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A Longitudinal Study on Bidirectional Relations between Executive Functions and English Word-Level Reading in Chinese American Children in Immigrant Families

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Abstract

This two-wave (1.5 years apart) longitudinal study examined the bidirectional relations between measures of executive function (EF; working memory, attention focusing, inhibitory control, and a comprehensive EF measure) and two types of English word-level reading (pseudoword reading and word reading) among 258 school-aged children (52.6% boys, age = 5.8–9.1 years, in 1st to 3rd grades at Wave 1) from Chinese American immigrant families. Cross-lagged panel analyses were conducted to test whether the four EF measures and English word-level reading proficiency predicted one another controlling for prior levels of EF or word reading, as well as demographic characteristics and children's English and Chinese language proficiency. We found a positive bidirectional association between the comprehensive EF measure and pseudoword reading. By contrast, although the comprehensive EF measure positively predicted word reading over time, word reading did not predict comprehensive EF. Additionally, both word reading and pseudoword reading positively predicted working memory over time. The results provided partial evidence that English word-level reading is bidirectionally related to EF among early elementary school-age dual language learners.

Keywords

executive functions; English word-level reading; Chinese American children; immigrant families

Executive functions (EF), defined as higher-order cognitive skills that guide goal-directed behaviors (Zelazo & Cunningham, 2007), have been shown to predict long-term academic achievement (see Best et al., 2009 and Diamond, 2013 for reviews). Past research has found positive associations between EF and word-level reading in school-aged monolingual children (see Cartwright, 2012 for a review). However, relatively few studies have examined the links between EF and English word-level reading in dual language learners (DLLs, i.e.,

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children who are exposed to or learning through two languages, U.S. Department of Health and Human Services, 2009). In particular, the links between EF and English word-level reading among English-Chinese DLLs have been understudied. This gap in the literature is striking considering the heterogeneity of academic outcomes among Chinese Americans. For example, while a higher-than-average percentage of Chinese American adults held a bachelor's degree, a lower-than-average percentage of Chinese Americans completed high school (Pew Research Center, 2012). Furthermore, previous research has found some cultural differences in EF development (e.g., Lan et al., 2011; Tran et al., 2015) between Asian/Asian American and European American children. Thus, Chinese American DLLs constitute an interesting population to test the generalizability of the EF-word reading links.

The present study examined the bidirectional relations between EF and two English word-level reading skills (pseudoword and word reading) in a longitudinal study of Chinese American school-age children in immigrant families. We used two tasks to tap various subcomponents of EF: a task measuring attention focusing (also known as sustained attention) and inhibitory control (also known as response suppression), and a complex rule use task tapping working memory, inhibitory control, and cognitive flexibility. Using two waves of objective EF and achievement measures, we tested whether EF predicted English word-level reading (and vice versa) controlling for prior levels, demographic characteristics (e.g., family socioeconomic status/SES, child age, generation status), together with children's English and heritage language (Chinese) proficiencies. Given the critical roles of EF and early reading proficiency for children's later academic achievement (e.g., Cunningham & Stanovich, 1997), the study has educational implications for promoting academic achievement in children of immigrant families.

Executive Functions

Executive functions have been conceptualized as an integrated construct with separable components (Garon et al., 2008), although there are continuing debates regarding the specific subcomponents of EF (or the broader umbrella term self-regulation) and the degrees of independence and interrelations among the subcomponents. Studies of school-age children and early adolescents have generally reported low to modest correlations among different EF measures (e.g., Authors, 2015; Zorza et al., 2019), providing justification for measuring the construct's subcomponents separately in this age group. Working memory, inhibitory control, and cognitive flexibility are the three subcomponents most commonly viewed as core EF skills (e.g., Miyake & Friedman, 2012). Working memory is the ability to hold information in mind while simultaneously performing other cognitive tasks (Baddeley, 1986; Gathercole et al., 2006). Inhibitory control refers to the degree to which one can inhibit prepotent responses (Miyake et al., 2000; Rothbart & Bates, 2006), and can be assessed using tasks such as Go/No-Go (e.g., Smith et al., 2004), Stroop (Miyake et al., 2000), or Delay of Gratification (e.g., Kochanska et al., 1996). Cognitive flexibility refers to the capacity to fluidly modify behavior in the face of changing situations (Davidson et al., 2006) and is ordinarily assessed using tasks that involve complex rule use (e.g., Zelazo et al., 2013). Attention focusing is sometimes considered an EF skill (e.g., Jacob & Parkinson, 2015) and at other times is conceptualized as a related self-regulatory process (e.g., Lonigan et al., 2017). Attention focusing refers to the ability to concentrate on pertinent contextual

stimuli (see Garon et al., 2008 for a review) and is typically assessed using tasks such as the Go/No-Go (Trommer et al., 1988) or Continuous Performance Task (Riccio et al., 2002). The terms “attention focusing” and “attentional control” are sometimes used synonymously in the literature. However, attentional control often refers to the capacity to shift attention (i.e., cognitive flexibility) in addition to the ability to maintain attention on a stimulus (e.g., Arredondo et al., 2017). Though distinct from inhibitory control, attention focusing is thought to closely relate to and support inhibition (Rothbart & Posner, 2005). Given the conceptual closeness of attention focusing and inhibitory control, we consider attention focusing to be an EF skill alongside the other three previously identified subcomponents.

Chinese American Children in Immigrant Families

In contrast to much of the existing literature, the present study focused on Chinese American children in immigrant families. The Chinese American population has grown more than six-fold since 1980 and is one of the fastest growing ethnic groups in the U.S. (Zong & Batalova, 2017). It has been noted that both heritage cultural orientation and bilingualism might have benefits for EF development in children of immigrant families. First, regarding cultural orientation, cross-cultural studies showed that preschoolers in China outperformed their North American counterparts on certain measures of EF (Lan et al., 2011; Sabbagh et al., 2006). Using Wave 1 data from the same sample of Chinese American school-aged children, Authors (2015) found that parents’ heritage (Chinese) cultural orientation was positively associated with children’s EF skills, suggesting potential EF benefits linked to heritage cultural values or culturally salient socialization practices in Chinese immigrant families. Second, regarding bilingualism, language has long been theorized to play an essential role in the development of self-regulatory skills (Vygotsky, 1962). Though debate on bilingualism’s relation with EF continues, a body of research suggests bilingualism may confer some benefits to EF development (see Bialystok, 2011 for a review). Consistent with theory, Authors (2019) found both heritage language and English proficiency to be positively associated with cognitive flexibility in a different sample of preschool-age DLLs from Latino and Chinese immigrant families. Similar relations between heritage language and English proficiency and EF were also found using Wave 2 cross-sectional data from the present study’s sample of Chinese American school-aged children (Authors, 2014).

Moreover, there is some theoretical reason to expect that EF might be differentially implicated in English reading development among monolingual and DLL children. For example, Gottardo et al. (2017) investigated processes underlying English word-level reading among adolescents in Chinese Canadian immigrant families. They divided their sample into two groups based on participants’ amount of English language exposure and observed different relations between phonological awareness and English word-level reading. Specifically, phonological awareness was related to word reading for the group with higher English language exposure. However, phonological awareness was unrelated to word reading among the participants with lower English language exposure. Though Gottardo et al. (2017) did not examine EF in their study, these findings suggest that factors related to multilingualism might influence the association between certain cognitive processes and English word-level reading, highlighting the need to test the EF-word reading links in English-Chinese DLLs.

The Role of Executive Functions in Word-Level Reading

Executive functions are theorized to play a critical role in children's advanced reading skills, such as fluency (e.g., Cartwright et al., 2019) and comprehension (e.g., Cartwright et al., 2017), as well as more basic skills such as word-level reading. To decode a single word, a reader must simultaneously utilize and coordinate awareness of print features in addition to language knowledge. Multiple executive processes have been theorized to underlie word-level reading, including sustaining attention on visual information, holding speech sounds in working memory (Doyle et al., 2018), inhibiting similarly spelled words when accurately decoding (Massol et al., 2015), and flexibly adjusting to different rule sets when decoding in languages with inconsistent grapheme-phoneme correspondences such as English (Cartwright, 2009). Indeed, positive associations between EF skills and word-level reading have been reported in studies of predominantly monolingual children (see Cartwright, 2012 for a review). Yet, the relations between EF and word-level reading may vary by language because grapheme-phoneme correspondence complexity and rules are language-specific (e.g., Georgiou et al., 2020).

