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BOSTON UNIVERSITY

SARGENT COLLEGE OF HEALTH AND REHABILITATION SCIENCES

Thesis

EXECUTIVE FUNCTIONING, WORD LEARNING, AND BILINGUALISM IN CHILDREN

by

GABRIELA RUSHI

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Submitted in partial fulfillment of the
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Master of Science
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EXECUTIVE FUNCTIONING, WORD LEARNING, AND BILINGUALISM IN CHILDREN

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ABSTRACT

Purpose: Cross-situational word-learning (CSWL) — the ability to learn words by tracking co-occurrence statistics of words and their referents over time — is a fundamental mechanism underlying lexical learning. Recent research suggests that memory and attention may support statistical word learning, but it is unclear if other cognitive processing skills, such as executive functioning skills (EF), may also play a role in CSWL. Therefore, the purpose of this study is to examine the role of EF skills in CSWL performance in monolingual and bilingual children. Specifically, we were interested in whether children's shifting, switching, and monitoring skills as indexed by the Dimensional Change Card Sort task (DCCS) predicted children's CSWL performance.

Method: Forty-three monolingual and thirty-four bilingual participants ages 5–9 were tested. Participants completed standardized measures of language and cognition. Word learning was measured via CSWL using a 2-alternative forced choice task. Children also completed a DCCS task. DCCS accuracy and reaction time (RT) data were collected. Three performance indices were computed for accuracy and RT: shifting costs (indexing task shifting skills); switching costs (indexing inhibition skills) and mixing costs (indexing monitoring skills).

Results: Main effects of cost indices and language group, as well as interactions between cost indices and language group were not significant in most models. However, a significant main effect of shifting cost was observed, such that higher shifting costs were associated with higher likelihoods of learning words. Age also significantly predicted CSWL performance such that older children were more likely to learn word-referent pairs than younger children.

Conclusion: Results suggest that EF skills and bilingualism may play a limited role in shaping and supporting how children acquire words via CSWL mechanisms. Our results also suggest that children's CSWL skills improve with age. Our findings are consistent with previous studies suggesting that bilingualism may not alter core statistical learning abilities as well as with studies suggesting different developmental patterns of CSWL skills.

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LIST OF ABBREVIATIONS

CSWL	Cross-Situational Word Learning
DCCS	Dimensional Change Card Sort
RT	Reaction Time

Introduction

Infants and children acquire new words quickly from the environment around them. One mechanism that aids in the development of vocabulary is cross-situational word learning (CSWL; Yu & Smith, 2007). In a typical CSWL experiment, participants are presented with trials of novel words and referents. Critically, participants are not explicitly told which word labels which referent. Yet, studies have shown that humans across the lifespan are capable of learning words via CSWL (Smith & Yu, 2008; Vlach & DeBrock, 2017; Yu & Smith, 2007). Researchers theorize that learning occurs via the tracking of co-occurring statistics between words and referents across experimental trials. Recent research has revealed that cognitive processes such as attention (e.g., Yu & Smith, 2011; Smith & Yu, 2013) and memory (e.g. Vlach & DeBrock, 2017; 2019) support CSWL performance in children. However, it remains unknown if other cognitive processes linked to word learning might also be implicated, such as executive functions (EF) - higher-level cognitive processes that are involved in goal-driven behavior (Best & Miller, 2010; Diamond, 2013; Miller & Cohen, 2001). Therefore, in the current study, we propose to examine the role of EF skills in CSWL performance in monolingual and bilingual children.

Cross-situational word learning (CSWL)

Studies in infants (e.g., Smith & Yu, 2008; Smith & Yu, 2013; Vlach & Johnson, 2013; Yu & Smith, 2011), children (e.g., Crespo & Kaushanskaya, 2021; Crespo et al., 2023; Vlach & DeBrock 2017; Vlach & DeBrock 2019), and adults (e.g., Benitez et al., 2016; Poepsel & Weiss, 2016; Yurovsky et al., 2013) have shown that there is significant variability in the ability to learn words via CSWL. In recent years, researchers have begun to explore how cognitive skills contribute to CSWL. For example, studies have shown that differences in attention have been linked to variability in CSWL performance, with stronger learners demonstrating longer durations of looks to correct word-object associations than weaker learners (Yu & Smith, 2011; Smith & Yu, 2013). Other studies have reported that memory also supports CSWL performance, predicting children's word learning above age and language skills (Vlach & DeBrock, 2017; Vlach & Johnson, 2013; Vlach & Sandhofer, 2014). Vlach and DeBrock (2017) theorized that participants may use global memory skills to remember visual and auditory stimuli to form word-object mappings over time (Vlach & DeBrock, 2017). Given the emerging evidence that explicit processes may support CSWL, we sought to investigate whether executive function skills might also be implicated in CSWL performance.

The competition hypothesis of CSWL proposed by Yurovsky and colleagues (2013) may offer additional support for the role of EF in CSWL. Yurovsky and colleagues (2013) found that learners track information about word-object associations both within and across trials during a CSWL experiment (Yurovsky, Yu, & Smith, 2013). The researchers proposed that as learners track co-occurring statistics, they engage in a competitive process where stronger word-referent representations actively inhibit competing word-referent representations (Yurovsky et al., 2013). Under this account, competition reduces attention toward spurious associations in the input, allowing the learner to converge on correct word-referent mappings more quickly. Critically, this theoretical account has not been tested experimentally. If competition underlies CSWL, then learners may recruit EF skills linked to inhibition among other processes needed to converge on correct word-referent pairings.

Supporting evidence for a role of EF in CSWL may also be found in the explicit word-learning literature, where objects are ostensibly labeled. For example, Kapa & Erikson (2020) found that EF accounted for significant variance in word learning. In their study, 41 preschool-aged children completed a word-learning paradigm in which they were introduced to ten novel pseudowords nouns that referred to familiar and unknown objects. Children also completed EF measures to index sustained selective attention, short-term memory, working memory, inhibition, and shifting. Results showed that inhibition and short-term memory were significant predictors of novel word learning outcomes.

