; Scionti & Marzocchi, 2021) or three-dimensional (Garon et al., 2014) and given that those studies have been conducted with a relatively wide age range of participants (3 to 6 years), there is a crucial need to disentangle the referred EF structure. Considering that cognitive maturation occurs rapidly during the first years of age, Chapter 4 examines correlations of three non-linguistic EFs in children of a narrower age-range (i.e., 4-year-olds) to find out which EF structure best fits our sample.

Language abilities and EFs are foundations of academic learning, development and lifelong wellbeing and both constructs are tightly related (Kaushanskaya et al., 2017; Weiland et al., 2014). However, studies analysing the relationship between language and EF in children have typically used vocabulary knowledge as the language development measure but rarely have used word-learning abilities as such. Hence, it is crucial to investigate which EF components are related to word-learning abilities as it will clarify whether non-linguistic EF mechanisms underlie word learning in the different scenarios. Therefore, Chapter 5 examines the relationship between children's novel word-learning in three word-learning scenarios and non-linguistic EFs.

Finally, in Chapter 6 a full thesis summary is provided along with a discussion, implications and avenues for future research. We finally acknowledge limitations and how they could be overcome in the future.

CHAPTER 3

PRE-SCHOOLERS' WORD-LEARNING SUCCESS DEPENDS ON THE LEARNING SCENARIO: DISAMBIGUATION MEETS STATISTICAL LEARNING AND EBOOK READING[1]

3.1. Introduction

Vocabulary proficiency in preschool children (i.e., 4-6-year-olds) is a strong predictor of school outcomes (Asaridou et al., 2017; Uccelli & Páez, 2007; Whitehurst & Lonigan, 1998), and school success is, in turn, an indicator of positive achievement and earnings later in life (Karoly et al., 2006). A child's vocabulary depends greatly on their ability to learn new words (Carey & Bartlett, 1978; Sénéchal et al., 1995) and to retain them for later use (Samuelson & McMurray, 2017). Successful word learning implies overcoming different degrees of word ambiguity across contexts (Beck et al., 1983; Hirsh-Pasek et al., 2004; Yu & Smith, 2007). The way children overcome this challenge may depend on the word-learning scenario or condition they are presented (Byers-Heinlein, 2018; Samuelson & McMurray, 2017), but also on children's developmental stage (Golinkoff et al., 1994; Hirsh-Pasek et al., 2004) and maturation of their domain-general cognitive processes (Samuelson & Smith, 1998; Vlach & DeBrock, 2017).

[1] This chapter has been submitted for publication (Pino Escobar, Tuninetti, Kalashnikova, Antoniou & Escudero, under revision).

Indeed, it has been hypothesised that word learning does not depend on a sole mechanism but a number of multifaceted linguistic and cognitive processes (Levine et al., 2017). These processes may operate and modulate word learning individually or complementarily in different proportions throughout the lifespan (Golinkoff et al., 1994; Hirsh-Pasek et al., 2004). During the preschool years (i.e., from 3 to 6 years of age), children become experienced word learners, with six-year-olds acquiring nearly 20 new words a day (Hollich et al., 2000). This impressive word-learning rate results from engaging a combination of processes, mechanisms and strategies (Bion et al., 2013; Hollich et al., 2000; Levine et al., 2017; Samuelson et al., 2017).

In this study, we consider three common word-learning scenarios that have been widely studied in the language development literature and involve different levels of ambiguity and context for the novel words that are encountered. *Disambiguation*, by applying the mutual exclusivity (ME) assumption (e.g., Bion et al., 2013), takes place when a novel word and its novel referent are presented alongside one or more familiar referents. *Tracking of statistical co-occurrences* via cross-situational word learning (CSWL) (e.g., Suanda et al., 2014) occurs when a novel word is encountered in the context of several possible novel referents without contextual cues to indicate the word-referent pairing. And, *inferring meaning* from storybook narrations (e.g., Ramachandra et al., 2011) where a novel word is accompanied by rich audio-visual contextual cues that aid the connection of word and meaning. While previous studies have examined each scenario separately, we argue that a full grasp of children's word-learning abilities requires a thorough understanding of the mechanisms involved in each word-learning scenario and a direct comparison of performance across scenarios.

The first step to learning a word is to link a novel label to its referent, an ability referred to as *fast-mapping* (Carey & Bartlett, 1978; Horst & Samuelson, 2008). If a learner is exposed to a novel label-referent association without conflicting information, the novel pair can be fast-mapped effortlessly (i.e., fast mapping one label to one referent). However, if faced with ambiguous information, a disambiguation process helps reducing the number of possible referents for a word (Halberda, 2003; Merriman & Bowman, 1989). In a typical experimental disambiguation task, the learner is exposed to auditory stimuli of a novel label (e.g., where is the ***wug***?) and to visual stimuli of a novel referent (e.g., colourful rare object) along with one or more familiar referents (e.g., a ball). To solve ambiguity, the learner may apply the ME assumption by inferring that *wug* is not the label that corresponds to the referent *ball*. Therefore, the disambiguation effect is a manifestation of ME, and it refers to the learners' tendency to assign an unfamiliar label to an unfamiliar referent rather than to a familiar referent (Markman, 1992; Markman & Wachtel, 1988; Merriman & Bowman, 1989).

Importantly, children apply ME differentially depending on their lexical skills, language experience and their cognitive and attentional developmental stage (Bion et al., 2013; Davidson et al., 1997; Kalashnikova et al., 2014). Furthermore, children's capacity to retain newly learned fast-mapped words over time is not fully understood, with children younger than 36 months not able to retain new ME mappings successfully (Bion et al., 2013; Horst & Samuelson, 2008). Therefore, this word-learning mechanism may be useful for identifying the referent of a novel word in an ambiguous referential situation, but does not necessarily lead to long-term retention and learning of the novel word-object association (Kucker et al., 2015).

Despite many word-learning situations in the real world involving disambiguation in a single moment of time, there are instances where a child does not have familiar words and referents available but rather a myriad of unknown words and referents. This occurs naturally in children who learn a new language in a new country, but it is also common when children encounter a new activity or environment. It has been proposed that in these situations, children are able to learn new words via CSWL by statistically tracking new labels to referents co-occurring across situations and moments in time (Yu & Smith, 2007). CSWL studies commonly expose the learner to only unfamiliar labels and visual referents without any familiar contextual support (Smith & Yu, 2008; Vlach & DeBrock, 2017, 2019). For instance, in each trial learners are shown two novel referents on the screen, one of them being a target referent (e.g., Object A) and the other a foil referent (e.g., Object B), while simultaneously being exposed to two novel labels (e.g., *dit* and *bon*). The correct association between each label and referent is not apparent until the target label-referent pair (e.g., bon – Object A) appears together in successive trials among various other foils. After being exposed to various labels and referents, the learner therefore tracks the statistical information and identifies the correct label-referent associations across multiple trials.

Although CSWL abilities have been observed from infancy (Escudero et al., 2016; Kuhl, 2004; Saffran, 2001), word learning via CSWL paradigms improves with age. For instance, while 3-year-olds' performance was just above chance (Vlach & DeBrock, 2017, 2019), 5 and 6-year-olds showed better performance in a CSWL paradigm (Hartley et al., 2020; Vlach & DeBrock, 2017, 2019). In addition to age, successful learning depended on the levels of contextual diversity surrounding the target words during the word-learning exposure phase rather than age per se (Suanda et al., 2014). This was demonstrated by Suanda et al. (2014) who introduced three levels of variability to the set of non-target words and referents pairings (i.e., foil pairings) co-occurring with the target pairings in a CSWL task, terming this manipulation as *contextual diversity*. The levels of variability depended on the diversity and the frequency with which the foil pairings co-occurred with the non-target words. In the three conditions one foil co-occurred with one target word-referent pairing; however, in the high diversity condition, the target pairings co-occurred with different foils each time, in the mid diversity condition, each foil appeared twice, and in the low diversity condition, each foil appeared three times. It was found that the high diversity condition led to more successful word-learning performance compared to the low and mid diversity conditions.

ME and CSWL are typically tested in the lab using paradigms that provide restricted or no context surrounding the target stimuli. In every-day experiences, children learn words in rich contexts with many possible referents, which can be mimicked in the lab by exposing learners to storybooks along with narrations (Abel & Schuele, 2014; Flack & Horst, 2018; Ramachandra et al., 2011). Children can successfully learn words from book reading, but also from hearing audio books accompanied with pictures. Ramachandra et al., (2011) exposed 4-to-5-year-old children to an audio-visual storybook containing novel words among novel referents and familiar words, and showed that children could successfully associate novel words with their referents from hearing narrations combined with visual input, which was demonstrated at an immediate retention test. However, a comprehensive meta-analysis of word learning in 2 to 10-year-old children including published and unpublished studies concluded that the word-learning success from sharing storybook reading was highly variable across studies, suggesting a possible publication bias favouring studies with significant effects (Flack et al., 2018). Across studies, children learned around 45% of the words presented to them, and learners' age did not significantly moderate learning effects, likely because researchers already considered participants' age when designing each experiment (Flack et al., 2018). The authors concluded that audio-visual narration may promote correct word-referent associations only when certain conditions are appropriate, including the style and context of the narrative (Horst, 2013; van den Broek et al., 2018), the number of novel target words, the number of repetitions of the story (Horst et al., 2011; Read & Quirke, 2018), the characteristics and features of the book (Strouse et al., 2018), and its illustrations (Takacs & Bus, 2018). Therefore, it remains unclear whether the word-learning success in Ramachandra et al. (2011) was due to the narration quality or to the particular characteristics of the word-learning paradigm used, namely introducing the novel words one at the time couched in story-blocks with five repetitions of the target word. We know so far that differences in results among storybook paradigms are most likely not due to the storybook's delivery format (e.g., paper printed vs electronic stories, Gaudreau et al., 2020; Reich et al., 2016). Indeed, reading tablet-based simple ebooks were found to be as efficient or sometimes more efficient than reading paper printed books to increase receptive vocabulary in 3-to-5-year olds; however this was not the case for heavily animated or game-enhanced tablet-based eBooks as they may lead to cognitive overload. Interestingly, the interaction modality (e.g., online vs face-to-face) does not affect the outcome either, as word learning from an online administered eBook was found being as good as learning from a face-to-face administered eBook (Escudero, Pino Escobar, et al., 2021). The challenging differences, therefore, lie in the content of the story, the quantity and quality of the narration, contextual cues and target words' repetitions (Flack, 2018), all of which hinder comparisons between word-learning studies that differ in levels of contextual information and ambiguity.

Importantly, effective word learning involves the ability to retain the word-referent association beyond the fast-mapping stage, so that the newly learnt word is recognised and retrieved subsequently (McMurray et al., 2012; Samuelson & McMurray, 2017). Previous work demonstrates that the degree of ambiguity and difficulty of word-learning scenarios has a direct impact on both immediate word learning and retention over time when exposed to various conditions of the same paradigm (Mulak et al., 2019; Vlach & Sandhofer, 2012). Particularly, Vlack and Sandhofer (2012) showed that the amount and quality of memory supports determine word-learning and retention outcomes in 3-year-olds. Children were provided with one, two or three of the following scaffolds to support memory: i) saliency of the novel referent, ii) additional repetitions of the new label, and iii) productive generation of the label. Results showed that the more scaffolds children received, the better word retention they achieved. However, the scaffolds provided may also be interpreted as devices that ameliorate the ambiguity in the word-learning situation. Integrating a variety of learning scenarios is therefore crucial to fully understand the mechanisms involved in handling ambiguity and contextual information when identifying and retaining newly learned words. So far, we do not know how fast-mapping performance compares across different exposure conditions, nor do we know how effective each of the word-learning strategies would be on inducing long-lasting word retention. A direct comparison of word-learning conditions and their delayed retention would contribute to determining the developmental maturation of word-learning strategies in 4-year-old children. Findings could contribute to inform educational decisions and early implementation of efficient word-learning environments for children in preschool settings.

The present study examines four-year-old children's novel word-learning using the three word-learning scenarios reviewed above, namely ME, CSWL and eBook (i.e., an electronic audio-visual storybook) using a methodology that enables direct comparison of word-learning accuracy in an immediate and delayed word recognition test. In this regard, each word-learning condition differs on the exposure characteristics of the target label-referent pairs and the contextual information provided. Specifically, in ME the child is exposed to novel and familiar referents along with novel labels; in CSWL the child is exposed to only novel referents and novel labels; and, in the eBook the child is exposed to novel words and labels couched within narrations and rich variety of referents. Crucially, the target label-referent pairs and the number of exposures to each pair throughout the experiment were identical across the three conditions.

Although we predicted that children would successfully fast-map the novel words under the three word-learning scenarios, we expected children to learn words more successfully when exposed to the ME paradigm compared to the other two scenarios. This is because seeing a familiar object next to the novel object in every learning instance provides an important cue during the fast-mapping process (Lewis et al., 2020), as demonstrated by pre-schoolers' high performance in this word-learning scenario in many previous studies (Kalashnikova et al., 2014, 2016; Waxman & Booth, 2000). We also predicted that CSWL and eBook word-learning would be more challenging because learning in these two scenarios requires higher cognitive demands. Specifically, CSWL presupposes a heavy memory load for the many occurrences of unfamiliar words and objects across trials, as reflected in learning success just above chance for three-year-old children (Vlach and DeBrock 2017, 2019). To learn words from an eBook, children need to select and attend to relevant information (i.e., target new words and objects), while inhibiting potentially more salient irrelevant information (i.e., characteristics of the protagonists, different objects and elements surrounding the depicted scenes, Flack, 2018).

3.2. Method

3.2.1. Participants

Forty-seven children participated in the present study (M_{age} = 4.7 years, SD_{age} = 0.38 years, range = 4.0 – 5.5 years; 27 females). Children had not started formal school education and did not have a diagnosed language or developmental disorder. Children were recruited from a database of parents who had volunteered to participate in child language research at a university laboratory (n = 29) and from childcare centres located in the Greater Sydney area (n = 18). Two additional children were recruited but were excluded from the final sample as they refused to start (n = 1) or to continue (n = 1) the experiment. All children were born in Australia; 28 children (M_{age} = 4.7 yrs, SD_{age} = 0.06 yrs; 16 females) were monolingual speakers of English and 19 children (M_{age} = 4.6 yrs, SD_{age} = 0.1 yrs; 11 females) had additional exposure to another language (Spanish = 14, Mandarin = 2, German, Greek and

Arabic = 1 each). To ensure that all children with additional language exposure were proficient in English and understood the English instructions, their English receptive vocabulary was assessed (see *Receptive vocabulary size* subsection). Children were assigned randomly to one of the three word-learning paradigms: ME (n=15, M_{age} = 4.5 yrs, 7 females, 5 bilingual), CSWL (n=17, M_{age} = 4.7 yrs 7 female, 6 bilingual), eBook (n=15, M_{age} = 4.9 yrs, 8 female, 5 bilingual). In general, participants were counterbalanced in terms of sex, age and site of testing (i.e., related to SES) to control external variables as much as possible. This study was approved by the Western Sydney University Human Research Ethics Committee with number H13141. Participation was voluntary, with parents providing written informed consent and children providing oral consent before participation.

3.2.2. Materials and apparatus

The experiment consisted of three phases. It began with a learning phase, where one of three different novel word-learning paradigms was administered (i) ME, (ii) CSWL or (iii) incidental word learning via an eBook. In average, the three word-learning paradigms had a similar time duration of around 6 minutes each. An immediate retention test was administered immediately after the word-learning paradigm, and a delayed retention test, which was identical to the immediate retention test, was administered thirty minutes after the novel-word-learning paradigm. There were three familiarisation trials in each of the paradigms, for the child to get accustomed to the format of the task, which was administered via a touchscreen. The three word-learning paradigms and tests were administered on a Surface Intel Core i5 touchscreen laptop running E-Prime 3 (Psychology Software Tools, 2019). In addition, children completed the Toolbox Picture Vocabulary Test (TPVT) as a measure of receptive vocabulary. The TPVT was administered on a 6th generation iPad. Throughout the experiment, instructions were presented via E-Prime 3 along with the stimuli, therefore verbal instructions from the experimenter were kept at minimum.