While some researchers have failed to find associations between EF and word-level reading (e.g., McClelland et al., 2014), there is a substantial body of evidence suggesting positive associations between EF and both English word reading and pseudoword (a novel word lacking any actual meaning in the lexicon) reading in predominantly monolingual samples. In regard to individual EF subcomponents, working memory has consistently shown positive associations with English word reading and pseudoword reading. Christopher et al. (2012), for instance, examined working memory and English word reading in monolingual children/adolescents and found positive relations among both school-aged children (aged 8 to 10 years) and adolescents (aged 11 to 16 years). Two recent meta-analyses, one examining word-level reading across a variety of languages (Ober et al., 2020) and the other focusing specifically on English reading (Peng et al., 2018), substantiated these findings by demonstrating a pattern of significant associations between word reading and working memory across the existing literature. Both Ober et al. (2020) and Peng et al. (2018) also demonstrated a comparable literature-wide pattern of significant relations between pseudoword reading and working memory. Of particular relevance to the present study, these two meta-analyses considered participant language characteristics. Ober et al. (2020) found that language characteristics including participants' spoken language (English vs. non-English), written language (alphabetic vs. non-alphabetic), and orthographic depth of alphabetic written language (deep vs. transparent) did not moderate the positive associations. After controlling for participant bilingual status and grade level, the relations reported by Peng et al. (2018) remained significant (though English word reading showed a stronger association than English pseudoword reading). These results suggest that positive associations between English word-level reading and working memory likely generalize to Chinese-English DLLs. Given such findings, we expected to find positive relations between working memory and English word-level reading.

Multiple studies have reported positive associations between attention focusing and (non-English) word-level reading. Bosse and Valdois (2009) found significant relations between sustained attention and both pseudoword as well as word reading among French-speaking,

monolingual elementary school students. Likewise, Varvara et al. (2014) noted significant associations between sustained attention and pseudoword/word reading among Italian-speaking, monolingual children aged 8 to 17 years. There has been relatively less evidence of direct relations between attention focusing and word-level reading in English. In fact, Arrington et al. (2014) did not find associations between attention focusing and a mixed measure of word and pseudoword reading in English-speaking monolingual 6th–12th grade students. Considering developmental changes in the relations between EF and reading performance suggested by researchers (see Peng & Kievit, 2020 for a review), these discrepant results might be due to age group differences in study samples. As children grow older and accumulate experience practicing literacy skills, many of these skills theoretically become less effortful and therefore require fewer executive resources to perform. Because the present study's participants were younger and were less experienced readers than Arrington et al.'s (2014) sample, we expected to find positive associations between attention focusing and English word-level reading.

Similarly, there is considerable evidence for a positive relation between inhibitory control and English word-level reading during the elementary school years, at least among monolingual children. For example, Altemeier et al. (2008) found that inhibitory control was positively associated with concurrent pseudoword reading and predicted later pseudoword reading in 1st through 5th grade monolingual children. They also found that the development of inhibitory control from 1st to 4th grade positively predicted children's pseudoword reading at 4th grade. Other researchers reported positive associations between inhibitory control and word reading proficiency among monolingual children aged 10 to 14 years (Doyle et al., 2018; Locascio et al., 2010). Furthermore, Ober et al.'s (2020) meta-analysis reported a positive relation between inhibitory control and word-level reading in child and adolescent samples. Based on these findings, we expected to find positive relations between inhibitory control and English word-level reading in Chinese American DLLs.

Comprehensive measures of EF have also showed relatively consistent positive relations with English word-level reading among monolingual elementary school children. For example, using teacher-reported EF ratings, Spencer and Cutting (2020) found positive EF-pseudoword reading relations among monolingual, English-speaking children (aged 6–8 years). In another study of monolingual, English-speaking children in preschool to 2nd grade, a performance-based comprehensive measure of EF positively predicted word reading (Skibbe et al., 2019). Because the present study used a comprehensive EF measure that also taps cognitive flexibility (Baym et al., 2008), it is worth noting that Ober et al.'s (2020) meta-analysis showed a positive association between cognitive flexibility and word-level reading. Positive associations between comprehensive EF measures and word-level reading have also been found in English-Cantonese DLLs in Hong Kong. Specifically, using composite EF scores from performance-based tasks tapping working memory and inhibitory control, Liu et al. (2019) found that EF positively predicted English word reading from kindergarten to 1st grade. Thus, we expected to find a positive relation between the comprehensive EF measure and English word-level reading in Chinese American DLLs.

The Role of Word-Level Reading in EF Development and Bidirectional Relations

Researchers have also theorized that the relations between EF and academic achievement are reciprocal: while children with higher EF skills tend to do better on academic tasks, children with higher academic skills may have greater improvement in EF because they are more likely to engage in learning activities that practice EF or self-regulation (Fuhs & Day, 2011; Stipek et al., 2010). The learning activities in which children engage in school often involve the use of EF skills and thereby provide frequent opportunities to develop self-regulatory "musculature" through practice (Evans & Stanovich, 2013; Peng et al., 2018). In support of the theorized positive path from academic learning to EF development, Brod et al. (2017) followed monolingual German 5-year-olds who entered 1st grade at different years depending on the proximity of birthdates to the official age cutoff and found that one year of formal schooling was associated with a larger improvement in performance on a comprehensive EF task and greater increase in activation of brain areas implicated in sustained attention.

Though few researchers have tested the contribution of English word-level reading to performance on individual EF measures among DLLs during elementary school, studies that tested this question among monolingual or differently aged children generally do not support reciprocal relations. For example, in Wagner et al.'s (1994) longitudinal study of children from kindergarten through 2nd grade, a combined measure of English word reading and nonword reading failed to predict participants' ability to hold language sounds in working memory. To our knowledge, there have been no recent studies testing the specific contribution of English word-level reading to later working memory among elementary school children. However, Zhang and Malatesha Joshi (2020) found that performance on an English reading measure assessing a wider range of literacy skills did not predict later working memory among DLLs from various backgrounds in kindergarten through 3rd grade. Considering these previous null findings, we did not expect word-level reading to predict working memory.

In regard to attention focusing and inhibitory control, Dittman (2016) reported that English word reading did not predict teacher ratings of attention among monolingual elementary school students, a finding also observed among adolescents (McGee et al., 2002). In another study following monolingual English speakers and Spanish-English DLLs from preschool to kindergarten, Son et al. (2019) found reciprocal relations between inhibitory control and math skills, but only unidirectional relations from inhibitory control to English word reading. The lack of prospective relations from English word reading to attention focusing and inhibitory control suggests these closely related cognitive components may be less involved in English word-level reading, particularly as it becomes increasingly automatic as development progresses (Blair & Razza, 2007). Thus, we did not expect word-level reading to predict attention focusing or inhibitory control.

Previous studies testing bidirectional relations between comprehensive measures of EF and word-level reading have yielded mixed results. For example, two longitudinal studies following children from pre-kindergarten to kindergarten (Fuhs et al., 2014; Schmitt et al.,

2017) and one study following children from kindergarten to 1st grade (McKinnon & Blair, 2019) found reciprocal relations between comprehensive EF measures and math skills, but only unidirectional relations from EF to word reading. The majority of these studies were based on monolingual samples with the exception of Schmitt et al.'s (2017), which included Spanish-English DLLs. However, the Spanish-dominant DLLs were assessed using a measure of Spanish word reading. Their word reading performance was combined with the English word reading results in data analyses, making it difficult to develop hypotheses for the present study based on Schmitt et al.'s (2017) findings. In contrast, Liu et al.'s (2019) longitudinal study of Chinese-English DLLs in Hong Kong found significant bidirectional relations between EF and English word-level reading. Given the greater similarity in age and language characteristics between Liu et al.'s (2019) sample and the present sample, we expected to find bidirectional relations between word-level reading and the comprehensive EF measure.

The Present Study

Using two waves of data from a socioeconomically diverse sample of Chinese American children in elementary school, the present study aimed to explore the bidirectional relations between EF and two types of English word-level reading (word reading and pseudoword reading). The data came from an ongoing longitudinal study on children's psychological adjustment and academic development in Chinese American immigrant families; the first two waves of the ongoing study included measures of EF and word-level reading. Multiple EF measures were incorporated, including specific measures of working memory, attention focusing, and inhibitory control, as well as a broader EF assessment tapping working memory, inhibitory control, and cognitive flexibility. Based on the literature, we hypothesized that children's working memory, attention focusing, inhibitory control, and performance on the broader EF measure would positively predict English word reading and pseudoword reading. Given previous studies testing the inverse relation from reading or academic achievement to EF, we hypothesized that both types of word-level reading would positively predict the comprehensive EF measure, but not working memory, attention focusing or inhibitory control. In testing the two hypothesized models (Figure 1 and Figure 2), we controlled for stability in EF and word-level reading, as well as potential confounding variables such as family SES, child age, sex, generation status, English language proficiency, and heritage language (Chinese) proficiency.