Similarly, Kapa & Colombo (2014) observed a link between EF and word learning performance. In their study, 79 monolingual college-aged adults and 44 preschool-aged children completed an artificial word learning task and EF tasks measuring inhibitory control, shifting, and monitoring skills. In the word learning task, participants were exposed to a simplified artificial language consisting of twelve nouns and four verbs. Results showed that participants with better EF skills were more successful in learning the artificial language. Specifically, for the college-aged students, inhibitory control predicted performance, whereas for the preschoolers, monitoring and shifting skills predicted learning (Kapa & Colombo, 2014). Given the link between EF skills and explicit word learning, we hypothesized a similar link may also be observed between EF skills and statistical word learning.

Executive Function

Performance on EF tasks, such as the Dimensional Change Card Sort (DCCS), are commonly used to examine EF skills in children (Doebel & Zelazo, 2015; Frye, Zelazo & Palfai, 1995; Zelazo, Frye & Rapus, 1996; Zelazo, Müller, Frye & Marcovitch, 2003). The DCCS task has good developmental sensitivity and convergent validity, allowing researchers to measure EF across childhood (Zelazo, Anderson, Richler, Wallner-Allen, Beaumont, & Weintraub, 2013).

In the DCCS task, children first sort shapes by color (i.e., pre-switch phase). Afterward, children are instructed to sort the same stimuli by shape (i.e., post-switch phase). A mixing phase is then introduced, where children are required to monitor the rule of each trial to sort either by color or shape. With this task, three performance indices are computed to index three executive functioning skills: shifting, switching, and monitoring (Monsell, 2003; Kiesel et al., 2010).

Shifting refers to the ability to switch between different mental sets (Miyake et al., 2000). Studies have found that children begin to succeed with shifting from one dimension to another at 4.6 - 5.0 years of age (Zelazo, 2006). Shifting costs on the DCCS task are calculated by comparing performance in the pre-switch phase, where children first sort by color, to performance in the post-switch phase, where children sort by shape. Shifting costs capture the decrease in accuracy and increase in reaction time that typically occurs when shifting to a different mental set (Monsell, 1996). Researchers theorize that this cost in performance may be due to the increased cognitive processing it takes to cease following the previous rule and focus on sorting according to the new rule.

Inhibition skills, the ability to suppress a response or ignore irrelevant information (Bialystok & Martin, 2004; Miyake et al., 2000), is believed to be recruited to support the ability to shift and sort by a new rule.

Switching may also implicate inhibition processes. Switching costs are calculated by comparing performance in the mixing phase on switch trials, where children sort by a different rule in back-to-back trials, to non-switch trials, where children sort by the same rule from the previous trial. Switching costs indexes inhibition because rules may persist in memory, facilitating performance when the sorting rule repeats (i.e., non-switch trials), but creating interference when the sorting rule switches (i.e., switch trials; Altmann & Gray, 2008; Monsell, 2003).

Monitoring, or updating, is the ability to update and maintain multiple tasks, recruiting working memory skills (Miyake et al., 2000). Mixing costs are calculated by comparing performance (i.e., accuracy or RT) for non-switch trials during the mixed phase, where participants are required to monitor the sorting rule, with overall performance in the pre-switch phase, where participants sort by color only. Participants are required to evaluate incoming information and determine its relevance to the task. If information is relevant, then it is used to replace older content that is no longer necessary to complete the task (Morris & Jones, 1990). Failures in updating may result from challenges with maintaining a “superordinate” rule in which participants must switch between the preswitch and postswitch rules (Zelazo & Frye, 1998; Chatham et al., 2012). They may also be credited to difficulty with assessing the environment for the demand to switch tasks (Chatham et al., 2012).

In the present study, we investigated the relationship between EF (as indexed by performance on the DCCS task) and CSWL performance. We used switching, shifting, and monitoring as our measure of EF, as these skills may be implicated in CSWL to keep track of novel words and referents over trials and inhibit incorrect word-referent pairings. We also explored the possibility that the relationship between EF and CSWL may be moderated by children's bilingual experience, through testing school-aged bilingual children with a range of second language acquisition histories.

Bilingualism

Studies examining the effects of bilingualism on CSWL performance generally report that monolinguals and bilinguals learn novel words equally well (e.g., Benitez et al., 2016; Crespo, Vlach, & Kaushanskaya, 2023; Poepsel & Weiss, 2016). However, Escudero et al. (2016) observed higher accuracy for bilingual than monolingual adults. The authors suggested that enhanced phonological working memory, executive functioning skills, or a combination of the two, supported CSWL performance in bilinguals. Conversely, Crespo & Kaushanskaya (2021) did not find a bilingual advantage in a CSWL task. Instead, the authors reported that monolingual children outperformed bilingual children; monolingual children showed longer looking times and faster word recognition of correct word-referent pairs than bilingual participants. It is unclear why some studies report null effects of bilingualism on CSWL performance, while others report advantages and disadvantages. It is possible that methodological differences across CSWL tasks and sample characteristics may be responsible for the mixed pattern of findings.

Variability in bilingual experience may yield variability in children's EF skills. However, mixed results have been found regarding whether bilingualism influences the development of EF skills. Some researchers theorize that bilingualism confers advantages in EF skills that stem from constantly managing two languages at once, a process that requires attention to the language they are using while also having to inhibit their other language (Kroll & Bialystok, 2013, Poarch & Bialystok, 2015).

Countering research provides no evidence for a bilingual advantage (e.g., Papp & Greenberg, 2013; Gathercole et al., 2014). For example, Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes, et al. (2014) found no differences between 252 monolingual and 252 bilingual children on different tasks indexing inhibition. Antón, Duñabeitia, Estévez, Hernández, Castillo, Fuentes, Davidson & Carreiras (2014), also reported that the bilingual advantage could not be replicated using a large sample of 180 Spanish monolingual children and 180 bilingual children speaking both Spanish and Basque.