Target novel words and objects stimuli

The novel visual stimuli consisted of four objects (see Figure 3.1) and the auditory stimuli were four words selected from the Novel Object and Unusual Name-NOUN database (Horst & Hout, 2016). The novel words, ***wug, lif, pok,*** and ***neem,*** have been used in previous research (Byers-Heinlein et al., 2013; Kalashnikova et al., 2018). These words were chosen for their phonetic distinctiveness with no vowel or consonant overlap and their monosyllabic CVC (consonant-vowel-consonant) structure, characteristic of English words (Yap et al., 2015). The target words, the full auditory stimuli (carrier sentences and narrations, depending on the paradigm) and the instructions for all three paradigms were produced and recorded by the same female native speaker of Australian English. Word-object pairings were identical for the three paradigms.

Figure 3.1. Target novel objects used in the three word-learning paradigms

Learning phase: Three word-learning tasks

Mutual Exclusivity (ME). Prior to the start of the learning phase, children were exposed to three familiarisation trials to get used to the touchscreen format of the learning trials. Each familiarisation trial consisted of two familiar pictures (an apple, a banana, a chicken, a flower, or a book) and the child was asked to identify one of the familiar objects (i.e., *Where is the cat? Find the banana! Touch the book!*). The child responded by pressing the corresponding picture on the screen. After this, the ME trials took place as explained below.

In a ME learning trial (adapted from Kalashnikova et al., 2018), two objects were presented on a white background on a laptop touchscreen, accompanied by an audio recording of a sentence intended to direct the child's attention to one of the objects (see Figure 3.2. for an illustration of ME trials). One was the target novel object and the other a familiar object (i.e., a drawing of a cup, ball, shoe, or car). The auditory stimulus consisted of a carrier sentence containing one of the novel words (i.e., *Where is the [novel word]?; Find the [novel word]*). The carrier sentence lasted for 1700 ms, and the trial lasted for an additional 3000 ms where the visual stimuli remained and the child had the option to touch the object on the screen that corresponded to the auditory label (in all cases, this was the novel object). Each learning trial lasted a maximum time of 4700 ms. If the child touched one of the objects on the screen before the maximum of 4700 ms, the trial terminated, an attention getter was displayed, and the next trial appeared on the screen. The attention getters consisted of a varied array of child-friendly cartoon images with a synthetic non-word sound and a duration of 1000 ms each. The attention getters were designed to keep children's visual attention on the screen. If the child did not choose (i.e., touch) an image, the attention getter was not displayed, and the next trial appeared on the screen. During the learning phase, the child was exposed to 24 learning trials, such that each of the 4 novel word-object pairs was presented 6 times in total. All participants were exposed to all trials in the same fixed order. (Please see Appendix B for a detailed list of word-learning trials).

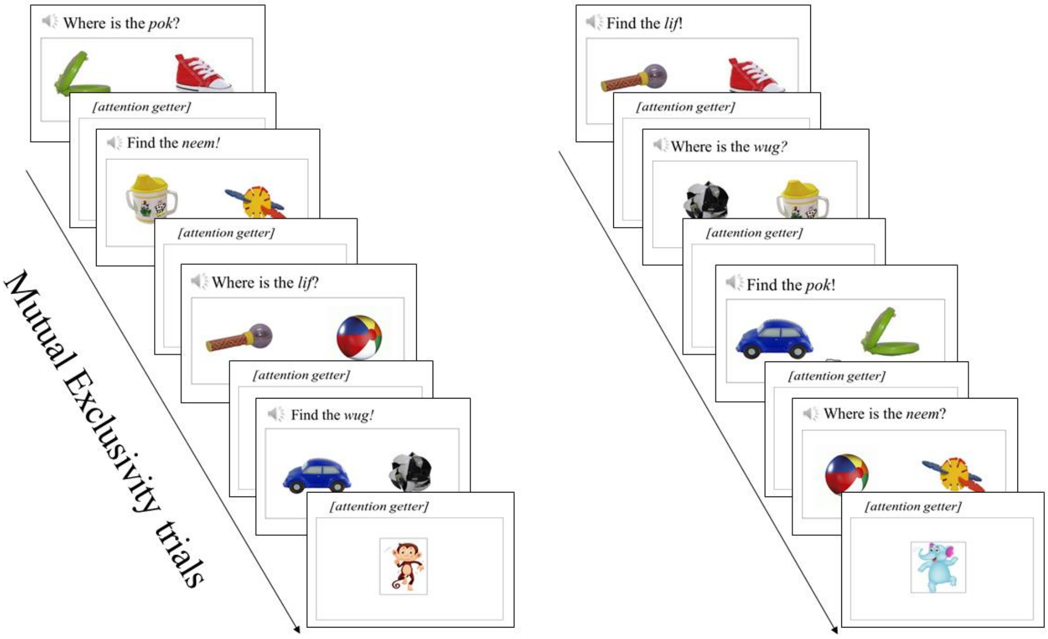

Figure 3.2. Illustration of Mutual Exclusivity trials

Cross Situational Word Learning (CSWL). In a CSWL trial (adapted from Vlach & DeBrock, 2017), two objects were presented on a white background on the laptop screen, accompanied by an audio recording of two isolated words. In each trial the child was exposed to an auditory stimulus consisting of one of the target novel words and one non-target novel word (i.e., *dand*, *bink*, *drit*, *bem*, *doff*, *posk*; Horst & Hout, 2016). Each learning trial lasted 3000 ms, in which a visual stimulus of two figures was presented on the screen; one of them was a target-novel object and the other a non-target-novel object (see Figure 3.3. for an illustration of Cross Situational Word Learning trials). We created a pseudo-randomised list with the presentation order of the objects (left/right side) and words (first/second) (Suanda et al., 2014). All participants were exposed to all trials in the same fixed order (please see Appendix C for the learning trial list used in the CSWL paradigm). During the visual presentation, the recording of two novel words (with a duration of 1000 ms each, a 500 ms silence between each word and 250 ms of silence at the beginning and end of each word) was presented; the total time of the auditory stimuli plus silence matched the 3000ms of the visual stimulus, in line with Vlach and DeBrock (2017) study. During the learning phase, the child was exposed to 24 learning trials, such that each of the 4 target novel word-object pairs was presented 6 times in total. The learning trials were presented in immediate succession, with a blank transition of 250 ms between each of them and an attention getter presented after every three trials, following Vlach and DeBrock (2017) arrangement of blocks of learning and attention getter trials. The attention getters were identical to those in the ME paradigm, with a duration of 1000 ms each. The child was not required to touch the screen at any time during the CSWL learning trials.

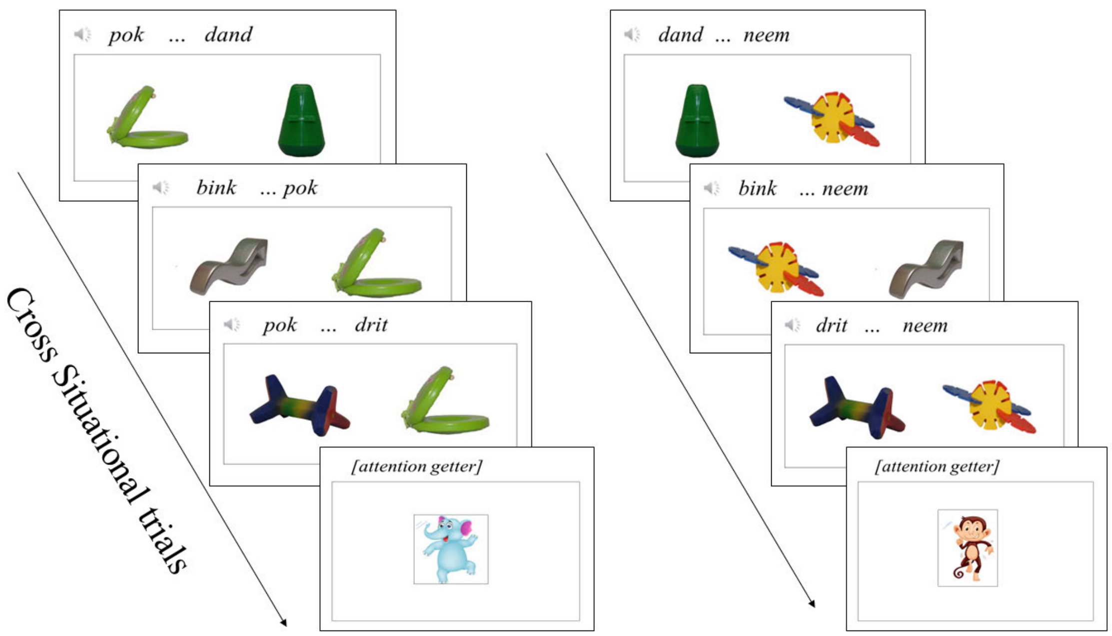

Figure 3.3. Illustration of Cross Situational Word Learning trials

EBook. The stimuli consisted of a story presented in an audio-visual eBook format, inspired and adapted from Escudero et al. (under review) and Ramachandra et al. (2011). The story was titled *"Sharing at School"* and consisted of 14 cartoon slides with a pre-recorded audio narrative. Twelve slides contained the target novel words, while the initial slide was the title page and the last slide was the closing page. The 4 novel-target words and their visual referents (i.e., novel objects) were couched in the story-plot among familiar English words and familiar images depicting a scene (see Figure 3.4. for an illustration of eBook trials). The audio narrative in each cartoon slide lasted 6000 ms. Then, a red arrow appeared on the inferior-right-hand side of the screen for 3000 ms while the visual stimuli remained, and the child had the option to touch the arrow to move to the next slide. This red arrow was added in the paradigm to encourage children's active participation in the story, but this was not a requirement for the task and no data were collected regarding the number of participants that touched the arrow to turn the page. During the whole story, children had a total of three exposures to each target novel word and their correspondent object. During the learning phase, the participants listened to the story twice, such that by the end of the eBook learning phase, they were exposed to each novel word-object pair six times. All participants were exposed to all trials in the same fixed order. See complete eBook story "Sharing at School" with words' order list in Appendix D and a more detailed illustration in Appendix E.

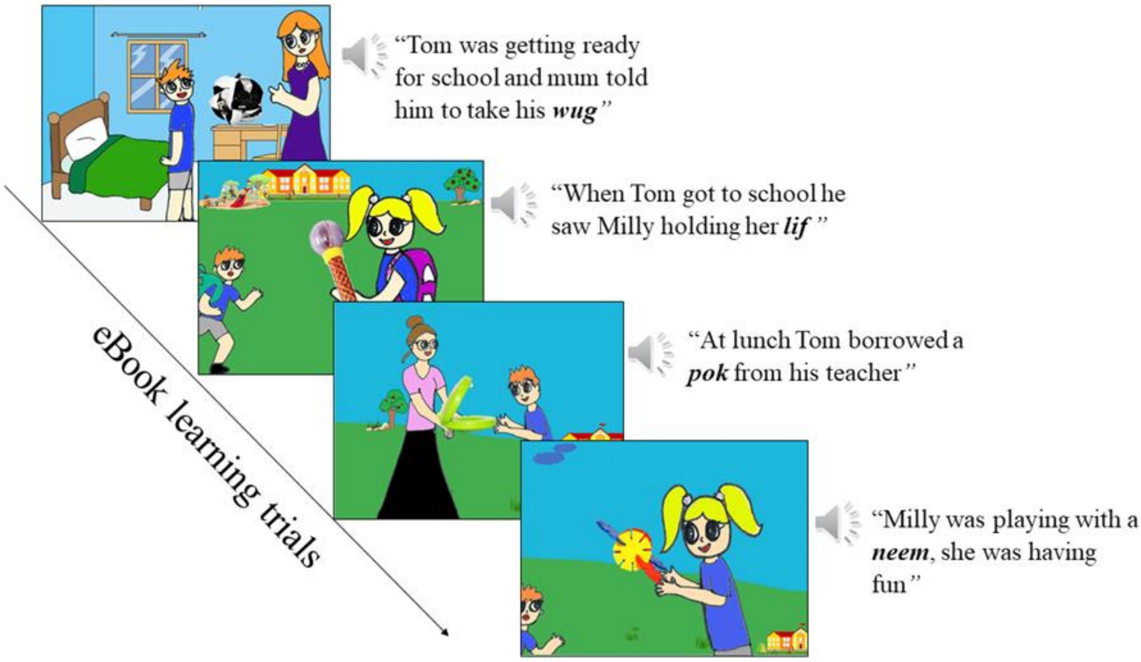

Figure 3.4. Illustration of eBook trials

Immediate and delayed retention tests

Prior to the immediate retention test, children participating in the CSWL and eBook conditions were exposed to three familiarisation trials to get used to the touchscreen test format and its response method. Each familiarisation trial consisted of four pictures. The child was asked to identify one of four familiar objects (i.e., *Where is the cat? Find the banana! Touch the book!*). The child responded by pressing the corresponding picture on the screen. Children participating in the ME condition were exposed to similar familiarisation trials before the learning stage, so this phase was not included for this group.

The immediate and delayed retention tests were identical for all children, regardless of the word-learning paradigm (see Figure 3.5. for an illustration of the immediate and delayed retention tests). The immediate retention test consisted of an explicit forced-choice picture recognition test where the participant had to identify the correct object from the four options presented on the screen after hearing its label, as in the familiarisation trials. In each test trial, the participant was shown the four target novel objects on the laptop screen and asked to choose the correct one after being asked "Which one is the [novel word]?". In total there were eight immediate retention test trials. Each of the four novel target words was tested twice. The position of the four novel objects on the screen changed in each trial in a pseudorandom order. In both tests, we measured children's proportions of correct responses (chance level = 0.25).

After the immediate retention task, the child was administered a receptive vocabulary test and three short screen-based executive function tasks. The three executive function tasks are outside the scope of the present study and will not be reported in the present paper. The child was offered a sticker to attach on a chart as a distraction and reinforcement after completing each task. The total duration of the experimental session was approximately 35 minutes. Subsequently, the delayed retention task, which was a repetition of the immediate retention task, was presented as the last activity in the experimental session.

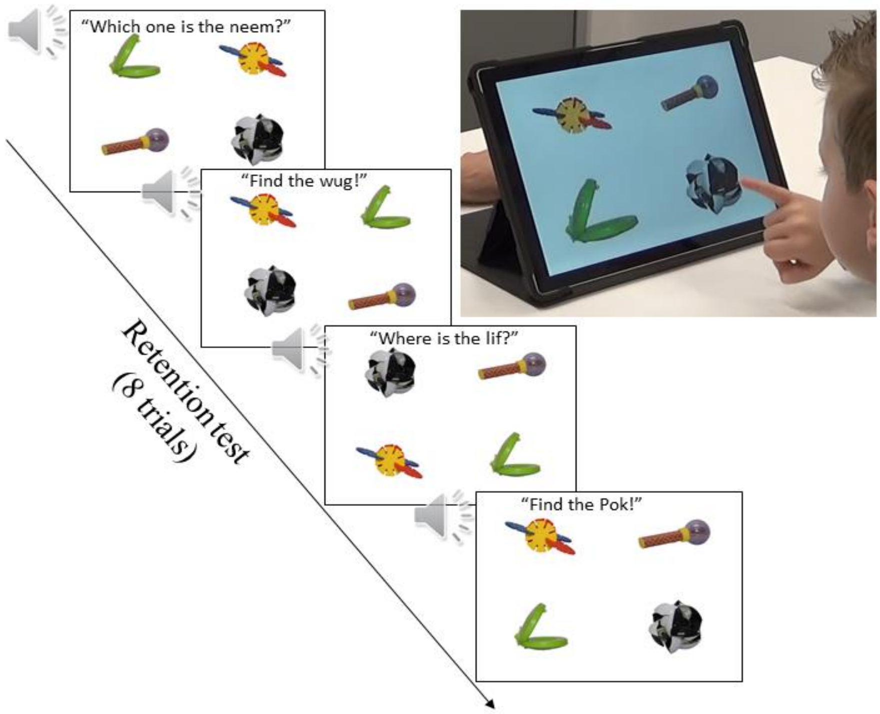

Figure 3.5. Illustration of the immediate and delayed retention tests.

Receptive vocabulary size

The Toolbox Picture Vocabulary Test – TPVT. We tested children's English receptive vocabulary to ensure they understood the task instructions and stimuli. Additionally, evidence shows a relation between vocabulary size and disambiguation trials (Bion et al., 2013), CSWL (Smith & Yu, 2013), and incidental word learning (Abel & Schuele, 2014; Sénéchal et al., 1995). Therefore, it was crucial to take into account participants' receptive English skills as a predictor of word learning. The TPVT (Gershon et al., 2013) is part of the NIH Toolbox Cognition Battery and is a normed measure of receptive vocabulary. All the instructions and procedures of the TPVT were pre-programmed and accessed from the NIH Toolbox App. During the task, single words were presented via an audio file and paired simultaneously with four images of objects, actions, and/or depictions of concepts. The child was asked to select one of the four pictures presented, choosing the one whose meaning aligned best with the spoken word. The selection and number of words administered depended on each participant's performance in real-time, with a maximum of twenty–five items. The TPVT was administered on an iPad and took approximately five minutes to administer. The dependent variable for receptive vocabulary was the age-corrected standard score calculated for each participant.