Methods

Participants

The sample included 258 children (52.6% boys, mean age = 7.4 years at Wave 1 or W1), age range = 5.8–9.1 years) and their parents who participated in the ongoing longitudinal study conducted in a northwestern metropolitan area of the United States (S. Chen et al., 2015; S.H.Chen, Zhou, Uchikoshi, & Bunge, 2014). The children attended over 80 elementary schools across three counties (94.5% of children were in public schools, and 5.5% were in private schools). The majority of children (76.4%) were second-generation (i.e., born in the U.S. and had at least one foreign-born parent), and the rest (23.6%) were foreign-born. By

contrast, the majority of parents were foreign-born immigrants from mainland China (72%), Hong Kong (9%), and Taiwan (3%). Only 4.3% of fathers and 1.2% of mothers were born in the United States. At Wave 1, the children were in first (48.8%), second (50.0%), or third (1.2%) grades. The average level of parental education was 13.4 years (i.e., some college education) with a range of 7 to 20 years (SD = 2.3). On average, the parents had spent 30% of their lives in the United States (the average number of years in the U.S. = 12.0, SD = 7.6, range = 1–38 years). Most children resided in two-parent households (92%) with the remaining (8%) coming from households in which parents were separated, divorced, single, or widowed. The participating families' average per capita income in the past year was $11,608 ($SD$ = $8,309, range = $625–$50,000), and 56% of children were eligible for free or reduced-price school lunches based on parent report.

At Wave 2 (W2, conducted 1.5 to 2.5 years after the child's W1 assessment), 239 children were reassessed (retention rate = 93%). The children were in the third, fourth, or fifth grades. All children at W2 chose English as their interview/questionnaire language. Attrition analyses were conducted to compare the children who were assessed at both waves (N = 239) with those who were assessed at W1 only (N = 19) on demographic (child age, gender, generation status, and family income and parental education) and W1 EF measures and academic achievement variables. Independent sample t-tests were computed to compare the two groups on continuous variables (age, family income, education, and EF variables), ts (Ns = 239 and 19) = −1.80 to 0.56, ps =.07 to .95. Pearson chi-square statistic was used to compare the two groups on categorical variables (gender and generation status), χ^2 (df = 1) = .08 and .004, ps = .78 and .95. Thus, no differences were found by attrition status.

Procedures

The sample was recruited using multiple strategies, including holding recruitment fairs in Asian American communities (e.g., Chinatown shopping centers, Asian grocery stores, Asian community events; 63.6% of the sample), seeking referrals from Asian American organizations (19%), and recruiting at elementary schools with large concentration of Asian students (17.4%). Interested parents filled out a contact sheet. And a bilingual interviewer conducted a phone interview with the parent to determine whether the child met the eligibility criteria: (a) the child was in first, second, or third grade, (b) the child resided with at least one biological parent, (c) both biological parents identified as ethnic Chinese, (d) the child was either a first- or second-generation immigrant, and (e) both the child and participating parent could understand or speak English or Chinese (Cantonese or Mandarin). Of the 380 children whose parents filled out a contact sheet, 353 were screened, 291 were eligible, and 258 completed the W1 assessment.

All research procedures were approved by the Institutional Review Board at University of California, Berkeley(Protocol title: "The risk and protective factors for mental health adjustment in 1st and 2nd generation Chinese American immigrant children"). At both waves, the child and one parent participated in a 2.5-hour laboratory assessment, which included one-on-one child achievement and neuropsychological tests, parent-child interaction tasks, and parent questionnaires. Because mothers were asked to participate in the lab assessment whenever possible, the majority of children (82% at W1, 80% at W2) had

mothers as the participating parents, and 18% of children at W1 and 20% children at W2 had fathers as the participating parent. All written consent and assent materials were available in English, simplified Chinese, or traditional Chinese. The assessment and questionnaires were administered in the parents' and children's preferred languages. The majority of parents (77% at W1 and 74% at W2) completed the questionnaires in Chinese, and the majority of children (95% at W1 and 100% at W2) completed the questionnaires in English. Based on parent report, at least some Chinese language was spoken at home for 99% of children at both Wave 1 and Wave 2. After the lab visit, the child's classroom teacher completed a teacher questionnaire by mail. Parents and teachers received payment and children received small prizes.

Measures

The present study used data from child EF, academic achievement, and language tasks, as well as items from parent and teacher questionnaires. Measures that had not been previously used in Chinese-speaking samples (i.e., the family demographics questionnaire, and verbal instructions for EF measures (the Go/No-Go task and the complex rule use task) were translated, back-translated, and piloted following the procedures outlined by Knight et al. (2009). Because some children received the verbal instructions for the EF tasks in Chinese at W1 (*N*s = 17 and 16 for Go/No Go and complex rule use, respectively), we compared their performance to the performance of children who received instructions in English (*N*s = 228 and 229), and no differences were found.

Executive functions (W1 & W2).—Attention focusing and inhibitory control were assessed using a computerized Go/No-Go task (Eriksen & Eriksen, 1974). Children were presented with a sequence of images and instructed to press a button only when the target stimulus appeared onscreen. A lack of response to the target stimulus (i.e., omission error) is thought to reflect weakness in attention focusing, while responding to non-target stimuli (i.e., commission error) is considered evidence of weakness in inhibitory control (Barkley, 1991; Halperin et al., 1988). Because trial-level data were unavailable for the full sample, data from a subsample were used to analyze task reliability. Reliability was evaluated by calculating Guttman's lambda 4 split-half reliability coefficient, which is considered a more accurate measure of internal consistency than Cronbach's alpha (Sijtsma, 2008). Guttman's lambda 4 reliability coefficient for the computerized Go/No-Go task was 0.81.

Working memory and comprehensive EF were assessed with a complex rule use computer task by Baym et al. (2008) that jointly tapped working memory, inhibitory control, and cognitive flexibility. A variety of researchers have used versions of this task with school-aged children (Church et al., 2017; Tharp et al., 2015; Wendelken et al., 2012). In this task, participants were presented with on-screen stimuli (i.e., images of fish selected from an animated film) and were taught to respond with a particular button press depending upon a given image's associated rule cue of Color (red or blue) or Direction (left or right). During Direction trials, participants were asked to press either a left or right button depending on the orientation of the on-screen image. Color trials involved participants pressing one button when presented with a red image and another for a blue image. The rule cue for any given trial either differed from that of the preceding trial (Switch trial) or remained the same

(Repeat trial). Trials were additionally classified as either “Incongruent” (requiring divergent responses depending upon the associated rule cue) or “Congruent” (requiring the same response regardless of the rule cue). Each image’s visual features and relevant rule cue changed at random intervals requiring dynamic rule implementation.

During each trial, the pertinent rule cue (“Direction” or “Color”) was presented onscreen for 2300 ms prior to the appearance of the stimulus for 1500 ms. For a participant taught to press the left button in response to a blue image when the trial’s rule cue was Color, an example of an Incongruent-Switch trial would be one in which the rule cue was Color, a right-facing blue image was presented, and the previous trial’s rule cue had been Direction. The correct response during this trial would be a left button press despite the incongruence with the Direction rule cue. For this participant, an example of a Congruent-Repeat trial would be one in which the rule cue was Color, a left-facing blue image was presented, and the previous trial’s rule cue had also been Color. The correct response during this trial would be a left button press, congruent with the Direction rule cue. Children first engaged in a 32-trial practice session during which the experimenter would remind the child of the correct response if it had not been provided. Subsequently, children completed a 98-trial testing session free of feedback. Accurate responses during Incongruent-Switch trials required cognitive flexibility, inhibitory control, as well as working memory (due to the arbitrary association between response and Color rule). Therefore, children’s accuracy percentage on the Incongruent-Switch trials was used as a broad indicator of EF. The split-half reliability (computed as Guttman’s lambda 4 reliability coefficient) for the Incongruent-Switch trials was 0.81. Children’s percentage of accuracy on Congruent-Repeat trials was used as an indicator of working memory, because these trials merely required participants to remember the task rules (i.e., goal maintenance). Indeed, working memory capacity was predictive of the ability to maintain a novel goal in 4-and 6-year-old children (Marcovitch et al., 2010). The Guttman’s lambda 4 reliability coefficient for the Congruent-Repeat trials was 0.96.

English word-level reading (W1 & W2).—Two subtests from the Woodcock-Johnson Tests of Academic Achievement III (WJ III ACH; Woodcock et al., 2001) were used. The Letter-Word Identification subtest, in which children are asked to read and name real words from a list, is a measure of word reading. The Word Attack subtest, in which children are asked to read non-words, is a measure of pseudoword reading. The WJ III ACH has been validated in culturally diverse samples with well-documented reliability and construct validity: individual subtests have yielded reliabilities of 0.80 or higher in ethnically diverse samples (Woodcock et al., 2001). It is standardized with a mean score of 100 and a standard deviation of 15. Age-standardized scores were used in data analysis.