Rather than a global EF advantage, some researchers have hypothesized that bilingual experiences may influence specific EF skills. For example, Park et al., (2018) investigated the development of EF skills in monolingual and bilingual participants at two time points, one year apart. Inhibition and monitoring skills were measured, among other EF skills. Results showed group effects on the development of inhibition, with monolingual performance remaining the same, while bilinguals showed improvement from year 1 to year 2. There was also evidence of a bilingual advantage with monitoring skills at both time points. Findings from this study suggest that specific EF may undergo different developmental trajectories in monolingual and bilingual children.

Similarly, Bialystok (2001) provided a comprehensive literature review noting advanced inhibition skills in children with bilingual experience. Measuring multiple EF skills in the current study allowed us to identify whether different EF support CSWL performance, as well as whether monolingual and bilingual children rely on different EF skills when learning new words via CSWL.

Current Study

The current study examined the role of EF skills in CSWL performance in monolingual and bilingual children. Specifically, we were interested in whether children's shifting, switching, and monitoring skills as indexed by the DCCS predicted children's CSWL performance. Based on findings implicating cognitive skills in CSWL (e.g., attention and memory; Yu & Smith, 2011; Vlach & DeBrock, 2019) and robust links in the explicit word learning literature between EF skills and word learning performance (Bohlmann et al., 2015; Gray et al., 2022; Kapa & Colombo 2014; Kapa & Erikson 2020), we hypothesized a relationship between EF and CSWL. Specifically, we anticipated that increases in EF skills would result in better CSWL performance.

It is challenging to make firm hypotheses about interactions between CSWL, EF and bilingualism given the current limitations in the evidence and in our theories. Here, we consider three exploratory hypotheses: Given the lack of evidence for bilingual advantages in CSWL (e.g., Crespo et al., 2023; Poepsel & Weiss, 2016) and in EF skills (Anton et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014; Papp & Greenberg, 2013), we expected monolinguals and bilinguals to perform similarly on the DCCS task and to learn novel words equally well. However, if bilingual advantages in CSWL

(Escudero et al., 2016) and/or in EF (e.g., Bialystok 2011; Park et al., 2018; Poarch & Bialystok 2015) were observed, then an alternative hypothesis is that bilingual children may outperform monolingual children on one or both tasks. A third hypothesis is that monolingual children and bilingual children may recruit different EF skills during CSWL. Evidence from Park et al. (2018) suggests that monolingual and bilingual children may differ in their development of EF skills. One possibility is that different developmental patterns of EF development may yield a different pattern of EF skills implicated in CSWL between monolinguals and bilinguals.

Methods

Participants

Seventy-seven children ages 5 – 9 were recruited nationally and tested remotely via Zoom. This age range was selected for three key reasons. First, age five is the youngest age children successfully complete the DCCS task; before age five, children typically show preservation of sorting by a single pattern (Doebel & Zelazo, 2015; Zelazo, 2006). Second, in this age range children are experiencing significant development in EF skills. These skills are expected to develop until age 12, where they are observed as relatively mature (Anderson, 2002; Welsh, Pennington, & Groisser, 2009). Additionally, early childhood is a time of rapid vocabulary growth (Bloom, 2000) and therefore it is theoretically important to understand how mechanisms of word-learning function during this period.

The current study included forty-three monolingual and thirty-four bilingual children. Participants were considered bilingual if they had 20% or more exposure to a second language per parent report. Inclusionary criteria included normal or corrected vision, normal hearing per parent report, language scores within normal limits on standardized assessments, and a nonverbal IQ standard score greater than 70. For bilingual children, inclusionary criteria included speaking Spanish. Exclusionary criteria included exposure to a third language, history of hearing loss, neurodevelopmental disorders, and other neurological conditions.

Monolingual and bilingual children were matched on age, SES (as indexed by mother's years of education), and nonverbal IQ. However, monolingual children were first exposed to English earlier, and had greater English exposure at the time of testing than bilingual children. Monolingual children also had more robust English language skills than bilinguals. However, when English and Spanish skills were both considered for bilingual children, monolinguals and bilinguals did not differ on overall language ability. See Table 1 for participant characteristics.

Procedure

Children participated in 3–4 sessions on Zoom where they completed standardized measures of language and cognition, and two experimental tasks: the CSWL task and the DCCS task. Our experimental tasks were administered on Gorilla Experiment Builder (https://gorilla.sc), an online platform for building and hosting experiments online. Caregivers completed the Language Experience Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007), and a background questionnaire to collect information regarding the caregiver's language skills and participant's demographic information, including information about their children's language acquisition histories and current language use.

Table 1

Participant Characteristics, M (SD)

	Monolinguals		Bilinguals		
	M (SD)	*Range*	*M (SD)*	*Range*	*t*
N	43 (18 boys)		34 (17 boys)		-
Age	7.70 (1.49)	5.08 – 9.83	7.62 (1.58)	5 – 9.92	0.25
Mother's Years of Education	18.81 (2.44)	14 – 24	17.40 (3.63)	9 – 25	1.95
Nonverbal IQ[a]	110.42 (14.83)	76 – 147	106.03 (14.18)	80 – 143	1.32
First Exposure to English (months)	0.0 (0.00)	0 – 0	11.24 (18.59)	0 – 72	-3.52^{**}
Current English Exposure (%)	98.35 (3.90)	84 – 100	59.65 (14.29)	30 – 80	15.57^{***}
English Language Skills[b]	111.56 (15.33)	79 – 145	102.62 (16.17)	75 – 148	2.46^{*}
First Exposure to Spanish (months)	-	-	0.54 (2.92)	0 – 17	-
Current Spanish Exposure (%)	-	-	40.35 (14.29)	20 – 70	-
Spanish Language Skills[c]	-	-	91.67 (18.58)	62 - 125	-
Overall Language Ability[d]	-	-	104.68 (16.36)	75 - 148	1.88
Race	*n*		*n*		
White or Caucasian	32		24		
Black or African American	3		1		
Asian	2		-		
Biracial	6[e]		3[f]		
Non-specified			6		
Ethnicity					
Hispanic/Latinx	6		29		
Not Hispanic/Latinx	37		5		
Child's Dominant Language			*n*		
English			17		
Spanish			4		
English & Spanish Equally			13		