A one-way analysis of variance showed no significant differences in participants' TPVT scores (M = 100.3, SD = 12.71) across the three word-learning paradigms F (2,44) = 0.499, p = .61; and a t-test revealed no significant difference in TPVT performance between monolingual (M = 101.79, SD = 14.31) and bilingual children (M = 97.95, SD = 9.82), t (2,44) = 1.01, p = .31. Therefore, all children had similar English receptive vocabulary skills across word-learning paradigms regardless of their language background.

3.3. Results

Children's responses from the immediate retention and delayed retention tests were scored as correct (1) or incorrect (0) and proportions of correct responses were calculated for the analysis. A one-sample t-test on the accuracy of children's responses averaged across all test trials was conducted for each of the word-learning scenarios (i.e., ME, CSWL and eBook) in each of the retention times (i.e., immediate and delayed). Children's average performance was significantly above chance (.25) for all scenarios at both test times (immediate, ME M = .56 (SD = .26), t(14) = 4.63, p <.001, CSWL M = .35 (SD = .23), t(16) = 1.70, p =.05, and eBook M = .66 (SD = .24), t(14) = 6.61, p <.001 and delayed, ME M = .62 (SD = .25), t(14) = 5.63, p <.001, eBook M = .60 (SD = .22), t(14) = 6.23, p <.001), except for CSWL delayed retention, M = .30 (SD = .21), t(16) = 1, p =.17 (Figure 3.6) .

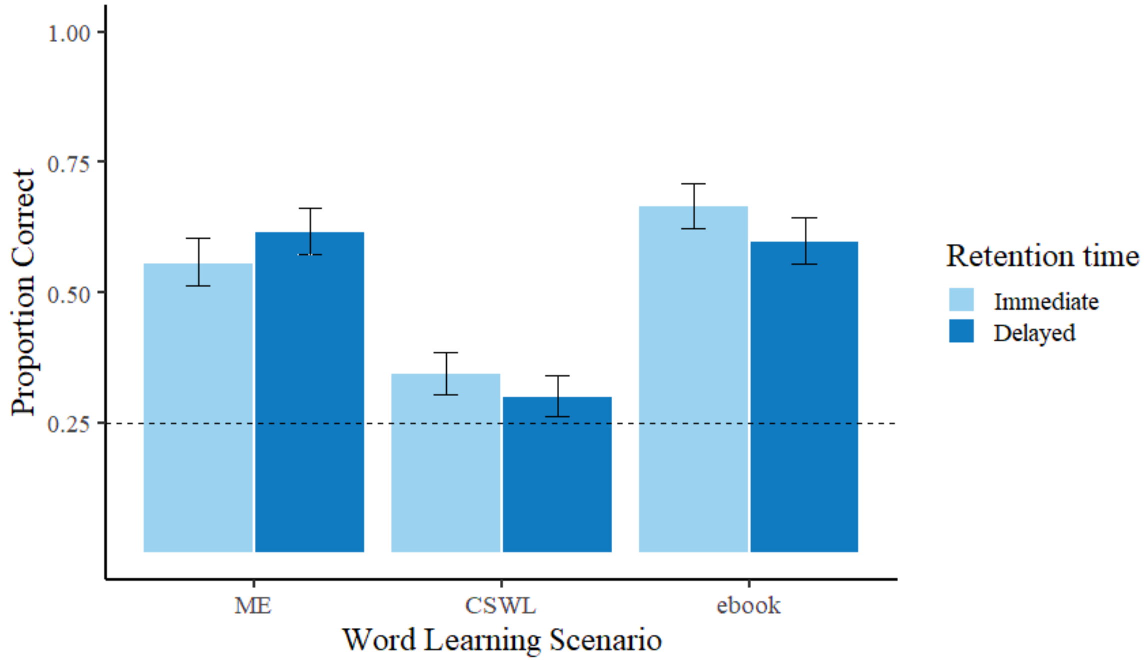

Figure 3.6. Retention accuracy across test trials in the immediate and delayed retention tests across word-learning scenarios (error bars display Standard Error of the Mean).

To compare word-learning accuracy across the three word-learning scenarios, we conducted a series of logistic binomial Generalised Linear Mixed Models using the glmer function from the lme4 package (Bates et al., 2015) in R (RStudio Team, 2020). We started with a first model (Model 1 for word-learning scenarios) including Word-learning Paradigm (i.e., ME, CSWL, eBook) as a fixed effect and intercepts for Participant and Trial. The model revealed a significant effect of Word-learning Paradigm, $F(2,45) = 11.31$, $p < .001$, $AIC =$ 949.3. A *post hoc* Tukey test showed that children learned more word-referent associations from the eBook than from CSWL ($p < .001$); more from ME than from CSWL ($p < .001$), and there was no difference between the eBook and ME ($p = .82$) (see Table 3.1). We then included Time (i.e., immediate and delayed retention) as a fixed effect in a subsequent model (Model 2). The fixed effect of Time was not significant and did not improve the predictive fit of the model, as evidenced by a higher Akaike information criterion (AIC). *AIC* value ($p =$ .57, $AIC = 951.0$), indicating that children were able to retain the newly learnt words to the same extent immediately after the learning phase and 35 minutes later.

Table 3.1.

Summary of Model 1 for word-learning scenarios

Formula: Accuracy ~ Paradigm + (1 | Subject) + (1 | Trial)				
Random effects		Variance	SD	
Subject	(Intercept)	0.5901	0.7681	
Trial	(Intercept)	0.1450	0.3807	
Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	−0.84	0.27	−3.11	<0.01
eBook	1.46	0.34	4.31	<0.001
ME	1.25	0.34	3.71	<0.001
	AIC	BIC	logLik	Deviance
	949.3	972.4	-469.6	939.3

Adding the Word-learning Paradigm * Time interaction (*p* = .40, AIC = 952.3) or TPVT (*p* = .99, AIC = 953) to Model 1 also did not improve Model fit, suggesting that retention did not depend on the word-learning paradigm, and it was not influenced by receptive vocabulary.

The main analysis is a generalised linear mixed model (logistic binomial family). A post hoc power analysis in G*Power (Faul et al., 2007) with the total sample size (*n* = 47) revealed a statistical power of 0.41. As common effect size statistics (i.e., eta-squared and Cohen's *d*) cannot be calculated in logistic regression models, odds ratios were estimated as an effect size statistic alternative (Dixon, 2008; Feingold, 2013; Hosmer et al., 2013). The odds ratio of the model's intercept was 0.45. The odds ratio for eBook was 4.32 and for ME 3.50, meaning that the odds for children performing better in eBook than in CSWL was 4.32, and better in ME than in CSWL was 3.50.

3.4. Discussion

The present study is the first to systematically test three different word-learning paradigms in one study. It integrates the fast-mapping stage with immediate and delayed retention tests as crucial indicators of word learning under three different word exposure conditions. Preschool children were presented with six repetitions of the same novel words and referents via either ME, CSWL or the eBook paradigm. We predicted that children would be able to learn the words from the three paradigms, but that they would perform better in the ME paradigm compared to the CSWL and eBook. We expected that the familiar referent in each ME trial would aid the fast-mapping process as it has been shown that children prefer to assign an unfamiliar label to an unfamiliar referent. Furthermore, we predicted that the high memory load required in the CSWL paradigm would tax participants' performance, and that the colourful visual referents and abundant phrases in the eBook would distract children from linking the target word-referent pairings. Our predictions were partially confirmed as children learned the novel words better in the ME and eBook paradigms compared to the CSWL paradigm. Children's high accuracy in the ME condition is in line with previous findings (Holland et al., 2015; Lewis et al., 2020), while low CSWL performance, with delayed retention at chance, supports Vlach and DeBrock (2017, 2019) findings. Contrary to our predictions, children were highly successful at learning the target words with the eBook suggesting that the visual and auditory elements in the task were appropriate for the developmental stage of the participants (Flack & Horst, 2018; Horst et al., 2011; Read & Quirke, 2018).

The word-learning strategies employed in our ME and CSWL conditions are essential for establishing accurate links between a novel word and its referent; however, children's daily word-learning experiences are very complex (Levine et al., 2014; Samuelson & McMurray, 2017; Vlach & DeBrock, 2017) and require a combination of learning strategies in order to successfully learn new vocabulary. Already from a young age, children increasingly learn words through the confluence of personal, and often conscious, engagement, effort and emotion along with the involvement of cognitive and affective processes (Bloom, 2000). The eBook provided the opportunity to apply multiple learning strategies, such as ME for novel object-word pairs among familiar referents and CSWL to establish correct pairing of novel words across scenes. Importantly, the eBook provided engagement and motivation to deploy the attentional and memory processes necessary to achieve successful word learning. As confirmed by a follow-up study, high enjoyment was reported from participating in the eBook paradigm, even when administered online (Escudero, Pino Escobar, et al., 2021), suggesting high engagement from participants.

Children displayed an astonishing capacity to learn words and retain knowledge for an extended time. When fast-mapping the new pairings under all three conditions, children could retain the newly learned words after 35 minutes to the same extent as immediately after learning. This is in contrast with previous studies showing that 2-year-old children forget fast-mapped words after five minutes (Horst & Samuelson, 2008). The present study thus demonstrates that the developmental gains in word learning and retention by 4 years of age are substantial. It is highly likely that children's cognitive processes have matured enough to sustain newly learnt labels for longer periods. Out of the three paradigms, the CSWL paradigm posed the highest memory load as it presented high ambiguity, with all the referents being novel, leading to less efficient retention. This observation aligns with previous adult studies that have pointed out that degrees of ambiguity (i.e., CSWL = highest ambiguity, ME = lowest ambiguity out of the three paradigms) and difficulty of word-learning scenarios have a direct impact on both immediate word-learning outcomes and retention outcomes over time (Vlach & Sandhofer, 2012, 2014)

It was also surprising that vocabulary proficiency did not predict word learning. Evidence has found vocabulary proficiency to be a predictor of word learning with narratives (Abel & Schuele, 2014; Sénéchal et al., 1995), and that children with larger vocabularies retain newly learned words better than children with smaller vocabularies (Bion et al., 2013;

Kucker & Samuelson, 2012; Samuelson et al., 2017). However, recent studies have found that performance in CSWL in preschoolers (Hartley et.al., 2020; Vlach & DeBrock, 2019) and 2-year-olds (Kucker et al., 2020) was not predicted by vocabulary size. Our results may indicate that children relied more on their cognitive resources rather than on their previously acquired lexical proficiency, which coincides with findings that word-learning emerges from domain-general cognitive processes (Samuelson & McMurray, 2017; Samuelson & Smith, 1998; Vlach & DeBrock, 2017).

Despite our interesting findings, we acknowledge that a larger sample size across conditions would be preferable. However, the current COVID-19 situation prevented us from pursuing further data collection. In response to this current challenge, experimental testing online appears to be the most viable solution for further research (Escudero, Pino Escobar, et al., 2021).

Due to the diversity of studies and methods employed across studies (Flack et al., 2018; Wasik et al., 2016), it has been difficult to harness the extent of the story time effects until now. The richness of audio-visual and contextual cues surrounding a novel word, rather than isolated words and meanings, increases the learner's engagement and attunes attentional and cognitive resources optimally, in line with Suanda et al.'s (2014) findings that more contextual diversity is beneficial for learners at this age. Although memory processes have been long deemed as crucial for word retention (Alloway et al., 2004; Gathercole et al., 2004; Vlach & DeBrock, 2017; Vlach & Sandhofer, 2012), our findings suggest that attentional processes and learner's engagement are as important as memory for preschoolers' word-learning foundations. The following chapters of this thesis assess memory and other EF components in the same sample of children and test the direct connection between word learning and EFs.

CHAPTER 4

BIDIMENSIONAL EXECUTIVE FUNCTION STRUCTURE IN 4-YEAR-OLD CHILDREN

4.1. Introduction

An outstanding characteristic that differentiates us from non-human animals is our ability to act in a controlled manner. As humans, we are generally able to control our impulses and act in act in systematic and congruent manners (Diamond, 2006). This controlled behaviour, as natural as it may seem, it is the result of complex cognitive development. When children are born, they act instinctively and depend fully on their carers. Increasingly, from birth, children's physical and cognitive abilities are strengthened, shifting from a fully automatic and instinctive behaviour to a controlled and reflective way of being. So far, the structure and development of these cognitive abilities during the first years of life remain in large part uncertain (Garon et al., 2008).

Particularly during the first five years of life, leading to their school beginnings, children start learning more about their potential and limits, observing and learning with the experience how to learn, how to proceed in each life scenario. As children learn to override their automatic thoughts and behaviours, an adaptive goal-directed behaviour emerges (Diamond, 2006; Garon et al., 2008). When children are capable of paying attention, following directions, taking turns and playing according to rules, this suggests that that their core executive functions (EFs) have emerged, usually by the age of 5 (Diamond, 2013;

Zelazo et al., 2013; Zelazo & Bauer, 2013). EFs are a collection of cognitive processes necessary for goal-directed behaviour that we use to govern our thoughts and actions (Carlson, 2005; Diamond, 2002). EFs are crucially involved in most areas of life across the lifespan (See Diamond, 2013 for a review). They also predict school readiness above and beyond IQ and determine success throughout the school years as well as the capacity to find, adhere to and succeed in a job position later in life (Bailey, 2007; Duncan et al., 2007; Gathercole et al., 2004). Weak EF abilities are related to physical and mental health issues, including obesity, substance abuse and poor treatment adherence (Crescioni et al., 2011; Miller et al., 2011) and impaired EFs characterise many mental disorders (Baler & Volkow, 2006; Diamond, 2005; Fairchild et al., 2009). People with strong EF abilities enjoy a better quality of life, including in marital and social aspects (Brown & Landgraf, 2010; Denson et al., 2011; Eakin et al., 2004). Accordingly, teachers report perceiving that the most crucial determinant of classroom success in kindergarten and early school years is children's capacity to sit still, pay attention and follow rules (McClelland et al., 2007). Relatedly, there is evidence that EFs predict later numeracy and literacy outcomes, and school readiness measures (Bull et al., 2008; Bull & Scerif, 2001; Roebers et al., 2011). Therefore, a deep understanding of the structure and content of EFs in children and its classification at each developmental stage is crucial to develop targeted cognitive assessments which will serve to monitor adequate executive functioning (EF) development and outcomes in children, as well as allowing to adequately detect and treat disorders relative to EF.

A broad classification of EFs in older children and adults comprises three main core components of inhibition, working memory and flexibility (Lehto et al., 2003; Miyake et al., 2000). However, the structure of EFs in young children is currently debated between three main approaches. The most accepted EF structure is that 3-6-year-old children have a unidimensional construct of EF, meaning that all three components, namely working memory, inhibition and flexibility are highly correlated (Akshoomoff et al., 2018; Carlson, 2005; Garon et al., 2008; Wiebe et al., 2008; Willoughby et al., 2012). It is thought that these EF components will differentiate as children's cognition develops with age, from around age 8, reflecting a multidimensional EF structure from that point forth (Akshoomoff et al., 2018; Lehto et al., 2003). In contrast, a small number of studies have found evidence for a bidimensional EF structure in 3-to-6-year-old children with models revealing a differentiation between inhibition as one factor and a composite working memory and flexibility factor (Monette et al., 2015; Scionti & Marzocchi, 2021). Finally, a less supported theory of an integrative EF framework for children from 1.5-to-5-year-old children sustains that the structure is composed of three related but differentiated components, similarly to adults, resulting in three commonly identified executive function components: working memory, inhibition and flexibility (Garon et al., 2014). In the first and second theories presented, studies used mixed verbal and non-verbal EF measures, including some phonological memory measures and visual measures for inhibition and flexibility. In the third approach, six non-language based novel EF tasks were used, finding a three-dimensional structure. One common characteristic in EF structure studies is that they are conducted with samples of relatively broad age ranges (on average 3 years), often mixing EF measures across verbal and non-verbal domains, which may be influencing different results across studies. Considering that different EFs components develop at different rates and that big developmental spurs can occur in short periods during the preschool years (Diamond, 2013; Garon et al., 2014), it remains unknown whether EF structure at 4 years is compatible with any of the theories previously described. The present experiment assesses relationships across three main components of EF in an age-restricted sample of 4-year-old children, using validated standard measures in the non-verbal domain for all EF components. Next, I provide a summary of the main EF components, namely working memory, inhibition and flexibility (Sections 4.1.1.-

4.1.3); subsequently I refer to the challenges for measuring EF (Section 4.1.4) to then introduce the present study (Section 4.1.5).