Heritage language (Chinese) proficiency and English language proficiency (W2).—Children were administered the Chinese version of the Peabody Picture Vocabulary Test-Revised (Lu & Liu, 1998), which assesses their receptive vocabulary in Mandarin or Cantonese. For each test question, participants were presented with four pictures and asked to point to the one corresponding to the word uttered by the assessor. The reported internal consistency of the test in native Chinese-speaking children ranged from .90 to .97 (Lu & Liu, 1998). The standardized scores were used in analyses (range = 2 to 119). Children’s

English language proficiency was rated by two items on parent questionnaire ("How well does your child speak English" and "How well does your child understand spoken English", both rated on a 5-point scale from 1 = extremely poorly to 5 = very well, Ms = 4.08 and 4.06, SDs = 0.68 and 0.69) and one item on teacher questionnaire ("For this child's grade level, how would you rate this child's English language skills", rated on a 5-point scale from 1 = far below grade level to 5 = far above grade level, M = 3.31, SD = 0.91). The alpha for the three-item scale is .64. Thus, a composite score of English language proficiency was created by averaging the standardized scores across the three items.

Family Demographic characteristics (W1).—Parents filled out the Family Demographic and Migration History Questionnaire adapted from a similar measure used for Mexican immigrant families (Roosa et al., 2008). It included questions on parental education, family income, and the child's generation status. We computed a family SES index by first averaging maternal and paternal education and then averaging the standardized scores of parental education and per capita income.

Results

Data analyses were conducted in two steps. First, correlation analyses were used to identify the covariates for testing the associations between EF and word-level reading. Second, to test the bidirectional relations between EF and English word reading, two cross-lagged panel analysis models were tested: one for word reading (Figure 1), and one for pseudoword reading (Figure 2). The effects of covariates on W2 EF and word-level reading variables were controlled.

Correlations between Covariates and Study Variables

Descriptive statistics for continuous study and demographic variables are presented in Table 1. The variables were screened for normality. Based on recommended high skewness and kurtosis cutoffs of 2 and 7 respectively (West et al., 1995), omission errors on Go/No-Go task (measuring weakness in attention focusing) at both waves were positively skewed and had high kurtosis, indicating that most children made few errors. Moreover, Congruent-Repeat accuracy (measuring working memory) at both waves were negatively skewed and had high kurtosis, indicating most children had high performance on this task. Because of the presence of nonnormally distributed variables, we used robust estimation in testing cross-lagged panel models. The sample means for standardized scores of word-level reading were 114 and 112 at W1 and 109 and 107 at W2.

The pairwise correlations of all study and demographic variables are presented in Table 2. The following demographic variables showed significant correlations with both EF and word reading measures: child age, sex, generation status, family SES, W2 English proficiency, and W2 Chinese proficiency. Based on these results, the six demographic variables were included as covariates in cross-lagged panel analysis.

Testing the Bidirectional Relations between EF and Word-Level Reading

Two cross-lagged panel analysis models were specified to test the study's hypotheses. The first model tested the relations between EF and word reading (Figure 1), and the second model tested the relations between EF and pseudoword reading (Figure 2). In both models, three sets of paths were specified: (a) the autoregressive paths predicting W2 EF or word-level reading from their W1 counterparts, (b) the cross-lagged paths predicting W2 reading from W1 EF variables, and (c) the cross-lagged paths predicting W2 EF variables from W1 reading scores. In both models, we controlled for the effects of demographic variables (family SES, child age, sex, generation status, and W2 English and Chinese proficiency) on W2 EF and reading variables (these covariates are not displayed in the figures to maintain readability). In addition, as recommended by Little (2013), the residual variances of variables from the same wave were allowed to be correlated with one another. The models were tested in Mplus 8.1 (Muthén & Muthén, 1998–2017) using full information maximum likelihood method to handle missing data. Due to the presence of nonnormally distributed variables, the Maximum Likelihood Robust (MLR, Muthén & Muthén, 1998–2017) estimator was used to adjust for correction of standard errors. Hu and Bentler (1999) suggested the cutoffs of comparative fit index (CFI) ≥ 0.95, root-mean-square error of approximation (RMSEA) ≤ 0.06, and standardized root-mean-square residual (SRMR) ≤ 0.08 as the criteria for a relatively good overall fit.

The model testing the relations between EF and word reading fit the data well based on the guidelines by Hu and Bentler (1999), $\chi^2(df = 9, N = 205) = 17.55$, $p = .29$, CFI = .99, RMSEA = .029, and SRMR = .036. As shown in Figure 1, all the autoregressive paths were significant in the positive direction, with the exception of the autoregressive path for working memory (which was marginally significant). This suggests there is cross-time consistency in rank-order of most EF measures and word reading. With regard to the effects of covariates, family SES and English proficiency both had unique and positive relations to W2 word reading (ps = .047 and .041), and child age had a unique and negative relation to W2 word reading ($p < .001$). Controlling for autoregressive paths and covariates, there were two significant cross-lagged paths: 1) the positive path from W1 comprehensive EF to W2 word reading ($p = .027$), and 2) the positive path from W1 word reading to W2 working memory ($p = 0.03$).

The model testing the relations between EF and pseudoword reading also fit the data well, $\chi^2(df = 20, N = 205) = 20.17$, $p = .45$, CFI = .999, RMSEA = .006, and SRMR = .038. As shown in Figure 2, the autoregressive paths were significant in the positive direction, with the exception of the autoregressive path for working memory (which was marginally significant). Among the covariates, child age had a unique and negative path to W2 pseudoword reading ($p < .001$). Controlling for autoregressive paths and covariates, there were three significant cross-lagged paths: 1) the positive path from W1 comprehensive EF to W2 pseudoword reading ($p = .011$), 2) the positive path from W1 pseudoword reading to W2 comprehensive EF ($p = .027$), and 3) the positive path from W1 pseudoword reading to W2 working memory ($p = .018$).

Discussion

This study used two waves of data from an ongoing longitudinal study to explore bidirectional relations between EF and English word-level reading during early elementary school years in dual language learners from Chinese American immigrant families. We hypothesized that all four measures of EF would positively predict pseudoword reading and word reading. We furthermore hypothesized that both types of word-level reading would positively predict the comprehensive EF measure but not working memory, attention focusing, or inhibitory control. These hypotheses were partially supported. Only comprehensive EF uniquely and positively predicted pseudoword reading and word reading. Pseudoword reading positively predicted comprehensive EF and working memory over time. By contrast, word reading only positively predicted working memory over time. Thus, we found some evidence of a bidirectional relation between EF and English pseudoword reading controlling for stability among Chinese-English DLLs during the early elementary school period.

The non-significant paths from W1 working memory to W2 word-level reading and significant paths from W1 word-level reading to W2 working memory run counter to our expectations. Given the robust evidence of relations between working memory and English word-level reading among both monolingual and DLL children (e.g., Christopher et al., 2012; Ober et al., 2020; Peng et al., 2018), the lack of significant findings may be due to our working memory measure. Mean participant scores on our working memory measure were quite high, suggesting the likely presence of a ceiling effect. This may have limited our ability to detect an association from working memory to later word-level reading. Though the significant paths from word-level reading to later working memory are at odds with previous null findings in the literature (e.g., Wagner et al., 1994), as previously noted, there is a dearth of recent research testing the specific contribution of English word-level reading to later working memory among children in elementary school. Recent studies have tended to assess multiple literacy skills simultaneously (e.g., Zhang & Malatesha Joshi, 2020), rendering it difficult to ascertain the specific contributions of word-level reading specifically. More work is needed to determine whether prospective relations from English word-level reading to working memory exist among children from other language groups and whether there indeed might be a bidirectional relationship between working memory and English word-level reading in this age group.

Though there were significant correlations between attention focusing and word reading at W2 (see Table 2), W1 attention focusing did not have a unique relation to W2 word reading after controlling for comprehensive EF. While Arrington et al. (2014) noted that sustained attention is required to maintain an active representation of the text being read, their observation of its significant contribution to comprehension but not word reading suggested that attention focusing may be more important for multi-word reading processes that require increased text representation maintenance than for single-word reading. Both the Letter-Word Identification task and the Word Attack task require the child to read one word at a time. Also, these tasks are relatively short and do not impose a high demand on children's sustained attention. Thus, it is not surprising that attention focusing plays a relatively minor role in children's word-level reading processes, especially in a sample of typically

developing children. Considering our null results together with previous findings of significant associations between attention focusing and non-English word-level reading (Bosse & Valdois, 2009; Varvara et al., 2014), an additional interpretation is that sustained attention might play a relatively small role in English word-level reading specifically. The lack of prospective relations from word-level reading to attention focusing aligns with the previously reviewed literature (Dittman, 2016; McGee et al., 2002).