Language Mostly Spoken at Home	
English	6
Spanish	12
English & Spanish equally	16

[a] Visual Matrices subtest, *Kauffman Brief Intelligence Test – 2nd Edition*
[b] Core Language Index Score from *Clinical Evaluation of Language Fundamentals – 5th Edition*
[c] Core Language Index Score from *Clinical Evaluation of Language Fundamentals – 4th Edition, Spanish*
[d] Highest Core Language Index Score from either CELF-5 English or CELF-4 Spanish.
[e] 5 White and Asian; 1 White and Black
[f] 2 Mixed; 1 White and Asian
* $p < .05$, ** $p < 0.01$, *** $p < .001$

Standardized Measures

The Clinical Evaluation of Language Fundamentals-Fifth Edition (CELF-5; Wiig, Semel, & Secord, 2013) was administered to assess participants' receptive and expressive language skills in English, and the CELF-4 Spanish (Wiig, Semel, & Secord, 2003) for the bilinguals' receptive and expressive language skills in Spanish. The Visual Matrices subtest from the Kaufman Brief Intelligence Test Second Edition (KBIT-2) was administered to assess participants' nonverbal intelligence (Kaufman & Kaufman., 2004). The Visual Matrices subtest required participants to identify relationships among pictures and complete visual analogies.

Experimental Tasks

CSWL Paradigm

Stimuli. The CSWL task used in this study is from Crespo, Vlach, and Kaushanskaya (2023). This task uses two lists of five novel words from the Gupta et al. (2004) database. Novel words consisted of English phonemes; followed a common English-language phonotactic structure (i.e., CVCVC); and were produced by monolingual English-speakers. The Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Densities (CLEARPOND) Database (Marian, Bartolotti, Chabal, & Shook, 2012) was used to compute English and Spanish biphone probability and neighborhood density for each word. Words were combined into lists, and pairwise comparisons indicated that there were no significant differences in English or Spanish biphone probability or neighborhood density across word lists. Colorful novel objects chosen from the Horst & Hout (2016) Novel Object & Unusual Name (NOUN) Database 2nd Edition were presented to participants and pseudo-randomized to map onto the novel words. See Appendix A for the lists of word-object pairings.

Experimental Procedure. The CSWL task had an exposure phase and a test phase.

Exposure Phase. Participants were instructed to learn the names of new toys by looking and listening. No information about which novel word mapped onto which object was provided. The exposure phase consisted of 25 trials, with each word-object pair appearing ten times in a pseudorandomized order. In each trial, two novel objects were presented, one on the right and one on the left. Participants heard one novel word at trial onset and the second novel word at 2000 ms after trial onset. Each trial lasted 6000 ms.

Test Phase. After the exposure phase, participants immediately moved onto the testing phase. Participants completed 10 testing trials, assessing knowledge of each word-object pair twice. In each trial, the participants were shown a target object and a foil object side by side via a 2-alternate force choice display. Each word-object pair acted as a foil twice and was paired with one of the other five word-object pairs from the exposure phase. Novel objects were shown at trial onset. The target word was produced once at 2,000 ms after trial onset. Participants were given 4,000 ms after the production of the target word to make a response by selecting a novel object. Target words in the testing phase were produced by a novel female speaker. Target objects were novel exemplars that varied by size or color from the exemplar children were shown during the exposure phase. See Appendix B for a visual depiction of the CSWL task.

Dimensional Change Card Sort (DCCS) Task

The DCCS task was used to measure EF skills via three cost indices: shifting, switching, and monitoring. The DCCS task used was adapted from Crespo et al. (2019). Instructions were pre-recorded and presented in English. Participants were instructed to sort two objects in this task — red circles and blue squares — by either color or shape. At the beginning of the task, participants were introduced to sorting cues that were provided at the top of the screen to indicate whether the participant should sort by color or shape.

Experimental Procedure. The DCCS task had a training block, pre-switch phase, post-switch phase, and a mixing phase (See Figure 1). At the beginning of the task, participants were shown an instruction video. In the training block, participants first sorted by color only. During this phase, participants were shown a row of amorphous color patches at the top of the screen in each trial to indicate that they should sort by color. In the pre-switch phase, participants continued sorting by color, following the rules used in the training block. In the post-switch phase, participants sorted by shape only. When sorting by shape they saw a row of gray circles and squares at the top of the screen in each trial to indicate that they should sort by shape. The sorting cues remained on the top of the screen throughout each phase of the DCCS task. In the mixing phase, the sorting rule changed each trial, requiring participants to monitor the sorting cue at the top of the screen.

Training Block. The DCCS task began with a 4-trial pre-switch training block. The training block was designed to familiarize the participants with the task and demonstrated how to sort the stimuli into the bins by color. In a pre-recorded video, the participants were instructed to sort the stimuli by color, selecting either red or blue. Responses were provided using the keyboard on the laptop or computer. To select red, the participant pressed “z” and to select blue, the participant pressed “m”. At trial onset, the sorting bins were displayed until 800 ms. Next, a sorting cue was shown for 500 ms. After the cue, a red square or blue circle appeared in the center of the screen. Participants had to press “m” or “z” to sort the target object and proceed to the next trial. If the participant responded correctly, they were provided feedback in the form of a smiley face. If the participant responded incorrectly, they were provided feedback in the form of a frowning face. If the participant scored below 75% accuracy, the training block was automatically repeated.

Pre-Switch Phase. After the training block, participants automatically progressed to the pre-switch trials, which followed the same presentation timings as the training trials. The pre-switch phase consisted of 5 randomized trials with no feedback.