4.1.1. Working memory

Working memory refers to the capacity to hold information in mind to mentally work with or manipulate despite it not being longer perceptually present (Baddeley & Hitch, 1974). Working memory has two domains: i) speech-based or verbal working memory, commonly measured with phonological memory and digit span tasks; and ii) working memory of visual and spatial information (visuospatial) or non-verbal working memory (Alloway et al., 2006; Alloway et al., 2004; Baddeley, 1992; Baddeley et al., 1998; Gathercole & Baddeley, 1989; Gathercole et al., 1994). Additionally, working memory has two crucial components; first, the ability to hold information in mind for a period, and second, the capacity to update this information, to mentally manipulate it or reorder it (Diamond, 2013). For instance, when a child is assigned a list of chores, such as sweep your room, make your bed and then have a shower, the child is required to store the list in memory. But upon realising that the broom is in use by another family member, the child cannot proceed in the prescribed order, and may elect to reorder the chores. The child may discover that the bathroom is empty, but may elect not to shower at this time so as not to get dusty while sweeping. And so, the child may settle on a new order: make the bed, sweep the room, and then have a shower. In this example, storing the chores in the prescribed order relies on short-term memory. The action of reordering the list and devising a new order relies on updating. The short-term memory component emerges very early in life; with evidence in 5-month-old infants and young children being able to hold sequences for up to 15 minutes (Diamond, 2013; Rose et al., 2016). However, the updating part of working memory, that is, being able to mentally manipulate the elements within sequences emerges after toddlerhood and progresses along with developmental gains (Cowan et al., 2011; Diamond, 2013) and is in place by 4 years of age (Alloway et al., 2006; Alloway et al., 2004).

There is a fine line that differentiates working memory and short-term memory. While short term memory involves holding information in mind, working memory additionally involves the capacity to mentally manipulate it. It is important to note that although visuospatial working memory and short-term memory tasks have a strong correlation in the 4-to-6-years group, they are two different constructs (Alloway, Pickering & Gathercole, 2006). This correlation is attributed to the dynamic nature of the short memory tasks which pose similar executive demands compared to working memory tasks, such as the tracking of blocks and dots for later recall, but possibly also due to cognitive immaturity (Alloway Pickering and & Gathercole, 2006).

The most widely used working memory tasks are phonological tasks, such as the verbal forward and backward digit span and the word repetition tasks (Alloway et al., 2004; Gathercole et al., 2004; Gathercole et al., 1994; Gathercole et al., 1992). However, Alloway et al. (2006) integrated four different memory measures including verbal and visuospatial tasks to find out the underlying processes of working memory. They found that while the phonological and visuospatial measures draw from common resources, the memory storage depends on the domain-specific resources, namely, verbal or visuospatial. Similarly, Gathercole (1998) pointed out that verbal and visuospatial working memory display different developmental paths, which supports the theory of sub-systems of working memory. As they do not require verbal processing, visuospatial working memory tasks have been used in multilingual populations (i.e., Morales et al., 2013; Park et al., 2018; i.e., Sorge et al., 2016). The Corsi blocks task and adaptations such the frog matrices memory task have shown to tap in the working memory in the non-verbal domain in children in previous studies, providing a reliable alternative to measure visuospatial working memory (Corsi, 1972; Milner et al., 1991; Morales et al., 2013). Interestingly, highly-proficient 5-year-old bilingual children outperformed a monolingual age-matched sample on the frog matrices task (Morales et al., 2013). To date, the relationship of visuospatial working memory with other EF components has not been fully addressed. The present study uses the frog matrices memory task it provides a reliable alternative to measure visuospatial working memory. Additionally, the dynamics and the game-like format of the task is appealing for young children.

4.1.2. Inhibition

Inhibition is the ability to control and direct attention, thoughts and behaviours, suppressing impulses, and allowing an individual to proceed in an appropriate manner (Miyake et al., 2000 and Diamond, 2013). Inhibition includes a wide variety of sub-functions of differing degrees of complexity, including interference suppression, response inhibition, self-control and delaying gratification (Miyake et al 2000; Bunge et al., 2002; Diamond 2016). The inhibition component emerges in infants for the most basic tasks such as inhibition of visual return (Valenza et al., 1994) and visual inhibition (Kovacs and Mehler, 2008) in pre-verbal infants. However, it does not fully mature until late adolescence for the most complex tasks (i.e., reward anticipation and processing, Geier and Luna, 2012; Simon task, Hommel, 2011; Flanker task, Eriksen & Eriksen, 1974) and later declines with old age (Diamond, 2013).

The present thesis focuses on the ability to suppress automatic responses in favour of accurate, deliberate ones. Importantly, for the inhibitory function to be classified as such, it requires that the control of these responses should be conscious and intentional (Miyake et al 2000). Several tasks measure inhibition, including the Stroop task (MacLeod, 1991), Simon task (Hommel, 2011), Flanker task (Eriksen & Eriksen, 1974), anti-saccade task (Munoz & Everling, 2004), go/no-go task (Cragg & Nation, 2008), and stop-signal task (Verbruggen &

Logan, 2008). There is controversy whether all these tasks tap the same executive sub-functions (Bunge et al., 2002; Diamond et al., 2002). However, the Flanker task has been validated as an age-appropriate measure of inhibition for children from 3 years onwards (Zelazo & Bauer, 2013) that captures participants' voluntary suppression of non-relevant stimuli to focus on the relevant one (Rueda et al., 2004). The present thesis uses the flanker task as the inhibition measure. In a typical flanker task, participants indicate the orientation of a central arrow (Ericsen & Ericsen, 1974) or fish (Rueda et al., 2004) while ignoring the orientation of stimuli presented on the right and left sides of the central stimulus. Studies using the Flanker task in participants of diverse language backgrounds have not found performance differences between bilingual and monolinguals (e.g., Blom et al., 2017; de Abreu et al., 2012) making it appropriate to assess inhibition in mixed background samples.

4.1.3. Flexibility

Flexibility is the capacity to adapt by switching strategies according to task demands (Zelazo et al., 1996). The ability to switch emerges around 3-to-4 years of age, however, this age group displays limitations when the rules become complex or multidimensional (Espy, 1997). By 9 years of age, performance on multidimensional flexibility tasks improves considerably and strengthens into adolescence (Anderson, 2002).

The present thesis adopts the Dimensional Card Change Sort (DCCS) as the flexibility measure. The DCCS task is a characteristic measure of cognitive flexibility, originally created for children (Zelazo, 2006; Zelazo et al., 1997; Zelazo et al., 2004). Children must first sort a set of cards by one dimension (i.e., shape) and must later sort the same set of cards by a different dimension (i.e., colour). When performing the basic version of the DCCS, most 3-year-old children, despite understanding the rules and knowing that they are expected to change the sorting dimension from shape to colour, keep on sorting by the previous dimension and fail trials after switching dimensions (Zelazo, 2006; Zelazo et al., 1996). Bialystok (1999) observed that 4-year-old bilinguals performed similarly to 5-year-old monolinguals in a variation of the DCCS task, attributing a bilingual developmental advantage of one year. Four-to-5-year-old bilingual children outperformed monolingual children in a subsequent study using the DCCS task (Bialystok & Martin, 2004). After 5 years of age, most children succeed in the DCCS standard version (Zelazo, 2006). The bilingual advantage in this task seems to be a time-based developmental window applicable to 4-year-olds.

4.1.4. Challenges for measuring EFs

Measuring EFs in adults is already a challenge, due to the impurity problem. This is the notion that EF tasks are not circumscribed to measure one specific component, as they usually require multiple components to be performed (Miyake et al., 2000; Friedman & Miyake, 2017). Measuring EFs in children is even more difficult because cognitive abilities manifest at different rates across children due to the dynamic nature of child development. Additionally, there is ongoing debate concerning whether children possess a unidimensional inseparable construct for EF, bidimensional or the three component EF structure.

For instance, the National Institutes of Health (NIH) developed a cognitive battery of tasks, including measures for inhibition and flexibility (Gershon et al., 2013). It was observed that the measure of inhibition and selective attention (i,e., the flanker task) and the measure of flexibility (DCCS) were highly correlated in the 3 to 6 years age group, however, these correlations progressively decreased in older age groups. The authors attribute this phenomenon to a unitary central EF in children that becomes increasingly differentiated with age (Bauer & Zelazo, 2014; Zelazo & Bauer, 2013).

This observation aligns with a recent analysis supporting the hypothesis of a unitary cognitive system during early childhood. In this study, the NIH Toolbox Cognition Battery was administered to five age groups of children: 3-6, 7–9, 10–13, 14–17, and 18–21 year-olds. It was found that the two NIH non-verbal EF measures, namely measures of inhibition and flexibility, were highly correlated to each other as well as to language-based measures of working memory, episodic memory and receptive vocabulary skills for the 3-to-6-year-old group; however, these correlations decreased with age. Furthermore, all these measures loaded into a single factor only for the 3- to 6-year-olds but not for the older groups (Akshoomoff et al., 2018). It was suggested that this was due to the involvement of overlapping systems across cognitive domains during early development and to the challenging characteristics of non-EF tasks for children which engage effortful control systems. This aligns with observations in children's common activations in the prefrontal cortical regions of the brain in a diversity of EF and non-EF tasks (Tamnes et al., 2010). Additionally, longitudinal physiological evidence with fMRI supports the idea of a shift from a unitary EF factor to two distinct EF components (working memory and flexibility) at 9 and 11 years of age, suggesting that this shift may start at around the third year of life (e.g., Durston et al., 2006). However, it remains uncertain when the unitary EF model developmentally shifts into a two-factor EF model.

As we can see, developmental observations have often assessed preschool children within a broad age range, normally from 3 to 6 years of age. However, it has been previously observed that children develop their cognitive skills in short time frames (Best & Miller, 2010; Garon et al., 2008; Korkman et al., 2001), so that small age differences would naturally impact on task sensitivity and therefore a task could tap different cognitive demands at different ages. Consequently, an assessment of EF correlates in a more restricted age range than previous studies would be an important contribution on defining unknown boundaries in the developmental model of EF in preschool children.

4.1.5. The present study

The present study examines a three componential model of EF in 4-year-old children, as well as receptive vocabulary correlates. For such endeavour, we include non-linguistic measures of the three EF components, namely working memory, inhibition and cognitive flexibility.

The study tests three predictions. First, it was predicted that children's performance in all measures of EF would significantly correlate with one another, supporting the unitary executive function theory in children younger than 7 years (Akshoomoff et al., 2018; Zelazo et al., 2013). Secondly, it was expected that vocabulary proficiency would correlate with all EF measures, in line with Alloway et al. (2004) for working memory and Mungas et al. (2013) for inhibition and cognitive flexibility. Finally, it was hypothesised that some differences between bilingual and monolingual language groups would be displayed and this would be modulated by the level of bilingualism. If bilingual participants have a low bilingualism level (i.e., disproportional low proficiency in their language other than English in function to their English level), it is predicted that their performance would be similar to that of monolingual children. Contrastingly, if bilingual participants are highly balanced and proficient bilinguals, it is probable that some EF differences would be displayed, favouring bilingual participants in the flexibility task (i.e., Bialystok, 2015; Carlson & Meltzoff, 2008) but not in inhibition or working memory (i.e., Hilchey & Klein, 2011; Morales et al., 2013; Sorge et al., 2016).

4.2. Method

4.2.1. Participants

Participants were the same 47 Australian-born children (27 female) as those reported in Chapter 3. Twenty-eight children (*M* age = 4.7 years, SD = 0.06; 16 female) were monolingual speakers of English, and 19 children (*M* age = 4.6 years, SD = 0.1; 11 female) were exposed to an additional language at home (Spanish = 14, Mandarin = 2, German, Greek and Arabic = 1 each). Parents were asked to fill out the Language and Social Background Questionnaire (Adapted from Luk & Bialystok, 2013, Appendix A) . Although 19 children were reported as bilingual, their current weekly exposure in the language other than English (LOTE) varied from 5% up to 50%. Five children were reported having between 5% to 15%, of LOTE exposure, six were reported between 20% to 35% and eight had a 50% LOTE exposure. All bilingual children were more proficient in English than in their LOTE. All children with additional language exposure were proficient in English and understood the English instructions as confirmed with an English receptive vocabulary test (see Section 3.2.2).

Maternal education was used as a proxy of SES and rated on a scale from 1 to 3 (1= high school education, 2 = technological college or incomplete university education, and 3= complete university education), with a median of 3 (complete university education) for the full sample. Additionally, no significant differences were found between monolingual (*Mdn* = 3) and bilingual (*Mdn* = 3) SES (Two-sided Wilcoxon rank sum test $Z = 245.5$, $p = .613$).

This study was approved by the Western Sydney University Human Research Ethics Committee with approval number H13141. Participation was voluntary, with parents providing written informed consent and children providing oral consent before participation.

4.2.2. Materials, apparatus and procedure

The present experiment assesses relationships across three main components of executive function in 4-year-old children in the non-verbal domain. We chose the frog matrices memory task (FMM) as a measure of working memory, the flanker task (Flanker) as a measure of inhibition and the Dimensional Card Change Sort (DCCS) as a measure of flexibility. These tasks were chosen because they are age-appropriate, widely used, and required a minimum involvement of language processing. This consideration was taken because children of this age may vary in their linguistic proficiency and language backgrounds, which could affect performance in measures with a high linguistic component. Additionally, we included the Toolbox Picture Vocabulary Test - TPVT (Gershon et al., 2013) as a measure of English receptive vocabulary proficiency. This was important considering that, for the present thesis, the recruitment criteria included children from all language backgrounds and with English exposure in different proportions. Although all children were reported to have a good verbal command of English, it was important to confirm this empirically to ensure that all participants understood the tasks' instructions and stimuli.

The Flanker, DCCS and TPVT are part of the NIH Toolbox Cognition Battery (Zelazo et al., 2013; Bauer & Zelazo, 2014), and therefore these three measures were administered through an app running on an Apple iPad (6th generation). The FMM was administered on a Surface Intel Core i5 touchscreen laptop running E-Prime 3 (Psychology Software Tools). FMM instructions were also delivered through the same program, and verbal instructions from the experimenter were kept at a minimum.

Children were tested individually either in a quiet space in their childcare centres (n = 18) or at the Western Sydney University BabyLab (n = 29). Participants completed a single testing session that lasted approximately 35 minutes. The session consisted of seven tasks presented in a fixed order (1) a word-learning paradigm, (2) a forced-choice word-learning immediate retention test, (3) the TPVT to measure English receptive vocabulary, (4) the Flanker to measure inhibition, (5) the DCCS to measure of flexibility, (6) the FMM, which is a visuospatial working memory task, and (7) a delayed word-learning recognition test which was identical to the immediate retention test. Tasks 1, 2 and 7 are outside of the scope of the present chapter and will not be discussed further (but see Chapter 3).

Frog matrices memory task - FMM

The FMM task was used as a measure of visuospatial working memory. In this task, children had to recall locations in which frogs appeared on the screen. In the FMM, children faced a computer screen and heard pre-recorded instructions (see instructions in Appendix G). Then a 3 × 3 matrix appeared on the screen running a pre-recorded example trial, the purpose of which was to familiarise children with the task (see Figure 4.1). After the example, the children were exposed to two practise trials with feedback to ensure they understood the task. Then the test trials began with two frogs' locations and increased after every two trials to a maximum of frogs in six locations across a total of 10 trials. All the frogs within a single trial appeared in the matrix simultaneously. The display was shown for 2000 ms followed by a 2000 ms delay during which empty ponds were presented. Then, a "ribbit" sound indicated to the children that they should respond by recalling the locations of the frogs. The children responded by tapping the touch screen to select the ponds. The ponds changed colours when they had been selected. Children were free to select the ponds in any order. Scores were calculated as the number of correct locations recalled (maximum score: 40). The duration of this task was approximately seven minutes.