The lack of prospective relations from word-level reading to inhibitory control is similarly expected given previous findings (e.g., Son et al., 2019). However, the absence of significant correlations between inhibitory control and word reading stands in contrast to the work of Altemeier et al. (2008), Doyle et al. (2018), and Locascio et al. (2010), which all reported positive associations between English word-level reading and inhibitory control. In light of Ober et al.'s (2020) meta-analysis, the lack of observed relations between inhibitory control and word-level reading is even more notable. Though Ober et al. (2020) found that spoken and written language characteristics did not moderate positive relations, they did not evaluate participants' multilingualism. Compared to the relative abundance of previous work investigating working memory, there has been less research exploring English word-level reading's relations to inhibitory control among DLLs. Consequently, the lack of significant relations between inhibitory control and English word-level reading may be unique to DLLs.

Our finding that the comprehensive EF measure predicted both word and pseudoword reading is consistent with the extant literature. Despite the lack of unique associations between word-level reading and the individual EF subcomponents assessed in the present study, our findings replicated previous results showing that EF more broadly supports English decoding. Broad measures of EF have been relatively consistently linked to higher English word-level reading accuracy during the elementary school years both among monolingual English speakers (e.g., Skibbe et al., 2019; Spencer & Cutting 2020) and DLLs (e.g., Liu et al., 2019). The present study extended Liu et al.'s (2019) work by showing that comprehensive EF predicted English pseudoword reading as well as word reading among English-Chinese DLLs, suggesting that EF relates to English decoding generally (as opposed to individual word-level reading sub-processes) in this age group.

The observed bidirectional relations between comprehensive EF and English word-level reading among DLLs in elementary school is also consistent with the findings of Liu et al. (2019). We are unable to directly compare our specific findings because pseudoword reading was not assessed in Liu et al.'s study (2019). In contrast to Liu et al. (2019), we did not observe reciprocal relations between EF and English word reading, which may be due to differences in the word reading and EF measures used in the two studies. Yet, in comparison to the null findings among largely monolingual children (Fuhs et al., 2014; McKinnon & Blair, 2019; Schmitt et al., 2017), both our study and Liu et al.'s (2019) found some evidence for bidirectional relations between EF and word-level reading in Chinese-English DLLs. As suggested by Gottardo et al.'s (2017), factors related to multilingualism might be associated with differential relationships between certain cognitive variables and English word-level reading. Though research shows that the academic trajectories of Chinese Americans differ from other groups (Pew Research Center, 2012), more work is needed to

explain how and why this is the case. Future research needs to replicate the present study's findings with other DLL samples.

The significant reversed relations from word reading to working memory and from pseudoword reading to both comprehensive EF and working memory are consistent with the general theory that learning-related processes such as reading can further promote children's EF development (Fuhs & Day, 2011; Stipek et al., 2010). Previous findings showed that schooling broadly can improve EF (Brod et al., 2017). Our finding suggested that decoding might be one element of schooling that promotes EF, at least among DLLs during early elementary school. Future research can test this hypothesis using experimental designs.

We controlled for several family demographic and child characteristics that might confound the relations between EF and word-level reading, including family SES, child age, sex, generation status, English and heritage language (Chinese) proficiency. Although these variables had significant correlations with EF or word reading, only three covariates showed unique relations to EF or word-level reading in the longitudinal models: family SES, English proficiency, and child age. The positive path from family SES to W2 word-level reading is consistent with the extensive body of research showing positive relations between academic achievement and family SES (Sirin, 2005). The positive relation between children's English oral proficiency (rated by parents and teachers) and W2 English word-level reading is expected and suggests that the more acculturated (especially in domain of English proficiency) children of immigrant families displayed more advanced English reading development compared to the less acculturated children. Finally, the negative relations between children's age and their age-standardized scores on English word reading and pseudoword reading suggested that compared to the younger children, the older children in our sample performed worse than their same-age peers on standardized read tests. This finding echoed the longitudinal finding from a national sample that children of East Asian immigrant families showed declining reading scores relative to their peers between kindergarten and 3rd grade, which might be driven by children of other immigrant and non-immigrant groups improving in their reading scores over time (Han, 2008).

Limitations and Directions for Future Research

This study has several limitations. Firstly, our study focused on dual language learners in Chinese American immigrant families, which somewhat limits the generalizability of our findings to other populations. Future research needs to replicate the results in other cultural or language groups or ethnically diverse samples. Second, we only measured Chinese and English proficiency at Wave 2. And English proficiency was measured by parent and teacher ratings (rather than an objective language test). This constrained our capacity to evaluate the prospective relation of bilingual proficiency to later EF development. Third, the high skewness and kurtosis on some EF measures (e.g., measures of attention focusing and working memory) suggested that those tasks might be too easy for participants in our study, although these measures showed some significant correlations with word reading and/or other EF measures. As previously noted, the lack of prospective relations from working memory to word-level reading is at odds with the literature. To better assess whether our null working memory findings are due to weakness in our measure, future studies should employ

more commonly used and robust measures of working memory. Fourth, we did not measure phonological awareness because it was not a key study construct of the ongoing larger longitudinal investigation. Given previous research suggested that phonological awareness might mediate the links between EF and literacy development (ten Braak et al., 2018), future research should examine the roles of phonological awareness in the development of EF and word-level reading in DLLs. Lastly, despite the significant bidirectional path coefficients between comprehensive EF and word reading, it is important to note that the zero-order correlations among these constructs are small in effect size (*r*s ranged from .12 to .24). Thus, suppression effects, which are indicative of measurement errors, might have affected the results.

The finding on the bidirectional association between general EF and English pseudoword reading suggests: 1) there may be differences in EF – English word-level reading associations between monolingual and DLL children in elementary school, and 2) there is empirical rationale to test a causal relationship from word-level reading to EF. Moreover, as prior research found support that family engagement in heritage culture and children's heritage language or bilingualism might be beneficial for children's EF development in Chinese American immigrant families (Authors 2014, 2015, 2019), the present study extends this work to further suggest that future research can explore whether interventions promoting these culture-salient asset factors might be a pathway to promote academic success in children of immigrant families.

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References

Altemeier LE, Abbott RD, & Berninger VW (2008). Executive functions for reading and writing in typical literacy development and dyslexia. Journal of Clinical and Experimental Neuropsychology, 30(5), 588–606. 10.1080/13803390701562818 [PubMed: 18569253]

Arredondo MM, Hu X-S, Satterfield T, & Kovelman I (2017). Bilingualism alters children's frontal lobe functioning for attentional control. Developmental Science, 20(3), e12377. 10.1111/desc.12377

Arrington CN, Kulesz PA, Francis DJ, Fletcher JM, & Barnes MA (2014). The contribution of attentional control and working memory to reading comprehension and decoding. Scientific Studies of Reading, 18(5), 325–346. 10.1080/10888438.2014.902461

Baddeley AD (1986). Working memory. New York, NY: Oxford University Press.

Barkley RA (1991). The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. Journal of Abnormal Child Psychology, 19(2), 149–178. 10.1007/BF00909976 [PubMed: 2056161]

Baym CL, Corbett BA, Wright SB, & Bunge SA (2008). Neural correlates of tic severity and cognitive control in children with Tourette syndrome. Brain, 131(1), 165–179. 10.1093/brain/awm278 [PubMed: 18056159]

Best JR, Miller PH, & Jones LL (2009). Executive functions after age 5: Changes and correlates. Developmental Review, 29(3), 180–200. 10.1016/j.dr.2009.05.002 [PubMed: 20161467]

Bialystok E (2011). Reshaping the mind: The benefits of bilingualism. Canadian Journal of Experimental Psychology / revue canadienne de psychologie expérimentale, 65(4), 229–235. 10.1037/a0025406 [PubMed: 21910523]

Blair C, & Razza RP (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development, 78(2), 647–663. 10.1111/j.1467-8624.2007.01019.x [PubMed: 17381795]

Bosse M-L, & Valdois S (2009). Influence of the visual attention span on child reading performance: A cross-sectional study. Journal of Research in Reading, 32(2), 230–253. 10.1111/j.1467-9817.2008.01387.x

Brod G, Bunge SA, & Shing YL (2017). Does one year of schooling improve children's cognitive control and alter associated brain activation? Psychological Science, 28(7), 967–978. 10.1177/0956797617699838 [PubMed: 28489500]

Cartwright KB (2009). The role of cognitive flexibility in reading comprehension: Past, present, and future. In Israel SE & Duffy G (Eds.), Handbook of research on reading comprehension (pp. 115–139). New York, NY: Routledge.