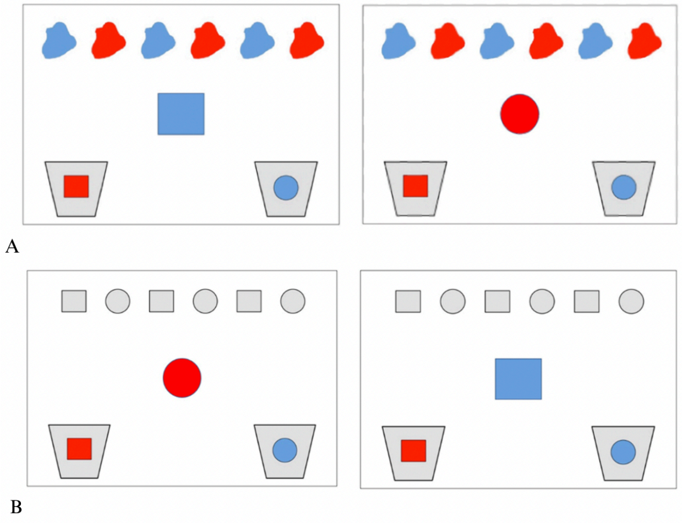
Post-Switch Phase. After the pre-switch phase, the participants immediately proceeded to the post-switch phase, where they were shown video instructions instructing them to sort by shape. The participants were shown the same stimuli of red circles and blue squares. They were instructed to sort the stimuli by shape, selecting either square or circle. Responses were provided using the keyboard on the laptop or computer. To select square, the participant pressed “z” and to select circle, the participant pressed “m”.

The post-switch phase consisted of 5 randomized trials with no feedback. Post-switch trials followed the same presentation timings as the training trials.

Mixing Phase. Following the post-switch phase, participants immediately moved onto the mixing phase. Participants sorted by both color and shape, as depicted by the cue at the top of the screen. This block consisted of 30 pseudorandomized trials, consisting of 23 shape trials with 7 color trials interspersed. Participants completed 2-5 shape trials between each color trial. There were 13 switch trials, in which participants switched sorting rules (e.g. from shape to color or color to shape) and 17 non-switch trials in which participants continued sorting by shape. Mixing trials followed the same presentation timings as the training trials.

Figure 1

Dimensional Change Card Sort (DCCS) Task



Note. The Dimensional Change Card Sort task consisted of a (A) Pre-Switch Phase, (B) Post-Switch Phase, and (C) Mixing Phase where children sorted by both color and shape. During each trial, a sorting cue was displayed at the top of the screen.

Analyses

Descriptive data for DCCS performance are presented in Table 2. Reaction time (RT) data were analyzed for correct responses only. RTs below 150 milliseconds and beyond 2.5 standard deviation of each individual child's mean were trimmed. Because RT data were not normally distributed, all RTs were log transformed to log10 values to reduce skewness.

Difference scores were calculated to create cost index. Three accuracy cost indices and three RT cost indices from the DCCS task were calculated to index shifting, switching, and monitoring costs. Shifting costs compared overall performance (i.e., mean accuracy or mean RT) on the pre-switch phase with overall performance in the post-switch phase. Larger numbers on the shifting cost index indicated greater difficulty in shifting from sorting by color to sorting by shape.

Switching costs were calculated from the mixing phase performance on non-switch trials (i.e., accuracy or RT), where participants sorted by shape on back-to-back trials, was compared with performance on switch trials, where participants switched from sorting to shape to sorting by color. Larger switching costs indicated greater difficulty in switching back and forth between sorting rules.

Mixing costs were calculated by comparing performance (i.e., accuracy or RT) for non-switch trials during the mixed phase, where participants were required to monitor the sorting rule, with overall performance in the pre-switch phase, where participants sorted by color only. Higher mixing costs indicated reductions in accuracy or increases in RT associated with monitoring the rule of each trial in the mixing phase.

We estimated six separate linear mixed effects models in R (R Core Team, 2022). We regressed proportion correct on the CSWL task on each cost index (mean centered), language group (contrast coded; -.5, .5) and the interaction between each cost index and language group. Stepwise model comparisons were conducted that included different demographic variables as covariates in the analyses. Age significantly improved model fits (*ps* < .05) and was thus included as a covariate in all final models given the broad age range of the children included in the study. The inclusion of mother's years of education, English age of acquisition, and English exposure did not significantly improve model fit (*ps* > .05).

Results

Results revealed that monolingual children (*M* = .81, SD = .21; *Range:* 0.33 – 1.00; *t*(42) = 9.95, *p* < .001) and bilingual children (*M* = 0.77, *SD* = 0.22; *Range*: 0.22 – 1.00; *t*(33) = 6.97, *p* < .001) learned word-object pairs above chance levels (i.e., .50) in the CSWL task. Monolingual children and bilingual children performed similarly on the CSWL task (*t*(68.19) = 0.93, *p* = .35).

Results also revealed that monolingual children (*M* = .79, SD = .17; *Range:* 0.33 – 1.00) and bilingual children (*M* = 0.78, *SD* = 0.17; *Range*: 0.30 – 1.00) had similar overall accuracy on the DCCS task (*t*(70.41) = 0.15, *p* = .88). Monolingual children ($M_{milliseconds}$ = 1840.48, $SD_{milliseconds}$ = 651.94; Range: 938.50 - 4029.44) and bilingual children ($M_{milliseconds}$ = 1726.04, $SD_{milliseconds}$ = 626.14; *Range*: 836.94 - 3413.60) also had similar overall RT on the DCCS task (*t*(72.16) = 0.78, *p* = .44). Accuracy and RT Shifting, Switching and Mixing Cost Indices did not significantly differ between monolinguals and bilinguals (*ps* > .05). See Table 2 for descriptive statistics for each cost index by group.