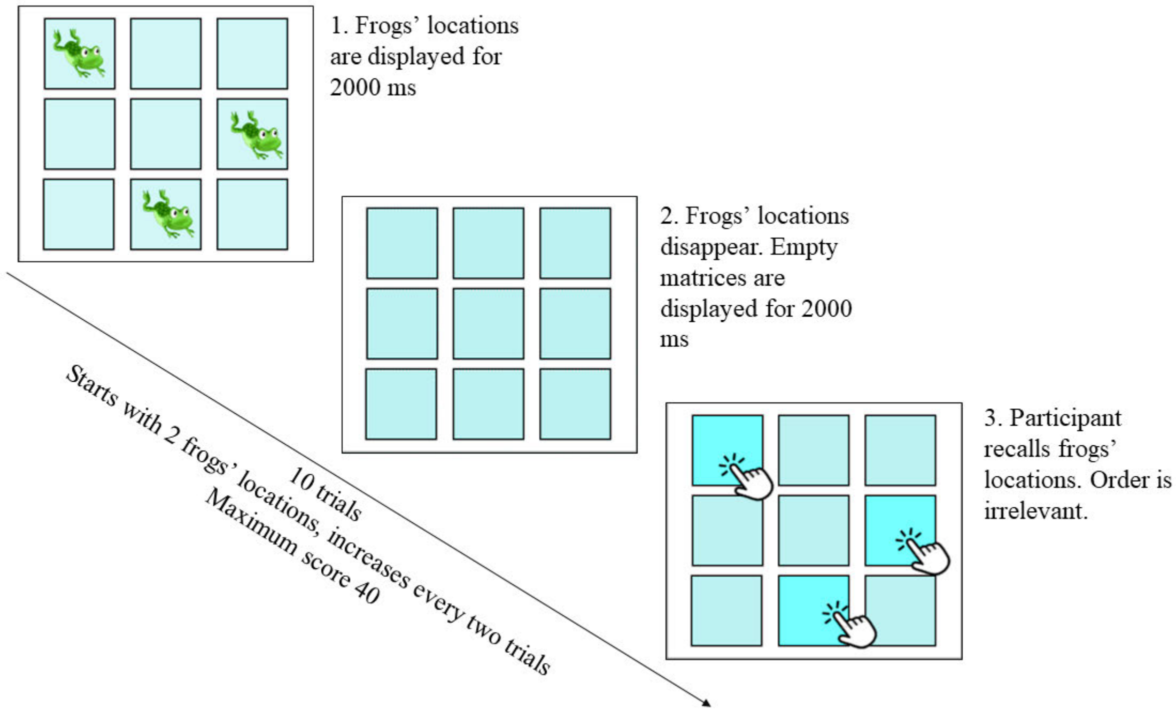

Figure 4.1. Trial sample of the Frog matrices memory task

Flanker task

A child version of the Attentional Network Test - ANT Flanker (Rueda et al., 2004), originally adapted from the Eriksen Flanker task (Eriksen & Eriksen, 1974) and developed, normed and validated for the NIH Toolbox Cognition Battery, was used as a measure of inhibitory control in the context of visual selective attention. Detailed procedures and score equations are detailed in Zelazo et al. (2013) and Zelazo and Bauer (2014). This cognitive task tested the children's ability to inhibit their attention to sometimes misleading information. The task consisted of three blocks: a practice block, a fish block and an arrows block. Instructions appeared visually on the iPad screen and were read aloud by the experimenter to all children. During this task, participants were first presented with an image of five fish lined up from left to right (see Figure 4.2 for a picture of the task). The fish in the middle was the target stimulus, whereas the two fish on either side were distractors. Children were instructed to press one of two touchscreen buttons that corresponded to the direction of the mouth of the fish in the middle. The two buttons were positioned at the lower part of the screen under the fish stimuli; the left button displayed an arrow pointing to the left and the right button displayed an arrow pointing to the right. Nearly all participants understood the task with only one practise block, with the exception of 4 participants (3 monolingual, 1 bilingual) that required one practice repetition to understand the task. In the fish block, the direction the target fish was facing was congruent with that of the distractor fish in 12 trials, but was incongruent in 8 trials. If a child got 5 or more incongruent trials correct, then they advanced to an arrows block, otherwise the task was terminated. The structure of the arrows block was identical to the fish block, with the exception that the figures of the fish were replaced with arrows. The measure of performance in this task was accuracy with a maximum score of 40, equivalent to 20 trials in the fish block and 20 in the arrows block. The duration of this task was approximately four minutes.

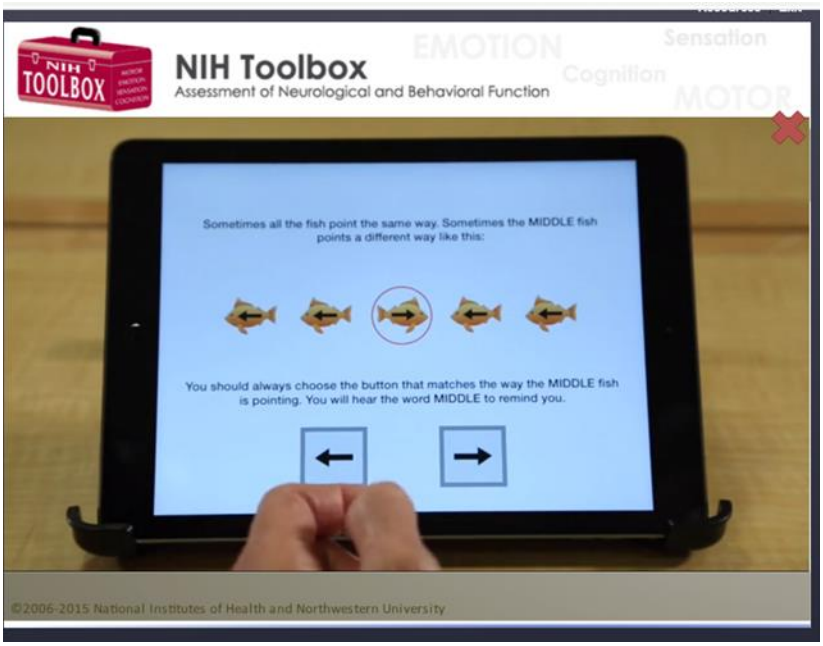

Figure 4.2. Sample of the Flanker instructions from the NIH Toolbox Cognitive Battery.

Dimensional Change Card Sort task - DCCS

A child-appropriate version of the DCCS (Zelazo et al., 1997; Zelazo et al., 1996) was used to measure of cognitive flexibility (Zelazo et al., 2013; Zelazo & Bauer, 2013). In this task, children must sort images based on their colour or shape (see Figure 4.3). Task instructions appeared visually on the iPad screen and were read aloud by the experimenter. This task consisted of four blocks: practise, pre-switch, post-switch, and mixed. In the practice block, participants were given 4 practise trials in which they were shown pictures on the screen and instructed to match the test image presented in the centre of the screen (e.g., a green rabbit) to one of two lateralised images (e.g., a white rabbit and a green boat) positioned under the test image. Participants were instructed to sort either by shape or by colour by tapping the picture that matched the test stimulus on the relevant dimension. Nearly all participants understood the task after a single practise block, with the exception of 2 participants (1 monolingual, 1 bilingual) who each required one practice repetition to understand the task. In the pre-switch block (5 trials) children were first shown a series of cards to sort by shape and then they were asked to switch (post-switch block; 5 trials) and sort the cards by colour. Children who got at least 4 correct post-switch trials passed to the mixed block. If they did not get at least 4 trials correct, the task was terminated. The mixed block consisted of 30 trials, presented in a pseudorandom order. In the mixed block, the children heard a voice saying either “shape” or “colour” in each trial, which directed them to sort the cards based on that dimension.

Performance accuracy was measured, with a maximum score of 40 composed of 5 points of the pre-switch, 5 of the post-switch and 30 of the mixed blocks. The duration of this task was approximately five minutes.

Figure 4.3. Sample of the DCCS “shape sort” from NIH Toolbox Cognitive Battery.

The Toolbox Picture Vocabulary Test – TPVT

The TPVT is a normed measure of receptive vocabulary. All instructions and procedures of the TPVT were pre-programmed and accessed from the NIH Toolbox app. During the task, single words were presented via an audio file and paired simultaneously with four images of objects, actions, and/or depictions of concepts. Children were asked to select one of the four pictures presented, choosing the one whose meaning aligned best with the spoken word. The words administered depended on each participant’s performance in real-time. Additionally, individual performance could lead to a different number of words presented, with a maximum of twenty–five items. The TPVT was administered by iPad with an administration time of approximately five minutes. The dependent variable for receptive vocabulary was the age-corrected standard score calculated for each participant.

4.3. Results

A *t*-test revealed no significant difference in TPVT performance between monolingual (*M* = 101.79, *SD* = 14.31) and bilingual children (*M* = 97.95, *SD* = 9.82), $t(2,44) = 1.01$, $p = 0.31$. Given that the bilinguals' vocabulary proficiency was similar to that of the monolinguals, it can be inferred that they did not find it more difficult to understand the tasks due to poor English proficiency. Table 4.1 shows descriptive statistics in all EF tasks and are graphically depicted in Figure 4.4. Three independent sample *t*-tests showed no difference between monolingual and bilingual participants in any of the EF tasks. T-test results are also presented in Table 4.1. Results indicated that vocabulary and EF performance did not significantly differ between bilingual and monolingual participants.

Table 4.1.

Mean scores and results of independent samples t-tests between language groups for each executive function measure.

Executive Function task	Monolinguals *M* (*SD*) *n* = 28	Bilinguals *M* (*SD*) *n* = 19	*t*-value	*p*-value
Frog Matrices Memory FMM	30.285 (8.89)	28.526 (7.14)	0.718	0.476
Flanker	32.2 (10.4)	30.9 (10.2)	0.441	0.660
Dimensional Card Change Sort DCCS	28.2 (13.1)	23.2 (14.0)	1.254	0.216

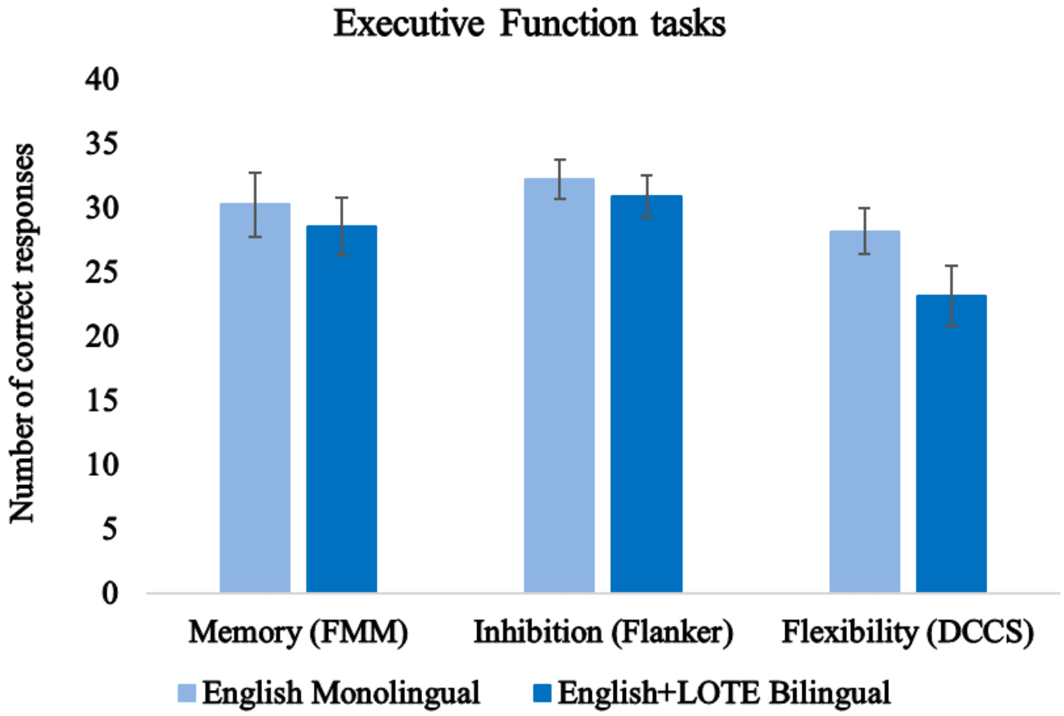

Figure 4.4. Monolingual and bilingual children's performance in EF measures (error bars display standard error of the mean).

As there was no difference between language groups in any of the measures, both groups were collapsed, and the sample was treated as a unitary group for subsequent analyses. Correlations for children's scores are displayed in Table 4.2 and Figure 4.5. Correlations revealed that the three EFs did not significantly correlate with vocabulary proficiency (i.e., TPVT), indicating that vocabulary proficiency did not relate to visuospatial memory (i.e., FMM), inhibition (i.e., Flanker) or flexibility (i.e., DCCS). A moderate positive significant correlation between DCCS and flanker was revealed. The FMM displayed low, non-significant correlations with the Flanker and DCCS.

Table 4.2.

Correlations between the executive function scores and the TPVT scores, collapsed across language groups.

	Flanker	DCCS	TPVT
FMM	.10	.16	.13
Flanker		.30 *	.19
DCCS			.03

*$p < .05$.

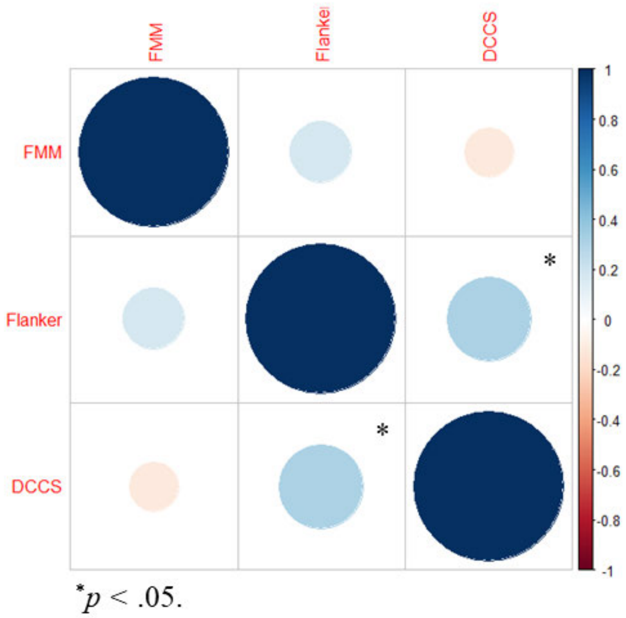

Figure 4.5. Correlations between the executive function scores of all participants.

4.4. Discussion

Preschool children were presented with three tasks to measure the three EF main components and a receptive vocabulary test. Visuospatial working memory was tested with the FMM task, inhibition was measured with the flanker task and flexibility with the DCCS. No language group differences were found in any of the EF tasks or in receptive vocabulary. Interestingly, both language groups displayed similar vocabulary proficiency. Therefore, the sample was treated as a unitary group in order to explore the validity of Miyake et al., 2000's three-component EF model in 4-year-old children.

It was expected that vocabulary proficiency would correlate with the three EF components in line with previous studies that have found correlations between receptive vocabulary and working memory (Alloway et al., 2004); receptive vocabulary and inhibition and receptive vocabulary and flexibility (Mungas et al., 2013). Our data did not reveal any significant correlations between vocabulary proficiency and any of the EF measures, indicating that, in our sample, vocabulary proficiency is not related with visuospatial memory, inhibition or flexibility. This however, resonates with findings indicating that performance in EFs measures at 4-years predict receptive vocabulary skills at 5-years of age, showing a longitudinal relationship of both variables (Weiland et al., 2014).

Contrary to the unitary EF structure theory, we found no support for our prediction that children's performance in all EF measures would correlate. The present study revealed a significant moderate positive correlation only between the inhibition and flexibility tasks but none of these correlated significantly with working memory. The correlation found between the inhibition and flexibility tasks in this chapter partially aligns with the NIH's EF structure analysis (Zelazo et al., 2013; Zelazo & Bahuer, 2013; Mungas et al., 2013), indicating that inhibition and flexibility form part of one EF construct at 4 years of age. However, this chapter's results differ from the NIH's EF structure in that we did not find correlations with working memory. This may be due to the fact that this study used a visuospatial working memory task, whereas the NIH's EF structure included only language-processing tasks of memory.