Cartwright KB (2012). Insights from cognitive neuroscience: The importance of executive function for early reading development and education. Early Education and Development, 23(1), 24–36. 10.1080/10409289.2011.615025

Cartwright KB, Coppage EA, Lane AB, Singleton T, Marshall TR, & Bentivegna C (2017). Cognitive flexibility deficits in children with specific reading comprehension difficulties. Contemporary Educational Psychology, 50, 33–44. 10.1016/j.cedpsych.2016.01.003

Cartwright KB, Marshall TR, Huemer CM, & Payne JB (2019). Executive function in the classroom: Cognitive flexibility supports reading fluency for typical readers and teacher-identified low-achieving readers. Research in Developmental Disabilities, 88, 42–52. 10.1016/j.ridd.2019.01.011 [PubMed: 30851482]

Christopher ME, Miyake A, Keenan JM, Pennington B, DeFries JC, Wadsworth SJ, Willcutt E, & Olson RK (2012). Predicting word reading and comprehension with executive function and speed measures across development: A latent variable analysis. Journal of Experimental Psychology. General, 141(3), 470–488. 10.1037/a0027375 [PubMed: 22352396]

Church JA, Bunge SA, Petersen SE, & Schlaggar BL (2017). Preparatory engagement of cognitive control networks increases late in childhood. Cerebral Cortex, 27(3), 2139–2153. 10.1093/cercor/bhw046 [PubMed: 26972753]

Cunningham AE, & Stanovich KE (1997). Early reading acquisition and its relation to reading experience and ability 10 years later. Developmental Psychology, 33(6), 934–945. 10.1037/0012-1649.33.6.934 [PubMed: 9383616]

Davidson MC, Amso D, Anderson LC, & Diamond A (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. Neuropsychologia, 44(11), 2037–2078. [PubMed: 16580701]

Diamond A (2013). Executive functions. Annual Review of Psychology, 64(1), 135–168. 10.1146/annurev-psych-113011-143750

Dittman CK (2016). The impact of early classroom inattention on phonological processing and word-reading development. Journal of Attention Disorders, 20(8), 653–664. 10.1177/1087054713478979 [PubMed: 23475828]

Doyle C, Smeaton AF, Roche RAP, & Boran L (2018). Inhibition and updating, but not switching, predict developmental dyslexia and individual variation in reading ability. Frontiers in Psychology, 9. 10.3389/fpsyg.2018.00795

Eriksen BA, & Eriksen CW (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. Perception & Psychophysics, 16(1), 143–149. 10.3758/BF03203267

Evans J. St. B. T., & Stanovich KE (2013). Dual-process theories of higher cognition: Advancing the debate. Perspectives on Psychological Science, 8(3), 223–241. 10.1177/1745691612460685 [PubMed: 26172965]

Fuhs MW, & Day JD (2011). Verbal ability and executive functioning development in preschoolers at head start. Developmental Psychology, 47(2), 404. 10.1037/a0021065 [PubMed: 21142363]

Fuhs MW, Nesbitt KT, Farran DC, & Dong N (2014). Longitudinal associations between executive functioning and academic skills across content areas. Developmental Psychology, 50(6), 1698–1709. 10.1037/a0036633 [PubMed: 24749550]

Garon N, Bryson SE, & Smith IM (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Bulletin, 134(1), 31–60. 10.1037/0033-2909.134.1.31 [PubMed: 18193994]

Gathercole SE, Alloway TP, Willis C, & Adams A-M (2006). Working memory in children with reading disabilities. Journal of Experimental Child Psychology, 93(3), 265–281. 10.1016/j.jecp.2005.08.003 [PubMed: 16293261]

Georgiou GK, Wei W, Inoue T, Das JP, & Deng C (2020). Cultural influences on the relation between executive functions and academic achievement. Reading and Writing, 33(4), 991–1013. 10.1007/s11145-019-09961-8

Gottardo A, Koh PW, Chen X, & Jia F (2017). Models of English and Chinese word reading for adolescent Chinese–English bilinguals. Reading and Writing, 30(7), 1377–1406. 10.1007/s11145-017-9728-2

Halperin JM, Wolf LE, Pascualvaca DM, Newcorn JH, Healey JM, O'brien JD, … Young JG (1988). Differential assessment of attention and impulsivity in children. Journal of the American Academy of Child & Adolescent Psychiatry, 27(3), 326–329. 10.1097/00004583-198805000-00010 [PubMed: 3379014]

Han WJ (2008). The academic trajectories of children of immigrants and their school environments. Developmental Psychology, 44, 1572–1590. 10.1037/a0013886 [PubMed: 18999323]

Hu L, & Bentler PM (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling: A Multidisciplinary Journal, 6(1), 1–55. 10.1080/10705519909540118

Jacob R, & Parkinson J (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. Review of Educational Research, 85(4), 512–552. 10.3102/0034654314561338

Knight GP, Roosa MW, Calderón-Tena CO, & Gonzales NA (2009). Methodological issues in research on Latino populations. In Villaruel F, Carlo G, Grau J, Azmitia M, Cabrera N, & Chahin J (Eds.), Handbook of US Latino psychology (pp. 45–62). Thousand Oaks, CA: Sage.

Kochanska G, Murray K, Jacques TY, Koenig AL, & Vandegeest KA (1996). Inhibitory control in young children and its role in emerging internalization. Child Development, 67(2), 490–507. 10.1111/j.1467-8624.1996.tb01747.x [PubMed: 8625724]

Lan X, Legare CH, Ponitz CC, Li S, & Morrison FJ (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American preschoolers. Journal of Experimental Child Psychology, 108(3), 677–692. 10.1016/j.jecp.2010.11.001 [PubMed: 21238977]

Little TD (2013). Longitudinal structural equation modeling. New York, NY: Guilford Press.

Liu C, Chung KKH, & Fung WK (2019). Bidirectional relationships between children's executive functioning, visual skills, and word reading ability during the transition from kindergarten to primary school. Contemporary Educational Psychology, 59, 101779. 10.1016/j.cedpsych.2019.101779

Locascio G, Mahone EM, Eason SH, & Cutting LE (2010). Executive dysfunction among children with reading comprehension deficits. Journal of Learning Disabilities, 43(5), 441–454. 10.1177/0022219409355476 [PubMed: 20375294]

Lonigan CJ, Allan DM, & Phillips BM (2017). Examining the predictive relations between two aspects of self-regulation and growth in preschool children's early literacy skills. Developmental Psychology, 53(1), 63–76. 10.1037/dev0000247 [PubMed: 27854463]

Lu L, & Liu HS (1998). The Peabody Picture Vocabulary Test-Revised in Chinese. Taipei, Taiwan: Psychological Publishing.

Marcovitch S, Boseovski J, Knapp R, & Kane M (2010). Goal Neglect and Working Memory Capacity in 4-to 6-Year-Old Children. Child Development, 81(6), 1687–1695. 10.1111/j.1467-8624.2010.01503.x [PubMed: 21077857]

Massol S, Molinaro N, & Carreiras M (2015). Lexical inhibition of neighbors during visual word recognition: An unmasked priming investigation. Brain Research, 1604, 35–51. 10.1016/j.brainres.2015.01.051 [PubMed: 25665529]

McClelland MM, Cameron CE, Duncan R, Bowles RP, Acock AC, Miao A, & Pratt ME (2014). Predictors of early growth in academic achievement: the head-toes-knees-shoulders task. Frontiers in Psychology, 5. 10.3389/fpsyg.2014.00599

McGee R, Prior M, Williams S, Smart D, & Sanson A (2002). The long-term significance of teacher-rated hyperactivity and reading ability in childhood: Findings from two longitudinal studies. Journal of Child Psychology and Psychiatry, 43(8), 1004–1017. 10.1111/1469-7610.00228 [PubMed: 12455922]

McKinnon RD, & Blair C (2019). Bidirectional relations among executive function, teacher–child relationships, and early reading and math achievement: A cross-lagged panel analysis. Early Childhood Research Quarterly, 46, 152–165. 10.1016/j.ecresq.2018.03.011

Miyake A, & Friedman NP (2012). The nature and organization of individual differences in executive functions: Four general conclusions. Current Directions in Psychological Science, 21(1), 8–14. 10.1177/0963721411429458 [PubMed: 22773897]

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, & Wager TD (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. Cognitive Psychology, 41(1), 49–100. 10.1006/cogp.1999.0734 [PubMed: 10945922]

Muthén LK, & Muthén BO (1998–2017). Mplus user’s guide (8th ed.). Los Angeles, CA: Muthén & Muthén.