Table 2

Descriptive Statistics for DCCS Cost Indices by Language Group

	Monolinguals		Bilinguals		
Accuracy	*M* (*SD*)	*Range*	*M* (*SD*)	*Range*	*t*
Shifting Cost	0.15 (0.26)	-0.40 – 0.80	0.12 (0.23)	-0.20 – 0.80	0.46
Switching Cost	0.09 (0.36)	-1.00 – 0.91	0.08 (0.44)	-1 – 1	0.06
Mixing Cost	0.16 (0.26)	-0.36 – 1.00	0.20 (0.24)	-0.11 – 1	-0.70
RTlog					
Shifting Cost	0.13 (0.12)	-0.07 – 0.46	0.13 (0.12)	-0.06 – 0.56	0.02
Switching Cost	0 (0.12)	-0.38 – 0.21	-0.01 (0.15)	-0.47 – 0.20	0.33
Mixing Cost	0.22 (0.14)	-0.06 – 0.58	0.22 (0.18)	-0.27 – 0.56	-0.04

Across the three models examining the relationship between CSWL performance and DCCS accuracy cost indices, results revealed a main effect of age where older children were more likely to learn word-referent pairs than younger children. Main effects of cost indices and language group, as well as interactions between cost indices and language group were not significant ($p > .05$). Refer to Tables 3–5.

Across the three models examining the relationship between CSWL performance and DCCS RT cost measures, results also revealed a main effect of age where older children were more likely to correctly identify word-referent pairs than younger children. A significant main effect of Shifting RT Cost was also observed ($B = 0.35$, $SE = 0.16$, $z = 2.19$, $p = .03$), such that higher Shifting Costs were associated with higher likelihoods of learning words (Figure 2). That is, children who slowed down more when shifting from sorting by color in the pre-switch phase to sorting by shape in the post-switch phase were more likely to correctly identify word-object pairs at test in the CSWL task. Main effects of Switching and Mixing RT costs, language group, and their interactions were not significant (*ps* > .05). See Tables 6-8 for full model results.

Table 3

Model Results for Shifting Costs in Accuracy

	B	*SE*	*z*	*p*
Intercept	-1.47	0.97	-1.52	0.13
Shifting Cost	-0.04	0.19	-0.22	0.83
Language Group	-0.30	0.32	-0.94	0.35
Age	0.42	0.13	3.21	<0.001***
Shifting Cost X Language Group	0.58	0.34	1.72	0.09
Model Fit				
Observations	707			
Pseudo-R² (fixed effects)	0.12			
Pseudo-R² (total)	0.31			

Table 4

Model Results for Switching Costs in Accuracy

	B	SE	*z*	*p*
Intercept	-1.78	0.80	-2.23	0.03*
Switching Cost	0.09	0.15	0.62	0.54
Language Group	-0.26	0.31	-0.84	0.40
Age	0.46	0.11	4.31	<0.001***
Switching Cost X Language Group	-0.54	0.30	-1.81	0.07
Model Fit				
Observations	707			
Pseudo-R² (fixed effects)	0.12			
Pseudo-R² (total)	0.30			

Table 5

Model Results for Mixing Costs in Accuracy

	B	SE	*z*	*p*
Intercept	-1.44	0.79	-1.81	0.07
Mix Cost Accuracy	-0.13	0.16	-0.83	0.41
Language Group	-0.32	0.31	-1.03	0.30
Age	0.41	0.11	3.91	<0.001***
Mix Cost Accuracy X Language Group	0.62	0.32	1.94	0.05
Model Fit				
Observations	707			
Pseudo-R² (fixed effects)	0.13			
Pseudo-R² (total)	0.31			

Table 6

Model Results for Shifting Costs in Reaction Time (RT)

	B	SE	*z*	*p*
Intercept	-1.73	0.78	-2.22	0.03*
Shift Cost RT Log	0.33	0.16	2.04	0.04*
Language Group	-0.21	0.31	-0.67	0.50
Age	0.45	0.10	4.35	<0.001***
Shift Cost RT Log X Language Group	0.25	0.32	0.80	0.42
Model Fit				
Observations	707			
Pseudo-R² (fixed effects)	0.13			
Pseudo-R² (total)	0.30			

Table 7

Model Results for Switching Costs in Reaction Time (RT)

	B	SE	*z*	*p*
Intercept	-2.06	0.84	-2.45	0.01*
Switch Cost RT Log	0.02	0.15	0.10	0.92
Language Group	-0.22	0.33	-0.65	0.51
Age	0.49	0.11	4.39	<0.001***
Switch Cost RT Log X Language Group	-0.32	0.31	-1.06	0.29
Model Fit				
Observations	661			
Pseudo-R² (fixed effects)	0.12			
Pseudo-R² (total)	0.31			