Additionally, our analyses did not reveal statistically significant correlations between between the visuospatial working memory task (FMM) and either the inhibition (flanker) nor the flexibility (DCCS) task, suggesting a pattern of dissociation of working memory from the inhibition and flexibility constructs. This may align with the theory that the EF structure is bidimensional and not unitary, aligning with previous studies (Monette et al., 2015; Scionti & Marzocchi, 2021). The present experiment suggests therefore that one dimension corresponds to the visuospatial memory construct and the other dimension to a composite construct that includes inhibition and flexibility, as revealed with significant correlations between their measures. Previous studies have observed that inhibition and flexibility are two tightly interrelated functions and some tasks tap both simultaneously (Best & Miller, 2010; Garon et al., 2008). The DCCS, for instance, has been observed to tap both flexibility and inhibition (Carlson, 2005; Carlson & Meltzoff, 2008). This is because, to be successful at the DCCS, children are required to focus, hold the rules in mind, and shift strategies according to the appropriate task demands. At the same time, the DCCS also requires overcoming a dominant salient cue (e.g., congruent rule) to opt for the more relevant but less salient cue (e.g., incongruent rule). It is not surprising that flexibility is deemed to be the most complex process out of the three EFs; the tasks to measure it are characteristically impure because they recruit aspects of inhibition and memory (Garon et al., 2008).

The present findings align with fMRI evidence supporting an emerging EF differentiation between working memory and flexibility somewhere between 3 and 9 years of age (Durston et al., 2006). This study shows that a differentiation in the EF structure may be already present at 4 years, coinciding with the maturity of working memory in children (Alloway et al., 2006; Alloway et al., 2004). We, therefore, suggest that the unitary EF structure in children developmentally starts shifting into a bidimensional executive function structure model in 4-year-old children, as shown in Figure 4.6. A correlational analysis however may not be sufficient to uncover the underlying constructs for these three measures. Future studies may target this question in a larger sample with, for instance, factor analysis.

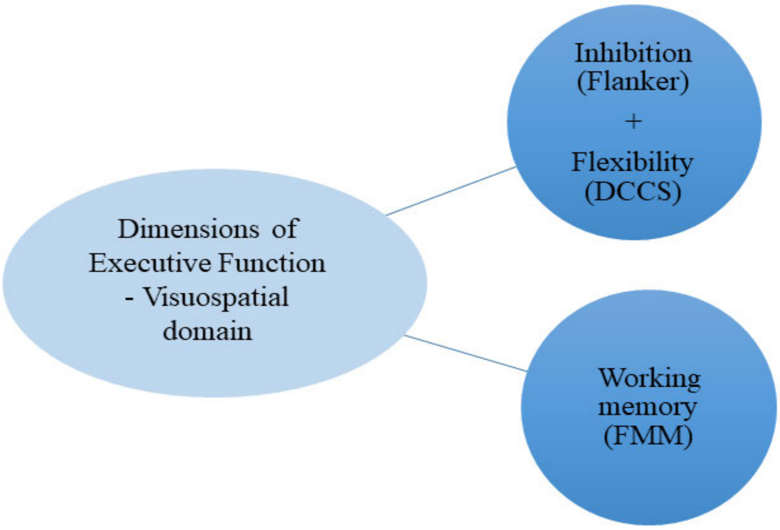

Figure 4.6. Bidimensional executive function structure model in 4-year-old children

So far, developmental observations have focused on a broad age range to observe preschool children's EFs, normally from 3 to 5 or 6 years of age. However, this may cause researchers and theories to overlook some fine-grain developmental milestones in children's EFs. Child development occurs in short time frames (Best & Miller, 2010; Garon et al., 2008; Korkman, et al., 2001), so important spurs can occur in short periods. Consequently, the present assessment of EFs correlates in a restricted age range has revealed an impressive contribution to defining so far unknown developmental boundaries in children's EFs.

CHAPTER 5

INTERRELATION BETWEEN WORD LEARNING AND NON-VERBAL EXECUTIVE FUNCTIONS

5.1. Introduction

In Chapter 4 we suggested that EF in the visuospatial domain is two dimensional, as we observed a positive relationship between inhibition and flexibility and an emerging differentiation of these from working memory.

It is often observed that children experience rapid growth and development for both language abilities and EF and during the time leading to their first school year (Kapa & Erikson, 2020; White et al., 2017). It appears that both language abilities and EF underpin learning, development and lifelong wellbeing, and that both constructs are tightly related (Kaushanskaya et al., 2017; Weiland et al., 2014). However, despite the intuitive assumption that EFs are crucial in the development of language skills in children, the relationship between word learning and EF is still not fully understood. Therefore, the present Chapter addresses this gap by integrating word-learning outcomes under three different scenarios with the three main executive functions components, namely working memory, inhibition and flexibility in the non-linguistic domain in one systematic study.

The focus on identifying and understanding the contribution of trainable, domain-general skills as EFs during language acquisition is crucial for several reasons. It is suggested that EFs have the potential to make up for lexical disparities among children of different SES and language backgrounds (de Abreu et al., 2012; Diamond, 2013). For instance, if the relevant EF skills are identified and fostered among children from low-income families, EFs potentially could countervail the negative effects in lexical proficiency and school outcomes associated with living in poverty (McClelland et al., 2000; White et al., 2017) and associated to low dominant-language usage (De Abreu et al., 2012). There is evidence to suggest a relationship between children's various domain-general EF skills and language development (Fuhs & Day, 2011; Weiland et al., 2014). However, studies analysing the relationship between language and a three-component EF model in children typically have treated receptive or productive vocabulary knowledge as a measure of language development (e.g. Kaushanskaya et al. 2017; Weiland et al., 2014). Although these studies have made important contributions to our understanding of the EF-word learning relationship, they do not address the relationship between non-linguistic EFs and the ability to learn and retain newly learnt words.

Additionally, studies focusing on the EF-word learning relationship have typically examined a specific word-learning phenomenon and one particular EF component, and consequently, a comprehensive integral account of word learning and EF remains elusive. Relationships have been observed between CSWL and phonological memory (Vlach & DeBrock, 2017) as well as one-label-one-referent word learning and phonological memory (Gathercole & Alloway, 2004). There is also evidence of a relationship between one-label-one-referent word learning with flexibility (White et al., 2017). In this last study, a flexibility task was used as a proxy of a unitary EF construct, following the idea of a unitary EF structure in children. However, it has been pointed out that additional EF components are also likely related to word-learning processes (Vlach 2017: Samuelson et al., 2017). Finally, when studies address the components of EF, they often do not address the domain(s) of the measure(s) used. For instance, a study may include an inhibition measure in the visual domain and a working memory measure in the phonological or verbal domain. Therefore, it is difficult to find homogeneity and consistency in the EF measures used within and across studies.

There is a tendency to use phonological working memory measures which are merely linguistic but this is not necessarily the case for measures of inhibition and flexibility. For instance, Kapa and Erikson (2020) investigated the relationship of the three-component model of EF using a word-learning paradigm that involved associating a novel word with a familiar referent and measured via a production task, a phonological recognition task and a comprehension task (i.e., word learning receptive retention task). The study measured working memory and short-term memory with two phonological memory tasks; inhibition with a receptive task of low linguistic processing demands and a go-no/go task focusing on sustained selective attention; and flexibility with a visual card task. Differing patterns of correlations were found between each of the word-learning measures (i.e., production, phonological recognition and comprehension task) and EF measures. The production task positively correlated only with short-term memory whereas the phonological recognition task positively correlated with short-term memory, working memory and inhibition. Finally, the comprehension task correlated with only short-term memory and inhibition. Multiple regression analyses revealed inhibition to be the only EF predictor for both productive and phonological recognition tasks and short-term memory was the only EF predictor of the word-learning comprehension task. This study shows how word learning is manifested in different aspects that include phonological recognition of the new words, receptive word-learning retention and production of the newly learnt words, and the manifestation of each of these aspects recruit different EF processes. Kapa and Erikson's comprehension task was related to phonological working memory; however, it remains unknown whether non-linguistic measures of working memory would play the same role in word learning.

Contrasting with the results of Kapa and Erikson (2020), White et al., (2019) found a relationship between a one-novel-word to one-referent word-learning paradigm with a flexibility measure of EF. Note that both studies used similar flexibility measures; however, the word-learning paradigms differed. Contrasting results across studies may be an indicator that success in different word-learning scenarios is predicted by different EF's. It seems plausible then that EFs may potentially predict the ability to learn words; however, this would depend on the nature of the word- learning scenario and on how word learning was manifested. In sum, it is likely that word-learning emerges from domain-general cognitive processes (Samuelson & McMurray, 2017; Samuelson & Smith, 1998; Vlach & DeBrock, 2017) and that the extent of the involvement of each EF component and vocabulary size will depend on the specific word-learning scenario and the word-learning testing mode as each of them crucially differ in complexity degrees.

It is critical to understand how various components of language interrelate with specific EF components to effectively target and support EF development during early childhood. To address this gap, we formulated the following questions:

1.- Is EF in the non-linguistic domain involved in word learning in children?

2.- If so, do different word-learning scenarios involve different EF components?

It was expected that EF would predict word-learning outcomes (Kapa & Erikson, 2020; White et al., 2017), which would be revealed by multiple linear regressions. However, the degree of involvement of each specific EF would depend on the complexity of the word-learning scenario and the strategy used. Therefore, individual regression analyses for each word-learning scenario were predicted as follows: CSWL would be predicted by working memory (Vlach & DeBrock, 2017); ME would also be predicted by working memory (Gathercole & Alloway, 2004). However, it is important to note that in both previous studies (Gathercole & Alloway, 2004; Vlach & DeBrock, 2017) the working memory measure was phonological in nature and required verbal retrieval of word segments in original and backward order. In the present thesis, in contrast, the working memory is visuospatial in nature, and hence it is possible that such a relationship may not be found if it is the case that different EF domains, namely linguistic versus non-linguistic, are related to different cognitive functions and abilities. We also predicted that it may be possible to find a relationship between ME with flexibility, as it was the case with a one-word-to-one-referent word-learning paradigm used in White et al. (2017). Although there is no empirical evidence to suggest which EF would predict word learning via eBook, it has been suggested that attentional processes are most crucial during this task (Flack, 2018) and therefore we hypothesised that the eBook would be predicted by inhibition and flexibility.

5.2. Method

5.2.1. Participants

The data of the forty-seven children (M_{age} = 4.7 years, SD_{age} = 0.38 years, range = 4.0 – 5.5 years; 27 females) described in Chapters 3 and 4 was re-analised for the present study.

5.2.2. Procedure

The procedure is described in Chapter 3. Children were tested individually either in a quiet space in their childcare centres (n= 18) or at the Western Sydney University BabyLab (n=29). Participants completed one session that lasted approximately 35 minutes. The session consisted of seven tasks presented in fixed order (1) a word-learning paradigm (i.e., one of the three conditions: ME, CSWL or eBook), (2) an immediate forced-choice word-learning retention test, (3) the Toolbox Picture Vocabulary Test (TPVT) as a measure of receptive vocabulary skills in English, (4) the attentional network test flanker (flanker) as a measure of inhibition (5) the Dimensional Change Card Sort task (DCCS) as a measure of flexibility, (6) the Frog matrices memory task (FMM) a visuospatial working memory task, and (7) a delayed word-learning retention test which was identical to the immediate retention test. Children were assigned randomly to one of the three word-learning paradigms: ME (*n*=15, M_{age} = 4.5 yrs, 7 females, 5 bilingual), CSWL (*n*=17, M_{age} = 4.7 yrs 7 female, 6 bilingual), eBook (*n*=15, M_{age} = 4.9 yrs, 8 female, 5 bilingual).

At the beginning of the experimental session the child was offered a sticker chart with five empty bubbles to fill with stickers. The experimenter explained that they would play some games and after completing each of the games, the child would get one sticker to place on the chart.

This study was approved by the Western Sydney University Human Research Ethics Committee with approval number H13141. Participation was voluntary, with parents providing written informed consent and children providing oral consent before participation.

5.2.3. Materials and apparatus and design

The tasks were described in Chapters 3 and 4 and the data was partially analysed in each of those chapters. The experiment had three word-learning conditions (i.e., ME, CSWL and eBook) as a between-subject factor. Participants were counterbalanced in terms of sex, age and site of testing (i.e., related to SES) to control external variables as much as possible. The cognitive tasks (i.e., Frog matrices task, flanker and DCCS) were a within subject measure.

The three word-learning tasks and the frog matrices task were administered on a Surface Intel Core i5 touchscreen laptop running E-Prime 3 (Psychology Software Tools). TPVT, flanker and the DCCS were administered on a 6th generation iPad within the NIH Toolbox App following the NIH Toolbox procedure and manuals (Gershon et al., 2013).

5.3. Results

A preliminary analysis was performed to address the effect of participants' language background across all tasks. We used children's correct responses in the immediate and delayed word-learning tests to predict performance. We fitted a linear mixed-effects model in R (version 1.4.1106; 2009-2021 RStudio, PBC), estimated using restricted maximum likelihood (REML) and nloptwrap optimizer from the lme4 package (Bates et al., 2015; Bates et al., 2012). Word-learning accuracy (number of correct responses from 0 to 8) was predicted with Word-learning paradigm (ME, CSWL, eBook), Language status (monolingual=1, bilingual=2) and Time (immediate retention=1 vs delayed retention=2) (formula: accuracy ~ paradigm + language status + time + (1 | Subject)). The model revealed a significant effect of Word-learning paradigm. However, the effects of language status and time did not reach significance, as shown in Table 5.1.

Table 5.1

Summary of Model 1

Formula: Accuracy ~ Paradigm + Language status + Time + (1 | Subject)				
Random effects		Variance	*SD*	
Subject	(Intercept)	1.480	1.217	
Fixed effects	*β*	*SE*	*t*	*P*
(Intercept)	1.761	0.768	2.294	<0.05
eBook	2.484	0.566	4.385	<0.001
ME	2.072	0.569	3.644	<0.001
Language status	0.680	0.477	1.426	0.161
Time	-0.127	0.302	-0.423	0.675
REML: 374.3	Marginal R^2: 0.28	Conditional R^2 :0.57		

This revealed that neither language background nor time were significant effects on word-learning performance. In Chapter 3, a *t*-test had revealed no significant difference in TPVT performance between monolingual (M = 101.79, SD = 14.31) and bilingual children (M = 97.95, SD = 9.82), t (2,44) = 1.01, p = 0.31. Additionally, in Chapter 4, three *t*-tests had revealed no significant differences between language groups in any of the EF tasks (see Table 4.1 in Chapter 4). Therefore, considering that the analyses suggested no language group effects in any of the tasks, language background was excluded as a variable from further analyses. Likewise, considering that there was no TPVT effect in the analysis, receptive vocabulary was not included in the subsequent models. Finally, considering that there was no effect of time in word-learning performance, immediate and delayed word-learning accuracy were summed for subsequent analyses.

To address the first question of whether non-linguistic EFs were involved in word learning we fitted a second model (Model 2, see Table 5.2) to explore the effect of the EF factors in word-learning outcomes. This model was a comprehensive view of the full data and included performance in the three word-learning paradigms using mean centred variables to zero. The linear mixed model was estimated using REML and nloptwrap optimizer, to predict word-learning accuracy with FMM, Flanker and DCCS and Paradigm as random effect to control for word-learning scenarios. None of the predictors reached significance.

Table 5.2.

Summary of Model 2

Formula: Accuracy ~ FMM + Flanker + DCCS + (1 | Paradigm)				
Random effects		Variance	*SD*	
Paradigm	(Intercept)	1.630	1.277	
Fixed effects	*β*	*SE*	*t*	*p*
(Intercept)	4.869	1.204	4.043	<0.01
FMM	0.009	0.026	0.361	0.719
Flanker	-0.024	0.020	-1.195	0.235
DCCS	-0.008	0.016	-0.505	0.615
REML: 409.3	Marginal R^2: 0.02	Conditional R^2 : 0.32		

Subsequently, to address the second question of whether different word-learning scenarios involve different EF components, I fitted three individual linear mixed models in R using REML and nloptwrap optimizer. These models explored the effects of visuospatial memory, response inhibition and mental flexibility and in each of the word-learning scenarios.

The ME model explored EF and vocabulary proficiency as predictors in the ME word-learning scenario and subject as random effect (formula: ME Accuracy ~ TPVT + FMM + Flanker + DCCS + (1 | Subject)). The same analysis was replicated to assess the effects of the EF measures in CSWL and the eBook conditions (CSWL model and eBook model). All the predictors on the three models were non-significant (see Tables 5.3, 5.4 and 5.5).

Table 5.3.

Summary of ME Model

Formula: ME Accuracy ~ FMM + Flanker + DCCS + (1 | Subject)				
Random effects		Variance	*SD*	
Subject	(Intercept)	2.907	1.705	
Fixed effects	*β*	*SE*	*t*	*p*
(Intercept)	8.499	3.405	2.496	<0.05
FMM	-0.047	0.083	-0.568	0.581
Flanker	-0.081	0. 058	-1.395	0.190
DCCS	-0.014	0.042	0.338	0.741
REML: 129.1	Marginal R^2: 0.10	Conditional R^2 : 0.69		

Table 5.4.