Ober TM, Brooks PJ, Homer BD, & Rindskopf D (2020). Executive functions and decoding in children and adolescents: A meta-analytic investigation. Educational Psychology Review. 10.1007/s10648-020-09526-0

Peng P, Barnes M, Wang C, Wang W, Li S, Swanson HL, Dardick W, & Tao S (2018). A meta-analysis on the relation between reading and working memory. Psychological Bulletin, 144(1), 48–76. 10.1037/bul0000124 [PubMed: 29083201]

Peng P, & Kievit RA (2020). The development of academic achievement and cognitive abilities: A bidirectional perspective. Child Development Perspectives, 14(1), 15–20. 10.1111/cdep.12352

Pew Research Center. (2012). The rise of Asian Americans. Washington, DC: Pew Social & Demographic Trends.

Riccio CA, Reynolds CR, Lowe P, & Moore JJ (2002). The continuous performance test: A window on the neural substrates for attention? Archives of Clinical Neuropsychology, 38.

Roosa MW, Liu FF, Torres M, Gonzales NA, Knight GP, & Saenz D (2008). Sampling and recruitment in studies of cultural influences on adjustment: A case study with Mexican Americans. Journal of Family Psychology, 22(2), 293. 10.1037/0893-3200.22.2.293 [PubMed: 18410216]

Rothbart MK, & Bates JE (2006). Temperament. In Eisenberg N, Damon W, & Lerner R (Eds.), Handbook of child psychology: Social, emotional, and personality development (Vol. Vol. 3, pp. 99–166). Hoboken, NJ: Wiley.

Rothbart MK, & Posner MI (2005). Genes and experience in the development of executive attention and effortful control. New Directions for Child and Adolescent Development, 2005(109), 101–108. 10.1002/cd.142

Sabbagh MA, Xu F, Carlson SM, Moses LJ, & Lee K (2006). The development of executive functioning and theory of mind. A comparison of Chinese and U.S. preschoolers. Psychological Science, 17(1), 74–81. 10.1111/j.1467-9280.2005.01667.x [PubMed: 16371147]

Schmitt SA, Geldhof GJ, Purpura DJ, Duncan R, & McClelland MM (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. Journal of Educational Psychology, 109(8), 1120–1140. 10.1037/edu0000193

Sijtsma K (2008). On the use, the misuse, and the very limited usefulness of Cronbach’s alpha. Psychometrika, 74(1), 107. 10.1007/s11336-008-9101-0 [PubMed: 20037639]

Sirin SR (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. Review of Educational Research, 75(3), 417–453. 10.3102/00346543075003417

Skibbe LE, Montroy JJ, Bowles RP, & Morrison FJ (2019). Self-regulation and the development of literacy and language achievement from preschool through second grade. Early Childhood Research Quarterly, 46, 240–251. 10.1016/j.ecresq.2018.02.005 [PubMed: 30636841]

Smith JL, Johnstone SJ, & Barry RJ (2004). Inhibitory processing during the Go/NoGo task: An ERP analysis of children with attention-deficit/hyperactivity disorder. Clinical Neurophysiology, 115(6), 1320–1331. [PubMed: 15134699]

Son S-HC, Choi JY, & Kwon K-A (2019). Reciprocal associations between inhibitory control and early academic skills: Evidence from a nationally representative sample of head start children. Early Education and Development, 30(4), 456–477. 10.1080/10409289.2019.1572382

Spencer M, & Cutting LE (2020). Relations among executive function, decoding, and reading comprehension: An investigation of sex differences. Discourse Processes, 1–18. 10.1080/0163853X.2020.1734416

Stipek D, Newton S, & Chudgar A (2010). Learning-related behaviors and literacy achievement in elementary school-aged children. Early Childhood Research Quarterly, 25(3), 385–395. 10.1016/j.ecresq.2009.12.001

ten Braak D, Kleemans T, Storksen I, Verhoeven L, & Segers E (2018). Domain-specific effects of attentional and behavioral control in early literacy and numeracy development. Learning and Individual Differences, 68, 6–71. 10.1016/j.lindif.2018.10.001

Tharp JA, Wendelken C, Mathews CA, Marco EJ, Schreier H, & Bunge SA (2015). Tourette syndrome: Complementary insights from measures of cognitive control, eyeblink rate, and pupil diameter. Frontiers in Psychiatry, 6. 10.3389/fpsyt.2015.00095

Tran CD, Arredondo MM, & Yoshida H (2015). Differential effects of bilingualism and culture on early attention: A longitudinal study in the U.S., Argentina, and Vietnam. Frontiers in Psychology, 6. 10.3389/fpsyg.2015.00795

Trommer BL, Hoeppner J-AB, Lorber R, & Armstrong KJ (1988). The Go—No-Go paradigm in attention deficit disorder. Annals of Neurology, 24(5), 610–614. 10.1002/ana.410240504 [PubMed: 3202613]

U.S. Department of Health and Human Services, Administration for Children and Families, Office of Head Start. (2009). OHS definition of dual language learners. Washington, DC. Retrieved from https://eclkc.ohs.acf.hhs.gov/sites/default/files/pdf/dll-policy-statement-final.pdf

Varvara P, Varuzza C, Padovano Sorrentino AC, Vicari S, & Menghini D (2014). Executive functions in developmental dyslexia. Frontiers in Human Neuroscience, 8. 10.3389/fnhum.2014.00120

Vygotsky LS (1962). Language and thought. Ontario, Canada: Massachusetts Institute of Technology Press.

Wagner RK, Torgesen JK, & Rashotte CA (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. Developmental Psychology, 73–87.

Wendelken C, Munakata Y, Baym C, Souza M, & Bunge SA (2012). Flexible rule use: Common neural substrates in children and adults. Developmental Cognitive Neuroscience, 2(3), 329–339. 10.1016/j.dcn.2012.02.001 [PubMed: 22669034]

West SG, Finch JF, & Curran PJ (1995). Structural equation models with nonnormal variables: Problems and remedies. In Hoyle RH (Ed.), Structural equation modeling: Concepts, issues, and applications (pp. 56–75). Thousand Oaks, CA: Sage Publications, Inc.

Woodcock RW, McGrew KS, & Mather N (2001). Woodcock-Johnson III Tests of Achievement. Itasca, IL: Riverside.

Zelazo PD, Anderson JE, Richler J, Wallner-Allen K, Beaumont JL, & Weintraub S (2013). II. NIH Toolbox Cognition Battery (CB): Measuring executive function and attention. Monographs of the Society for Research in Child Development, 78(4), 16–33. 10.1111/mono.12032 [PubMed: 23952200]

Zelazo PD, & Cunningham WA (2007). Executive function: Mechanisms underlying emotion regulation. In Gross JJ (Ed.), Handbook of emotion regulation (pp. 135–158). New York, NY: Guilford Press.

Zhang S, & Malatesha Joshi R (2020). Longitudinal relations between verbal working memory and reading in students from diverse linguistic backgrounds. Journal of Experimental Child Psychology, 190, 104727. 10.1016/j.jecp.2019.104727 [PubMed: 31726244]

Zong J, & Batalova J (2017). Chinese immigrants in the United States. Migration Policy Institute.

Zorza JP, Marino J, & Acosta Mesas A (2019). Predictive influence of executive functions, effortful control, empathy, and social behavior on the academic performance in early adolescents. The Journal of Early Adolescence, 39(2), 253–279. 10.1177/0272431617737624

Highlights

- Four measures of executive functions and two types of English word-level reading were assessed in a two-wave study of Chinese American school-aged children
- The comprehensive executive function measure positively predicted pseudoword reading, and pseudoword reading also positively predicted comprehensive executive function, showing bidirectional relations
- The comprehensive executive function measure positively predicted word reading. However, word reading did not predict comprehensive executive function
- Although working memory did not predict word-level reading, both pseudoword reading and word reading positively predicted working memory
- Attention focusing and inhibitory control did not have unique relations to word-level reading

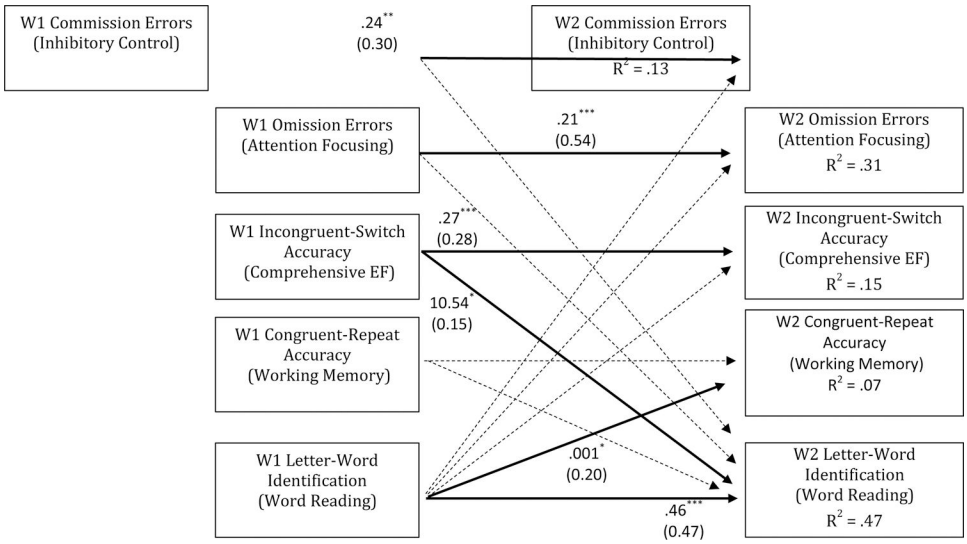

Figure 1.