Table 8

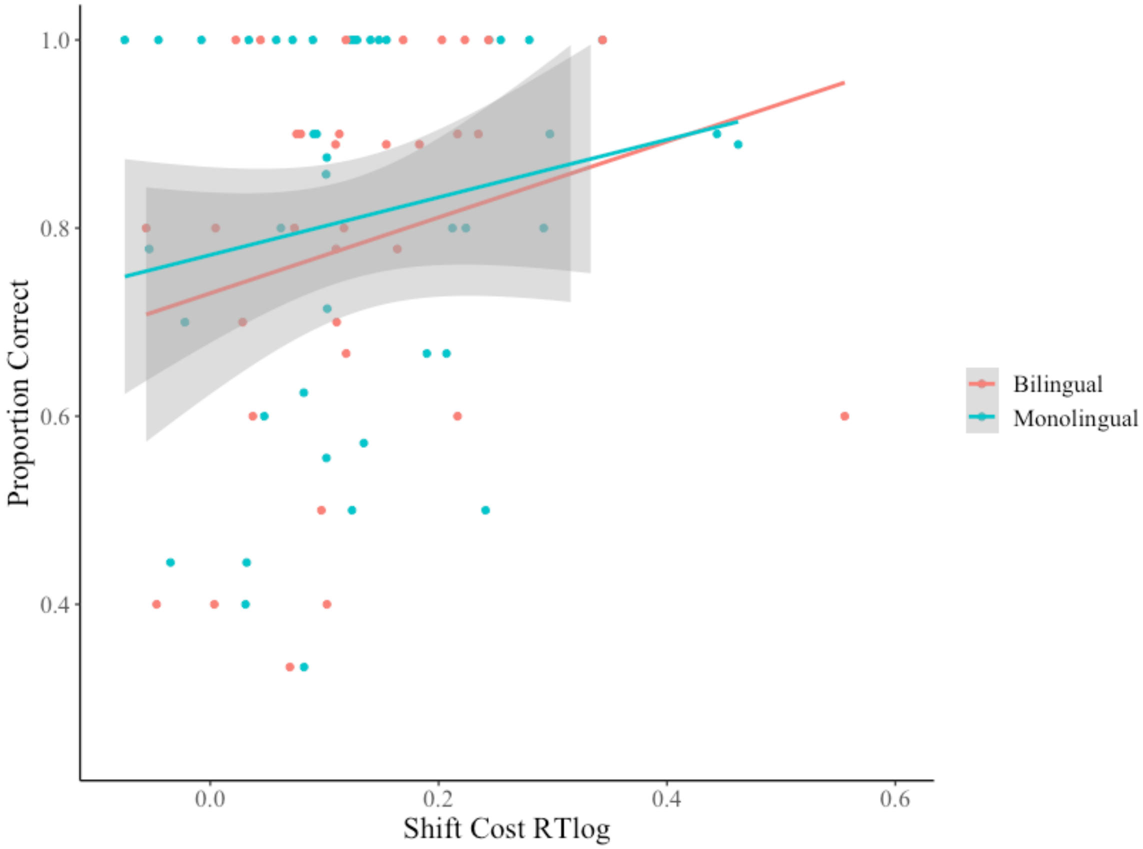
Model Results for Mixing Costs in Reaction Time (RT)

	B	SE	*z*	*p*
Intercept	-1.85	0.90	-2.06	0.04*
Mix Cost RT Log	-0.07	0.18	-0.41	0.68
Language Group	-0.31	0.33	-0.93	0.35
Age	0.47	0.12	3.91	<0.001***
Mix Cost RT Log X Language Group	0.34	0.33	1.03	0.30
Model Fit				
Observations	680			
Pseudo-R² (fixed effects)	0.11			
Pseudo-R² (total)	0.31			

* $p < .05$, ** $p < 0.01$, *** $p < .001$.

Figure 2

Shifting Costs and Word Learning Accuracy by Group



Note. A significant main effect of Shifting RT Cost was observed such that children with higher shifting costs showed higher accuracy in learning words.

Discussion

The purpose of this study was to examine the role of executive functioning skills in CSWL performance in monolingual and bilingual children. Our measures of EF were derived from performance on the DCCS task, where we computed three accuracy and three RT cost indices to measure children's shifting, switching, and monitoring skills. Overall, results revealed that children's shifting, switching, and monitoring skills did not predict their CSWL performance. One exception is that children who obtained higher shifting costs in RT and slowed down more to sort by a different rule, were more likely to learn novel words via CSWL. Results also revealed that monolingual and bilingual children performed equally well on both CSWL and DCCS, and that language experience did not influence the role of EF in children's CSWL performance. Together, the results suggest that EF skills and language experiences may play a limited role in shaping and supporting how children acquire words via CSWL.

EF and CSWL

In the current study, children's EF skills related to task shifting, switching, and monitoring did not significantly predict their CSWL performance. This finding was surprising given previous work suggesting that explicit learning processes may support CSWL (e.g., Vlach & Debrock, 2017, 2019). Moreover, we specifically were interested in shifting, switching, and monitoring skills due to evidence of competition in CSWL (Yurovsky et al., 2013). In Yurovky et al.'s (2013) study, participants completed four CWSL tasks, manipulating the number of referents for each word and including noise words that did not map onto any words. Specifically, in their study, each trial consisted of words labeling one referent, words labeling two objects, and words labeling none of the objects. Each version of CSWL provided a role for global and local competition, both within and across trials. In our task, we used one-one to mappings, with each novel word matching onto one object consistently, which is consistent with other paradigms used with children (Smith & Yu, 2008; Vlach & Johnson, 2013). It is plausible that our less complex design may have decreased competition, thus not requiring the use of EF. The inclusion of noise words in their first task may also have increased the need for inhibition in Yurovsky's experiment, as participants were required to learn which word did not map onto an object, while then having to suppress this word on remaining trials. Future research should investigate the relationship between competitive processes and switching, shifting, and monitoring in more complex CSWL tasks.

While broad effects of EF were not observed, we did observe an unexpected finding where shifting costs in RT were associated with better word learning performance. That is, participants who slowed down more when shifting from sorting by color (i.e., the pre-switch phase) to sorting by shape (i.e., the post-switch phase) showed better performance on the CSWL task. One explanation is that children who slowed down in the post-switch phase may have been more conscientious about sorting correctly by shape, and in turn demonstrated increased engagement and subsequent learning on the CSWL task. Another possibility is that this inverse relationship between DCCS performance and CSWL performance may be a fluke in the data. Therefore, future research should examine these relationships with larger samples of children to determine whether relationships between children's shifting skills and their CSWL performance are indeed inversely related.

Furthermore, significant effects of age were consistently observed in all our models. This finding is consistent with previous research suggesting an improvement in cross-situational learning with age (Fitneva & Christiansen, 2017; Vlach & Debrock, 2019; Vlach & Johnson, 2013). Compared to later infancy and toddlerhood, the participants in our study were at the highest rate of vocabulary growth (Bloom, 2000). Our results are consistent with the maturation account, which proposes that improvements in language learning abilities result from general maturation of the brain over time (Newport, 1990; Vlach and DeBrock, 2017). Indeed, it may be that the developing language skills used in everyday life helped support CSWL, with older participants having more experiences to support word-learning.