Summary of CSWL Model

Formula: CSWL Accuracy ~ FMM + Flanker + DCCS + (1 | Subject)			
Random effects		Variance	*SD*
Subject	(Intercept)	0.033	0.182

Fixed effects	*β*	*SE*	*t*	*p*
(Intercept)	3.219	1.176	2.736	<0.05
FMM	0.011	0.032	0.362	0.723
Flanker	-0.073	0. 045	-1.620	0.129
DCCS	0.051	0.035	1.449	0.171
REML:148.1	Marginal R^2: 0.08	Conditional R^2 : 0.09		

Table 5.5.

Summary of eBook Model

Formula: eBook Accuracy ~ FMM + Flanker + DCCS + (1 | Subject)				
Random effects		Variance	*SD*	
Subject	(Intercept)	2.463	1.569	
Fixed effects	*β*	*SE*	*t*	*p*
(Intercept)	5.779	2.676	2.160	=0.05
FMM	0.041	0.091	0.446	0.664
Flanker	-0.015	0. 048	-0.323	0.753
DCCS	-0.051	0.036	-1.427	0.181
REML:125.8	Marginal R^2: 0.10	Conditional R^2 :0.67		

5.4. Discussion

The present chapter integrates word-learning outcomes under three different scenarios with executive functions that do not require linguistic processing in one systematic study. We examined the relationship between the three core EF components described by Miyake et al., 2000 (studied in Chapter 4), and three commonly studied word-learning scenarios (studied in Chapter 3) in a sample of 4-year-old children. Importantly, the three-component model of EF in this chapter informs whether working memory, inhibition and flexibility in the visual and visuospatial domain are involved during three different word-learning scenarios ME, CSWL and eBook paradigms. Our analysis failed to reveal visuospatial working memory, inhibition or flexibility as significant predictors of word learning in any of the word-learning scenarios.

The present results align with Kapa and Erikson (2020) who did not find a significant relationship between receptive word-learning retention and flexibility measured with DCCS. Furthermore, this study found that only phonological short-term memory processes but not phonological working memory, inhibition, or sustained attention predicted performance on this word-learning receptive task. Our analysis did not reveal significant involvement of either inhibition or flexibility in any word-learning scenario.

Contrastingly to the findings presented in this chapter, White et al. (2017) found a relationship between word learning and flexibility as a unitary measure of EF. However, it is important to note that this study included participants as young as 3 years of age from low-income backgrounds, living in poverty. Additionally, the study did not specify whether the participants had a language background other than English. In contrast, both this thesis' and Kapa and Erikson's (2020) participants were older (4 years) and came from families of mid-to-high maternal education and the proportion of children that spoke a language was addressed in the analysis.

White et al.'s (2017) contrasting results may indicate that both conditions, that is, young age (i.e., 3-years) and low SES (i.e., living in poverty), defined the recognition of newly learnt words as effortful and complex. In consequence, children had to recruit EF processes to aid in the word-learning process. This idea aligns with the theory that the involvement of EF ameliorates lexical disparities among children of different SES and language backgrounds (De Abreu et al., 2012; Diamond 2013).

Our hypothesis that word learning would be predicted by memory was not supported. In previous studies, word learning was predicted by memory; however, the memory measures used in those studies were phonological in nature (Gathercole & Alloway, 2004; Vlach &

DeBrock, 2017). It appears that, at this developmental stage, phonological memory processes but not visuospatial memory are actively recruited during receptive recognition of newly learnt words. Results may therefore suggest that 4-year-old children do not recruit to a great extent visual memory, response inhibition or mental flexibility when receptively recognising newly learnt words. Conversely, the current results suggest that domain-general cognitive processes in the visual domain may in fact not play a large role in lexical acquisition and proficiency at this stage. Our results should be interpreted with caution, as a larger sample size would have been preferable and our interpretation stems from a null hypothesis. These limitations can be overcome with extra data collection when the current COVID-19 pandemic allows or, failing that, with a follow-up analysis using Bayesian statistics. Probabilistic Bayesian analyses could be an exciting avenue as this approach provides the advantage that evidence can be tested for and against a null hypothesis without requiring a specific sample size. As Bayesian analyses may be considered a new and still-emerging approach in the field of psychology and social sciences, it falls beyond the scope of the present thesis. However, these considerations are explored in more detail in Chapter 6. Despite the challenges, the present interpretation of our findings aligns with relevant current research.

CHAPTER 6

GENERAL DISCUSSION

6.1. Thesis summary

This thesis examined 4-year-old children's word learning in three different scenarios by comparing learning outcomes in three paradigms, namely ME, CSWL and eBook (Chapter 3). In response to a current debate, it also assessed children's EF structure (Chapter 4), and the involvement of EFs in 4-year-old's abilities to learn new words (Chapter 5).

Chapter 3 provided a cohesive overview of the most common scenarios involved in word learning during childhood, namely ME, CSWL and eBook. I examined children's novel word-learning in three word-learning scenarios that involve different linguistic information, context and levels of ambiguity. All scenarios required the ability to fast-map novel words to their corresponding objects: i) ME: target novel word-referent pair presented with a familiar referent prompting fast-mapping via disambiguation, ii) CSWL: target novel word-referent pair presented next to an unfamiliar referent prompting statistical tracking of target pairs across trials and iii) eBook: target word-referent pairs presented within an audio-visual electronic storybook prompting the incidental inferring of meaning. Although children were successful at learning the new words above chance in all three conditions, performance was higher in the eBook and ME conditions compared to the CSWL condition, and this pattern held both when word learning was tested immediately after exposure, and after a 35-minute delay. These results suggested that at 4 years of age children respond better to ME and storybooks than to CSWL.

Chapter 4 explored the structure of EFs in 4-year-old children by examining correlations of working memory, inhibition and flexibility, as well as receptive vocabulary. As the development of EFs is crucial for children's academic future and life success (Diamond, 2013 Bull et al., 2008; Roebers et al., 2011), there is a need to have a detailed understanding of these cognitive processes. For instance, determining the structure of EFs in children would help to more effectively target EF training and early intervention. However, there is a lack of consensus on the structure of EFs in preschool children, with three contrasting theories. The most accepted theory substantiates that EF's in children younger than 6 years have a unidimensional structure and that the components become differentiated with age and cognitive maturation (Akshoomoff et al., 2018; Carlson et al., 2004; Lehto et al., 2003); a second theory supports a bidimensional EF structure (Monette et al., 2015; Scionti & Marzocchi, 2021); and lastly, a third theory supports a three-dimensional structure of three related but distinct EF components comprising working memory, inhibition and flexibility (Garon et., al 2014). I predicted that I would find evidence of a unidimensional structure with all three EF components correlating with one another. However, the analyses in Chapter 4 revealed that inhibition correlated with flexibility but not with visuospatial working memory. This finding therefore supported the view that 4-year-olds have a bidimensional EF structure (Monette et al., 2015; Scionti & Marzocchi, 2021), differentiating flexibility and inhibition from visuospatial working memory.

Finally, in Chapter 5 I discuss that although language abilities and EFs are related and are both at the foundation of academic and lifelong wellbeing (Kaushanskaya et al., 2017; Weiland et al., 2014), the relationship between word learning and EFs is still not fully understood. Studies analysing the relationship between language and EFs in children have typically used vocabulary knowledge as a measure of language development, but have rarely used word-learning abilities as such. Hence, Chapter 5 investigated the involvement of the non-linguistic EFs studied in Chapter 4 in the three word-learning scenarios referred to in Chapter 3. This study did not reveal visuospatial working memory, inhibition or flexibility as significant predictors of word learning in any of the scenarios, suggesting that the cognitive processes tapped with our EF measures were not relevant for lexical acquisition. Additionally, we suggested that language-based EF skills may be more involved during word-learning processes.

6.2. General Discussion

In sum, this thesis has revealed three main findings. First, children at 4 years of age learn and retain new words better by using the ME assumption and from stories (i.e., eBook) than through CSWL (Chapter 3). Second, we found a correlation between inhibition and flexibility but not between either of these and working memory, suggesting that children's EF structure is bidimensional (Chapter 4). Finally, as there were no statistically significant relations between the EFs and word-learning scores, we suggested that word learning may not be predicted by either receptive vocabulary (Chapter 3 and 5) or any of the EFs assessed in Chapter 4.

From the findings in Chapter 3, it seems 4-year-old children are competent word learners who have mastered the ability to use already known words and situations to support learning as they rapidly grow their lexicon. Although children showed that they can learn through CSWL effectively, this was not the most efficient scenario for word learning. This finding is understandable as, in our CSWL paradigm, children were exposed to new words and referents without any familiar referents or contextual information that could be used as learning support. Nonetheless, children demonstrated a capacity above chance to learn under such difficult circumstances indicating that young children can learn new words implicitly, for instance if immersed in a new language. Even though the focus of this thesis was to provide a snapshot of lexical acquisition in the first language, it would be of interest to continue further investigation into second language learning scenarios (e.g., Junttila & Ylinen, 2020). Children learnt better with ME and the eBook than with the CSWL paradigm. In the ME paradigm, children saw one familiar and one novel referent and listened to a question referring to one novel label (i.e., where is the wug?). In this paradigm, both visual and auditory information allowed children to infer that the only unfamiliar elements were one novel referent and one novel label. Therefore, the children could confidently apply the ME assumption by associating the novel label to the novel referent rather than to the familiar one (i.e., ball). During the eBook paradigm, the novel labels and referents were couched within an audiovisual storybook. In this case, the narration segments containing one novel label each were longer and more complex than the questions provided in the ME paradigm, and the visuals were also richer and saturated with diverse objects and figures. Interestingly, children's performance in the eBook paradigm was similar to that in the ME paradigm, indicating that children engaged resources optimally and selectively attended to the relevant information, aiding them to correctly associate the novel referent and label during story reading. These findings highlight the importance of referential information and attentional resources during 4-year-olds' word-learning process.

The findings from Chapter 4, demonstrating that children's EF structure is bidimensional, contribute to defining a developmental boundary in 4-year-old children's EFs. It proposes that one EF dimension is composed of inhibition and flexibility and the other dimension is composed of visuospatial working memory. However, a larger variety of measures would be optimal to confirm these results with factor analyses. For instance, considering that Chapter 4 included only non-linguistic EF measures or those that required minimal linguistic involvement, it would be informative to include three additional EF linguistic measures of the same components (i.e., working memory, inhibition and flexibility). This would allow us to observe whether EF measures correlate across non-verbal and verbal domains and whether the bidimensional EF structure revealed in Chapter 4 is confirmed with a multifactorial analysis.

Finally, Chapter 5 found no evidence that the non-linguistic EF components were involved in the ability to learn novel words. Hence, it may be plausible our word-learning paradigms and the EF measures we used differed in underlying complexity, and therefore did not tap into the same cognitive resources. Furthermore, our measures predominantly required visual processing; it also may be possible that during word learning children recruit EFs related to linguistic and verbal processing, such as phonological memory and verbal fluency, which could be assessed in a follow-up study including verbal EF measures as possible predictors of word learning.

6.3. Limitations and future directions

We acknowledge that the original aim was to collect a larger data sample. However, as reported in Chapter 2, this was not possible due to COVID-19 restrictions. Further face-to-face data collection is currently and in the foreseeable future not possible, with a strict lockdown currently in place in Sydney, Australia, at the time of thesis submission. For multiple reasons, presented in Chapter 2, online data collection was also not a viable option within the present candidature. However, the use of online platforms to socialise, study and work became the new normal during the pandemic (Gentili & Cristea, 2020). So despite the difficulty of implementing online testing for all of the tasks within my PhD project, I decided to collaborate with my principal supervisor's Future Fellowship Project team to conduct an online experiment with the task from my PhD project that seemed easiest to implement for online delivery. This was the eBook I report in Chapter 3 and in my article under revision (Pino Escobar, Tuninetti, Kalashnikova, Antoniou & Escudero, under revision). My principal supervisor's team included two full-time research assistants who were instrumental in the recruitment and data collection of over 90 children. These children were all tested online with either the eBook used in the present thesis, or with an eBook developed by my supervisor to test the learning of words differing in a single sound (Escudero, Sommer, Bredemann, Fennell & Vlach, under review). When we compared the performance of the 41 children tested online to the 15 children who were tested face-to-face as part of the present thesis project (Chapter 3), we found comparable word-learning outcomes (see Appendixes D and E). This finding has recently been published (Escudero, Pino Escobar, Casey, & Sommer, 2021).

During the review process for Escudero et al. (2021) we addressed the interpretation of null results as potential type II error (i.e., no differences between face-to-face and online testing modalities) and the small participant sample of the face-to-face experiment ($n = 15$). This was done by providing detailed explanatory information of the data and by proposing follow-up studies with a probabilistic statistical approach (i.e., Bayesian statistics) when comparing face-to-face and online results, and therefore providing an alternative explanation and probability ratio to null results and small sample sizes. The Bayesian analysis of the three online tasks administered within the study is ongoing (Escudero, Smit, Pino Escobar, in preparation). My involvement as a co-author in this novel direction allows me to start learning the probabilistic Bayesian approach to later explore it for my future research.

As mentioned above, due to COVID-19 restrictions the limited sample size and null results of the studies presented in this thesis are unlikely to be addressed with further face-to-face data collection. The possibilities that are available are online data collection and a probabilistic data analysis with Bayesian statistics, so that we can explain whether the non-significant observations can have an alternative explanation rather than falling within type II error. Bayesian statistics allows for quantification of the evidence for or against a hypothesis, calculating evidence ratios. Despite the potential data size limitations, it is noteworthy to mention that previous studies in word learning (Giezen, Escudero, & Baker, 2016; Junttila &

Ylinen, 2020) and executive functions (Desideri & Bonifacci, 2018; Durston et al., 2006; Pino Escobar et al., 2018) had similar sample sizes.

Future research directions for this thesis thus include 1) following up analyses of Chapters 4 and 5 with Bayesian statistics for publication, and 2) administering and validating the two remaining word-learning tasks from Chapter 3 (i.e., ME and CSWL) via online delivery to contribute to a comprehensive task validation framework. The analysis and findings of my new collaborations and findings from other colleagues suggest that online testing is the right path to follow, as it offers equal or sometimes better outcomes than face-to-face testing (Escudero, Pino Escobar, et al., 2021; Escudero, Smit, et al., 2021; Escudero et al., in preparation). Additionally, online testing offers a more convenient approach time wise and logistically for experimenters and participants, eliminating onerous transportation and the risk of COVID infection. This suggests that online administration combined with Bayesian analysis is the path to the future for this and many more studies to come. Crucially, the present PhD thesis and the collaborations I took part in beyond the scope of my PhD project have given me the confidence to pursue this direction in my future research career.

6.4. Conclusion

The present study demonstrates that 4-year-old children are successful at learning words across three word-learning scenarios: ME, CSWL and an eBook. Crucially, different word-learning scenarios foster different learning outcomes, with eBook reading and disambiguation via ME facilitating rapid and more accurate word learning, while CSWL yielded less success. We conclude that at this crucial age prior to entering formal schooling in Australia, children benefit from contextual information and referential input during the word-learning experience. Four-year-olds easily disambiguate and learn novel label-to-referent associations when presented alongside a familiar referent in virtue of the ME assumption. They also successfully activate attentional resources to detect and learn novel label-to-referent associations among abundant visual and auditory input when listening and observing a colourful eBook. These findings should be considered in early childhood education settings to support lexical acquisition in children. For instance, the ME paradigm could be an attractive pedagogical strategy for children with low lexical proficiency or second language learners, as familiar referents can be adjusted to the individual skills. The use of eBooks can be used as an engaging strategy for children due to the interesting, rich audio-visual and contextual cues, rather than isolated words and meanings.

In addition, findings point out a bidimensional structure of EF in 4-year-old children, with one of the dimensions corresponding to a composite construct comprised of inhibition and flexibility, while the other dimension corresponds to working memory. However, our analyses did not reveal visuospatial memory, inhibition or flexibility as significant predictors for any of the word-learning scenarios. Altogether, the present thesis advances the knowledge of children's cognitive structure and their relationship with different word-learning scenarios, providing foundations to help further bridge the research gap between word learning and cognitive processes.

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Appendix A: Language and Social Background Questionnaire adapted from Luk and Bialystok, 2013.