The cross-lagged panel model testing bidirectional relations between EF and word reading. *Notes.* The numbers above parentheses are unstandardized path coefficients, the numbers inside parentheses are standardized path coefficients. Hypothesized but statistically nonsignificant paths are displayed in dashed lines. The effects of covariates (child age, sex, generation status, family SES, English proficiency, and Chinese proficiency) on W2 EF and word reading were controlled but not displayed in the figure. W1 = Wave 1, W2 = Wave 2. *$p < .05$. **$p < .01$, ***$p < .001$.

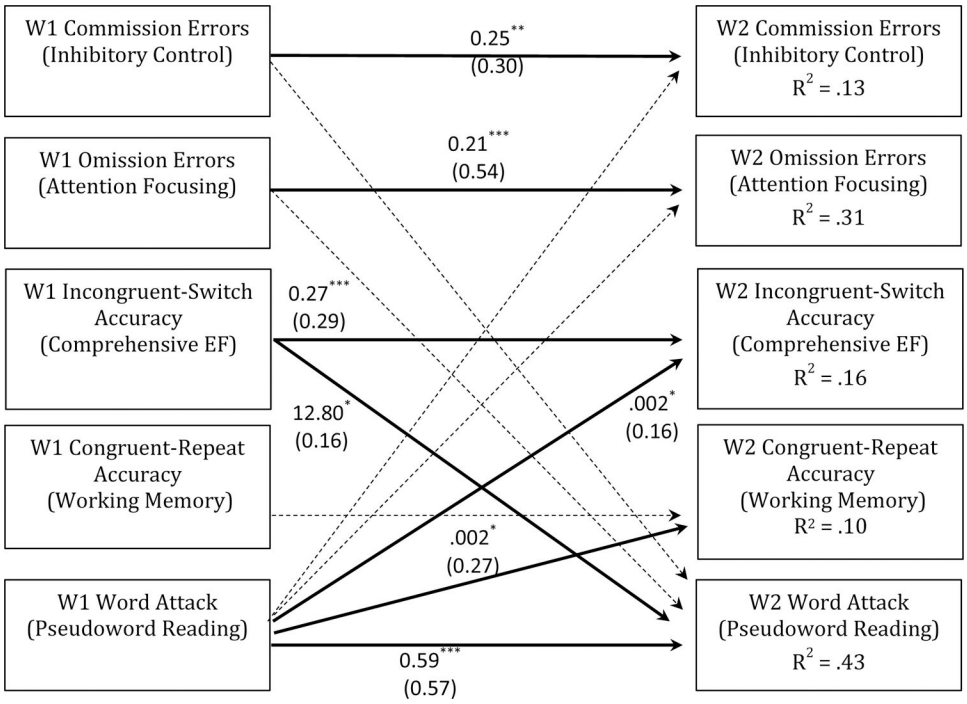

Figure 2.

The cross-lagged panel model testing bidirectional relations between EF and pseudoword reading. *Notes.* The numbers above parentheses are unstandardized path coefficients, the numbers inside parentheses are standardized path coefficients. Hypothesized but statistically nonsignificant paths are displayed in dashed lines. The effects of covariates (child age, sex, generation status, family SES, English proficiency, and Chinese proficiency) on W2 EF and pseudoword were controlled but not displayed in the figure. The path from W1 working memory to W2 pseudoword reading cannot be estimated due to problem with model convergence. W1 = Wave 1, W2 = Wave 2. *$p < .05$. **$p < .01$, ***$p < .001$.

Table 1.

Sample descriptive statistics for word reading and Executive Function variables at Wave 1 and Wave 2

Variable	Wave 1					Wave 2				
	N	**Mean**	***SD***	**Skewness**	**Kurtosis**	***N***	**Mean**	***SD***	**Skewness**	**Kurtosis**
Letter-Word Identification	258	114.05	10.00	−0.27	1.46	237	108.59	9.92	−0.07	0.01
Word Attack	257	111.88	10.45	−0.26	0.73	237	106.98	10.44	0.17	−0.08
Commission Errors (IC)	246	9.61	6.48	1.34	3.72	239	9.37	5.64	1.49	4.25
Omission Errors (AF)	246	5.68	8.75	3.46	14.27	239	1.94	3.09	2.75	9.45
Incongruent-Switch Accuracy (CEF)	242	0.74	0.14	−0.30	−0.71	237	0.82	0.13	−0.61	−0.31
Congruent-Repeat Accuracy (WM)	242	0.96	0.08	−3.49	14.89	237	0.97	0.06	−4.30	22.05
English Language Proficiency	--	--	--	--	--	235	−0.003	0.81	−0.10	−0.51
Chinese Receptive Vocabulary	--	--	--	--	--	224	48.01	22.33	0.27	−0.27

Note. SD = standard deviation, IC = inhibitory control, AF = attention focusing, CEF = comprehensive executive function, WM = working memory.

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Table 2.

The correlation matrix of demographic and study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. W1 Letter-Word Identification	--																
2. W1 Word Attack	.79***	--															
3.W2 Letter-Word Identification	.62***	.63***	--														
4.W2 Word Attack	.52***	.61***	.79***	--													
5. W1 Commission Errors (IC)	−.04	−.03	.01	.01	--												
6. W2 Commission Errors (IC)	.04	.01	.02	.03	.37***	--											
7. W1 Omission Errors (AF)	−.06	−.05	−.06	−.05	−.02	.06	--										
8.W2 Omission Errors (AF)	−.14*	−.12	−.19**	−.22**	.01	.04	.48***	--									
9.W1 Incongruent-Switch Accuracy (CEF)	.20**	.15*	.13	.14*	−.26***	−.18*	−.21**	−.13*	--								
10. W2 Incongruent-Switch Accuracy (CEF)	.21**	.24***	.13	.12	−.25***	−.23***	−.09	−.18**	.38***	--							
11. W1 Congruent-Repeat Accuracy (WM)	.05	.03	.01	.05	−.13	−.10	−.12	−.31***	.38***	.20**	--						
12. W2 Congruent-Repeat Accuracy (WM)	.16*	.21*	.12	.11	−.15*	−.09	−.04	−.06	.17*	.39***	.14*	-					
13. Child Age	−.15*	−.12	−.28***	−.22**	−.14*	−.16*	−.15*	−.12	.31***	.13	.15*	.10	--				
14. Child Sex [a]	.04	−.12*	−.06	−.08	.14*	.05	.05	−.01	−.17*	−.13	−.11	−.04	−.06	--			
15. Family SES	.24***	.24***	.27***	.21**	.14*	.15*	−.01	−.02	.04	.10	−.003	.03	−.16*	−.03	--		
16. Child Generation [b]	.19**	.18**	.08	.09	.16*	.15*	.01	.03	−.03	−.03	−.03	.08	−.06	−.06	.20**	--	
17. W2 English Language Proficiency	.46***	.43***	.44***	.37***	−.07	.02	−.14*	−.14*	.23**	.15*	.13	.03	−.08	−.20**	.33***	.22**	--
18. W2 Chinese Receptive Vocabulary	.01	.07	.00	−.04	−.13	−.11	−.14*	−.07	.15*	.13	.14*	.03	.23**	−.08	−.05	−.23**	−.08

Note. The *n*s for the correlations ranged from 213 to 258; IC = inhibitory control, AF = attention focusing, CEF = comprehensive executive function, WM = working memory;

[a] Child sex is coded as: 0 = girls, 1 = boys;

[b] Generation status is coded as: 0 = 1st generation, 1 = 2nd generation;

* $p < .05$,

** $p < .01$,

*** $p < .001$.