Bilingualism and CSWL

In addition to the role of EF skills, we examined the effects of language experience on children's CSWL performance. Our results revealed that monolingual and bilingual children performed similarly on CSWL. This finding is inconsistent with Escudero et al. (2016), who observed better performance in bilingual adults than monolingual adults. However, our results are consistent with studies demonstrating that bilingualism may not impact core statistical learning skills (e.g., Yim & Rudoy, 2013) or skills in CSWL such as one-to-one word referent mappings (e.g., Benitez at al, 2016; Crespo et al., 2023; Poepsel & Weiss, 2016, Crespo & Kaushanskaya, 2021;).

Although most studies suggest that monolinguals and bilinguals have similar CSWL abilities, we consider the possibility that perhaps the absence of a bilingual advantage in the present study might be due to the task's difficulty level. Past research has shown that under complex learning conditions, bilingualism may impact CSWL performance (Benitez et al., 2016; Crespo et al., 2023; Poepsel & Weiss, 2016). For example, Poepsel & Weiss specifically did not find a bilingual advantage in learning one-to-one mappings, which is what children learned in the present study. However, the researchers found that bilinguals learned two-to-one mappings with less exposure and higher overall proficiency than monolinguals. Other research looking more widely at statistical learning and bilingualism suggest that bilingual advantages are most predominant in tasks with increased complexity, including using multiple cues or remapping words (e.g., Antovich & Graf Estes, 2018; Benitez et al., 2016; Crespo et al., 2023; Onnis et al., 2018).

EF, CSWL, and Bilingualism

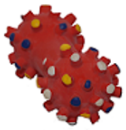
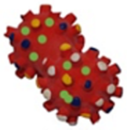
The results from the current study also revealed no differences in DCCS performance between monolinguals and bilinguals, and no differences in how language groups relied on EF skills during CSWL. The lack of bilingual advantages in EF is consistent with prior research demonstrating similar results in both groups across different EF measures including inhibition, switching, and attention (Anton et al., 2014; Duñabeitia et al., 2014; Papp & Greenberg, 2013; Gathercole et al., 2014). While global EF advantages were unlikely, we considered the possibility that a different pattern of EF skills may be implicated in CSWL between monolinguals and bilinguals (e.g., Park et al., 2018). We failed to observe this trend as well. One possibility is that developmental differences in EF skills may be smaller in younger children than in older children school-aged children. Future studies are needed to elucidate relationships between EF skills CSWL across early childhood in children with a range of second language acquisition histories.

In conclusion, the current study demonstrated that EF skills related to switching, shifting, and monitoring as well as linguistic background may not impact children's CSWL performance. Our results also suggest that the use of shifting, switching, and monitoring skills may not differ between monolingual and bilingual children during CSWL. It is plausible that children did not recruit these specific EF measures during the CSWL task, and instead relied on other skills for successful word learning. Future research is needed to further investigate the cognitive skills implicated in CSWL and whether these specific EF skills may be recruited under other learning conditions.

APPENDIX A

Word Lists

Appendix A1. Word List One. (Crespo et al., 2023)

Novel Word	Novel Object	
	Exposure Item	Test Item
Gonepe		
Basim		
Kemig		
Dofege		
Tinuf		

Appendix A2. Word List Two. (Crespo et al., 2023)

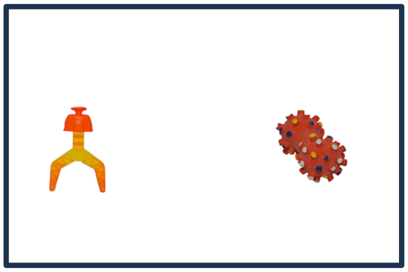
Novel Word	Novel Object	
	Exposure Item	Test Item
Gabek		
Bilob		
Kadad		
Denose		
Tafat		

APPENDIX B

Methodological Details for Exposure and Test Trials (Crespo et al., 2023)

Appendix B1. Exposure Phase.

Instructions: *"Hi! Let's play a game! In this game, you'll see some new toys. To win this game, you'll have to learn the names of these new toys! Let's look!"*

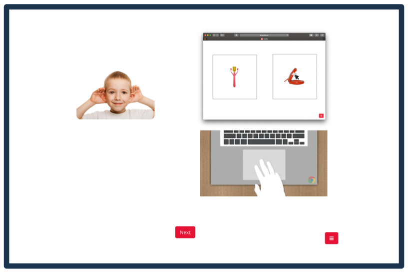


"Tinuf"
(0 ms)

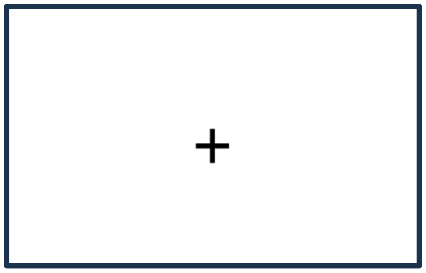
"Dofege"
(2000 ms)

Note. Each exposure trial was approximately 6000 ms.

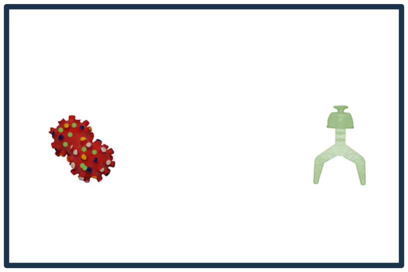
Appendix B2. Testing Phase.



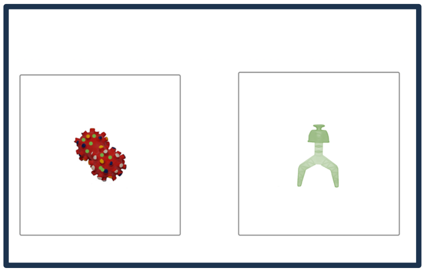
Instructions: *"Listen to the word and pick the picture that matches the word."*



(500 ms)



(On screen 0 ms - 2000 ms)



"Dofege" (2100 ms)

Note. Participants had 4000ms after word onset to select a novel object. Each trial was approximately 8000 ms.

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