Participant information – *To be filled out by the researcher*

Project code: __________________ Today's date: _________________ Participant code:

Language and Social Background Questionnaire[2]

Today's Date: ____________________________ 1. Sex: Male ☐ Female ☐

Day **Month** **Year**

3. Handedness: Left ☐ Right ☐ 4. Date of Birth: ____________________________

Day **Month** **Year**

4. Does your child have a hearing impairment or language development or speaking difficulties (e.g., delayed language development, stuttering, lisping, etc.) **Yes** ☐ **No** ☐

If **yes**, please explain: ____

5. Does your child play action video games? **Yes** ☐ **No** ☐

If **yes**, on average how many hours per week? ____________________

6. Does your child have hearing problems? **Yes** ☐ **No** ☐

If **yes**, does your child wear a hearing aid? **Yes** ☐ **No** ☐

7. Does your child have vision problems? **Yes** ☐ **No** ☐

If **yes**, does your child wear glasses or contacts? **Yes** ☐ **No** ☐

Is his/her vision corrected to normal with glasses or contacts? **Yes** ☐ **No** ☐

8. Is your child colour blind? **Yes** ☐ **No** ☐

If **yes**, what type? ____

9. Has your child ever had a serious head injury **Yes** ☐ **No** ☐

If **yes**, please explain: ____

10. Does your child have any diagnosed psycho/developmental disorders (e.g., or neurological impairments? (e.g., epilepsy etc) **Yes** ☐ **No** ☐

If **yes**, please indicate: ____

11. Is your child currently taking any psychoactive medications? **Yes** ☐ **No** ☐

If **yes**, please indicate: ____

12. Please indicate the highest level of education and occupation for each parent:

[2] Adapted from Anderson, Mak, Chahi, & Bialystok (2018). The language and social background questionnaire: Assessing degree of bilingualism in a diverse population. Behavior research methods, 50(1), 250-263.

Mother			Father		
1.	______	No high school diploma	1.	______	No high school diploma
2.	______	High school diploma	2.	______	High school diploma
3.	______	Some post-secondary education	3.	______	Some post-secondary education
4.	______	Post-secondary degree or diploma	4.	______	Post-secondary degree or diploma
5.	______	Graduate or professional degree	5.	______	Graduate or professional degree
Occupation:		______________________	Occupation:		______________________
First Language:		______________________	First Language:		______________________
Second Language:		______________________	Second Language:		______________________
Other Language:		______________________	Other Language:		______________________

13. Where you born in Australia? **Yes** ☐ **No** ☐

If **no**, where were you born? ________________________________

When did you move to Australia ________________________________

Month/Year

Was your child born in Australia? **Yes** ☐ **No** ☐

If **no**, where was your child born? ________________________________

When did he/she move to Australia ________________________________

Month/Year

Current Australian postcode and suburb ________________________________

14. Has your child ever lived in a place where English is not the dominant communicating language? **Yes** ☐ **No** ☐

		From	To
If **yes**, where and for how long?	1. ______________________________	______________	______________
	2. ______________________________	______________	______________
	3. ______________________________	______________	______________
	4. ______________________________	______________	______________
	5. ______________________________	______________	______________
		DD/MM/Year	**DD/MM/Year**

15. List all the language and dialects your child can speak and understand including English, ***in order of fluency***:

Language	Where did he learn it?	At what age did he/she learn it? (If learned from birth, write age "0")	Were there any periods in his/her life when he/she did not use this language? Indicate duration in months/years.
1.______	☐**Home** ☐**School** ☐**Community** ☐**Other:** ______		
2.______	☐**Home** ☐**School** ☐**Community** ☐**Other:** ______		
3.______	☐**Home** ☐**School** ☐**Community** ☐**Other:** ______		
4.______	☐**Home** ☐**School** ☐**Community** ☐**Other:** ______		
5.______	☐**Home** ☐**School** ☐**Community** ☐**Other:** ______		

Relative to a highly proficient speaker's performance of the same age, rate your child's proficiency level on a scale of 0-10 for the following activities conducted in English and your other language(s).

16.1 **English**

	No Proficiency 0	5	High Proficiency 10
Speaking	●———|———|———|———●		
Understanding	●———|———|———|———●		
Reading	●———|———|———|———●		
Writing	●———|———|———|———●		

16.2 Of the time your child spends engaged in each of the following activities, how much of that time is carried out in English?

	None	Little	Some	Most	All
Speaking	☐	☐	☐	☐	☐
Listening	☐	☐	☐	☐	☐
Reading	☐	☐	☐	☐	☐
Writing	☐	☐	☐	☐	☐

17.1 **Other Language:** ______________________

	No Proficiency 0	5	High Proficiency 10
Speaking	●————|————|————|————●		
Understanding	●————|————|————|————●		
Reading	●————|————|————|————●		
Writing	●————|————|————|————●		

17.2 Of the time your child spends engaged in each of the following activities, how much of that time is carried out in this language?

	None	Little	Some	Most	All
Speaking	☐	☐	☐	☐	☐
Listening	☐	☐	☐	☐	☐
Reading	☐	☐	☐	☐	☐
Writing	☐	☐	☐	☐	☐

18. Please indicate which language(s) your child most frequently heard or used in the following life stages, both inside and outside home.

		All English	Mostly English	Half English half other language	Mostly the other language	Only the other language
18.1	Infancy	☐	☐	☐	☐	☐
18.2	Preschool age	☐	☐	☐	☐	☐

19. Please indicate which language(s) your child generally uses when speaking to the following people.

		All English	Mostly English	Half English half other language	Mostly the other language	Only the other language
19.1	Parent 1	☐	☐	☐	☐	☐
19.2	Parent 2	☐	☐	☐	☐	☐
19.2	Siblings	☐	☐	☐	☐	☐
19.3	Grandparents	☐	☐	☐	☐	☐
19.4	Other Relatives	☐	☐	☐	☐	☐
19.7	Neighbours	☐	☐	☐	☐	☐

20. Please indicate which language(s) your child generally uses in the following situations.

	All	Mostly	Half English	Mostly the	Only the

		English	English	half other language	other language	other language
20.1	Home	☐	☐	☐	☐	☐
20.2	School	☐	☐	☐	☐	☐
20.4	Social activities (e.g. playdates with friends, movies)	☐	☐	☐	☐	☐
20.5	Religious activities	☐	☐	☐	☐	☐
20.6	Extracurricular activities (e.g. hobbies, sports, dancing, music)	☐	☐	☐	☐	☐
20.7	Shopping/ Restaurants/ Other commercial services	☐	☐	☐	☐	☐
20.8	Health care services/ Government	☐	☐	☐	☐	☐

21. Please indicate which language(s) your child generally uses for the following activities.

		All English	Mostly English	Half English half other language	Mostly the other language	Only the other language
21.1	Story time (reading or listening while being read)	☐	☐	☐	☐	☐
21.2	Playing with siblings	☐	☐	☐	☐	☐
21.3	Playing alone	☐	☐	☐	☐	☐
21.4	Complaining	☐	☐	☐	☐	☐
21.5	When demonstrating affection	☐	☐	☐	☐	☐
21.6	Watching TV/ listening to radio	☐	☐	☐	☐	☐
21.7	Watching movies	☐	☐	☐	☐	☐
21.8	Singing	☐	☐	☐	☐	☐
21.9	Praying	☐	☐	☐	☐	☐

22. Some people switch between the languages they know within a single conversation (i.e. while speaking in one language they may use sentences or words from the other language). This is known as "language-switching". Please indicate how often your child engages in language-switching. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Never	Rarely	Sometimes	Frequently	Always
22.1	With parents	☐	☐	☐	☐	☐
22.2	With siblings and other family	☐	☐	☐	☐	☐

22.3	With friends	☐	☐	☐	☐	☐

23. Educational activities

- Does your child attend preschool or childcare? Yes ( ) No( )
  - Preschool: ……………………………………………………… Time(s) per week ……………….
  - Childcare: ……………………………………………………… Time(s) per week …………………

- Does your child play a musical instrument? If so, please list the musical instrument(s) and the total time of practice playing the instrument per week.
  - ……………………………………………………… Time per week ……………………………
  - ……………………………………………………… Time per week ……………………………
  - ……………………………………………………… Time per week ……………………………

- Does your child practice dance or a sport? If so, please list the physical activities your child practices and the total time of practice per week.
  - ……………………………………………………… Time per week ……………………………
  - ……………………………………………………… Time per week ……………………………
  - ……………………………………………………… Time per week ……………………………

- Does your child practice(s) any other activity? (yes) (not)
  - ……………………………………………………… Time per week ……………………………
  - ……………………………………………………… Time per week ……………………………

Thank you for participating!

Appendix B: Trial list used during the learning phase of the Mutual Exclusivity (ME) paradigm. Target words are in italics.

Picture 1	**Picture 2**	**Sound**
pok	cup	Where is the *pok*?
neem	ball	Where is the *neem*?
cup	*pok*	Find the *pok*!
pok	ball	Where is the *pok*?
ball	*neem*	Find the *neem*!
cup	*neem*	Where is the *neem*?
ball	*pok*	Find the *pok*!
neem	cup	Find the *neem*!
lif	shoe	Where is the *lif*?
wug	car	Find the *wug*!
lif	car	Find the *lif*!
shoe	*lif*	Where is the *lif*?
car	*wug*	Find the *wug*!
wug	shoe	Where is the *wug*?
car	*lif*	Find the *lif*!
shoe	*wug*	Where is the *wug*?
pok	shoe	Where is the *pok*?
car	*neem*	Where is the *neem*?
lif	ball	Where is the *lif*?
wug	cup	Find the *wug*!
car	*pok*	Find the *pok*!
neem	shoe	Find the *neem*!
ball	*lif*	Find the *lif*!
cup	*wug*	Where is the *wug*?

Appendix C: Trial list used during the learning phase of the Cross Situational Word Learning (CSWL) paradigm. Target words are in italics.

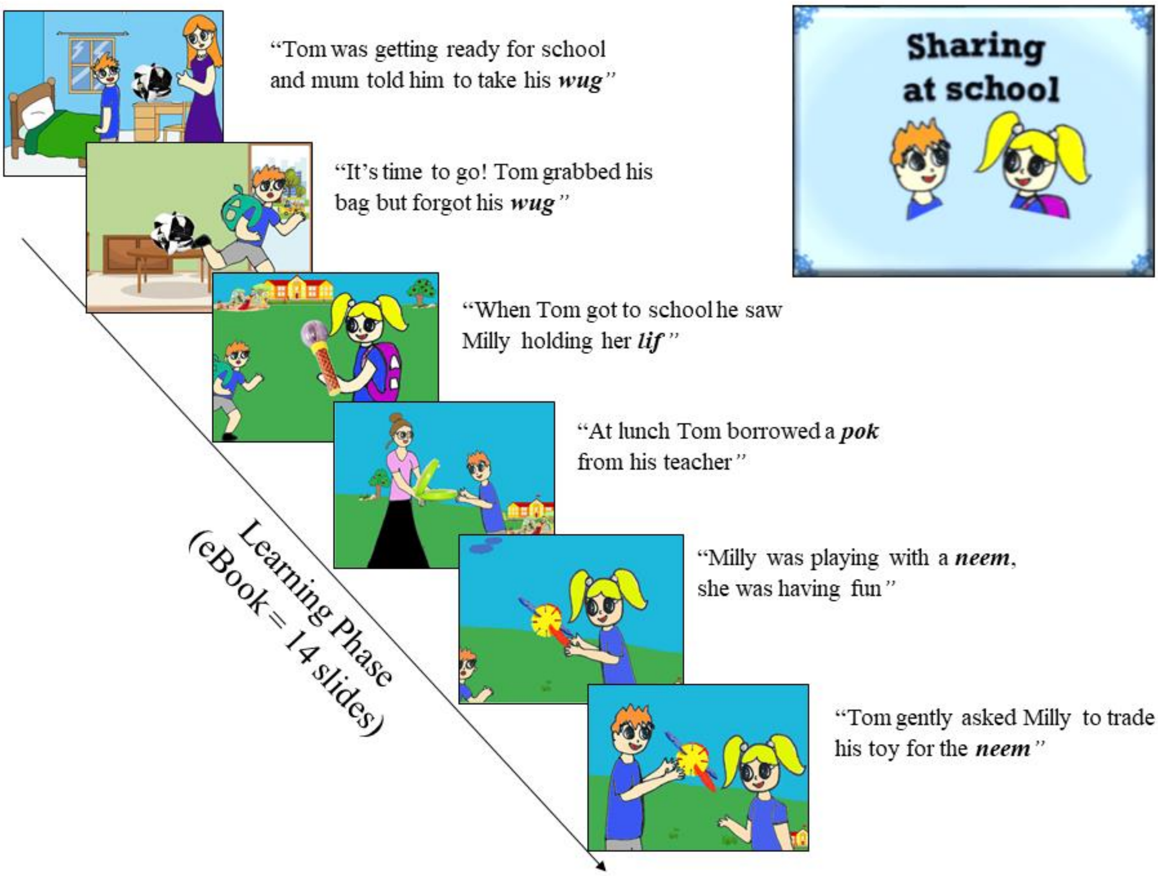
BLOCK 1		
Picture 1	**Picture 2**	**Sound**
pok	dand	*pok*-dand
bink	*pok*	bink-*pok*
drit	*pok*	*pok*-drit
attention getter		
pok	bem	*pok*-bem
pok	doff	doff-*pok*
posk	*pok*	posk-*pok*
attention getter		
BLOCK 2		
Picture 1	**Picture 2**	**Sound**
dand	*neem*	dand-*neem*
neem	bink	bink-*neem*
drit	*neem*	*neem*-drit
attention getter		
bem	*neem*	*neem*-bem
doff	*neem*	doff-*neem*
neem	posk	*neem*-posk
attention getter		

BLOCK 3		
Picture 1	**Picture 2**	**Sound**
lif	dand	*lif*-dand
bink	*lif*	bink-*lif*
drit	*lif*	*lif*-drit
attention getter		
bem	*lif*	bem-*lif*
doff	*lif*	*lif*-doff
lif	posk	*lif*-posk
attention getter		
BLOCK 4		
Picture 1	**Picture 2**	**Sound**
dand	*wug*	dand-*wug*
wug	bink	*wug*-bink
drit	*wug*	*wug*-drit
attention getter		
wug	bem	*wug*-bem
wug	doff	doff-*wug*
posk	*wug*	posk-*wug*
attention getter		

Appendix D: Original story used in the eBook paradigm. Target words are in italics.

1. Title slide: This is a story called Sharing at School!
2. Tom was getting ready for school and mum told him to take his *wug*.
3. It's time to go! Tom grabbed his bag but forgot his *wug*
4. When Tom got to school he saw Milly holding her *lif*.
5. Oh no! Tom realised he forgot his *wug* and was very sad!
6. Milly let Tom play with her *lif* and that cheered him up!
7. Tom thanked Milly and off he went to play with the *lif*!
8. At lunch Tom borrowed a *pok* from his teacher.
9. He was excited and went to show Milly the *pok*.
10. Milly was playing with a *neem*, she was having fun!
11. Tom had the *pok* for too long and didn't want it anymore!
12. Tom gently asked Milly to trade his toy for the *neem*.
13. Milly was happy to trade her *neem* and gave it Tom
14. Closing slide: Tom and Milly were very good at sharing! Great job guys!

Appendix E: An example of the visuals accompanying the eBook story.



Appendix F: The test trial order used for the three word-learning paradigms. Target words are in italics.

Picture 1 Top-left	Picture 2 Top-right	Picture 3 Bottom-left	Picture 4 Bottom- right	Sound
pok	*neem*	*lif*	*wug*	Where is the *neem*?
neem	*pok*	*wug*	*lif*	Find the *wug*!
lif	*wug*	*pok*	*neem*	Where is the *lif*?
wug	*lif*	*neem*	*pok*	Find the *pok*!
neem	*lif*	*pok*	*wug*	Where is the *lif*?
pok	*wug*	*neem*	*lif*	Find the *neem*!
wug	*lif*	*neem*	*pok*	Where is the *pok*?
lif	*wug*	*pok*	*neem*	Where is the *wug*?

Appendix G: Instructions for the Frog Matrices Task

Frog matrices scripts (pre-recorded)

Hello, we are going to play the jumpy frog game!

You are going to see nine ponds on the screen, some of the ponds have a frog on them.

Jumpy frog always forgets what pond he jumped on before! Can you show him what ponds he has jumped on so that he doesn't jump on them again? Please do it as quickly as possible, before he gets lost!

Please pay attention to this example (recorded example appears on the screen)

Let's have a short practice first. … Q. Where was the frog? (2 practice trials)

Are you ready to play the jumpy frog game? Please touch the frog to start!
