Abstract

Background: This study examined the bidirectionality between kindergarten children's

executive functioning (EF) and word reading across two time points. **Methods:** Participants

were 523 Hong Kong Chinese-speaking children (mean age at time 2 = 64.59 months; 52.9%

male) and their parents. At time 1, children were administered the measures of EF skills:

inhibitory control, attention shifting, and working memory, and Chinese word reading. They

were reassessed with these measures at time 2 one year later. **Results:** Results from the cross-

lagged panel model revealed that, controlling for child age, gender, and parental educational

levels, children's word reading at time 1 was significantly predictive of their working

memory at time 2, but that the three EF skills at time 1 were not predictive of word reading at

time 2. **Conclusions:** The findings underscored the role of early word reading in promoting

children's working memory.

Keywords: bidirectionality, executive functioning, Chinese word reading, kindergarten

children

Implications for Practice

What is already known about this topic

- Executive functioning (EF) is an important correlate of kindergarten children's word reading

- The relationships between EF and word reading may be potentially bidirectional

What this paper adds

- Children's word reading is predictive of their subsequent working memory

- Of the three EF skills, working memory is the strongest correlate of children's concurrent word reading

Implications for theory, policy or practice

- Working memory training may promote reading development in early education

Executive functioning and word reading in Hong Kong Chinese children: A one-year

longitudinal perspective

Executive functioning (EF) is conceptualized as the abilities to inhibit non-adaptive

responses (inhibitory control), to change focus on appropriate target and ignore distraction

(attention shifting), and to hold and manipulate information in mind (working memory)

(Miyake et al., 2000). This conceptualization is common in early childhood developmental

research (Best & Miller, 2010). Previous work has demonstrated the association between

kindergarten children's EF and English word reading (e.g., Becker, Miao, Duncan, &

Mcclelland, 2014; Lan, Legare, Ponitz, Li, & Morrison, 2011). Given the visual complexity

of Chinese characters, EF is especially important for children to learn to read Chinese (Fung

& Chung, 2019) and research has revealed the positive relationship between EF and Chinese

word reading (e.g., Chung, Lam, & Cheung, 2018; Liu et al., 2018). A recent study has also

revealed the bidirectional relationships between children's EF (conceptualized as verbal

working memory and inhibitory control) and word reading in the school transition from

kindergarten to grade one (Liu, Chung, & Fung, 2019). However, little is known whether the

bidirectionality between EF and word reading might be found in kindergarten children at ages

of 4 to 5 and how EF skills of inhibitory control, attention shifting, and working memory

might be associated with word reading across time (Butterfuss & Kendeou, 2018). This study,

therefore, examined the bidirectional associations among children's inhibitory control,

attention shifting, working memory, and word reading across two time points separated by

one year.

EF and word reading

Chinese is a morpho-syllabic writing system with visually complex characters. Chinese

characters have noticeable perceptual units that differ from thousands of other characters in

terms of the strokes and subcharacter components that are combined to form radicals. More

than 80% of Chinese characters are compound characters, often combining both semantic

radicals, providing semantic hints, and phonetic radicals, providing phonological information

(Kang, 1993). There are over 50,000 characters in Chinese and around 4500 of which are

commonly used characters (Gao et al., 2019). Many of these characters look the same and

sound alike. Chinese words are mostly composed of two or more characters (Taylor &

Taylor, 1995). Character recognition is the crucial skill learned by Chinese children. To either

read or process Chinese characters in reading, children must use working memory to read and

learn characters, inhibit irrelevant information when encountering characters with similar

sounds and visually confusable characters, focus on the relevant visual, phonological and

semantic features of characters, and shift attention between characters. Thus, the efficient

performance of EF such as working memory, inhibitory control, and attention shifting is

needed to read and learn Chinese words for kindergarten children. EF is likely to play an

important role in Chinese word reading, particularly to children who have not yet attained automatization in word reading process (Liu et al., 2019).

Although the three EF skills may be less distinctive in early childhood (Wiebe, Espy, & Charak, 2008), these skills may develop in varying paces and contribute to different stages of child development (Miyake & Friedman, 2012). Research has suggested that the three EF skills may relate differently to word reading (e.g., Chung & McBride-Chang, 2011; Lan, Legare, Ponitz, Li, & Morrison, 2011). For example, Chung and McBride-Chang (2011) examined the predictive roles of verbal working memory and inhibitory control in kindergarten children's word reading over one year. The results revealed that both working memory and inhibitory control were predictive of children's prospective word reading with their vocabulary knowledge, phonological awareness, and morphological awareness statistically controlled; but the predictive effects of working memory and inhibitory control became non-significant after controlling for their initial word reading. However, Chung and McBride-Chang (2011) study did not consider children's attention shifting and the results were based on only 85 children at ages of 4 to 5. Relatedly, findings from Lan et al. (2011) revealed that attention shifting was the most robust predictor of kindergarten children's concurrent word reading compared to working memory and inhibitory control. Therefore, further investigation of the longitudinal links between word reading and all three aspects of

EF with a large sample size may yield more comprehensive findings and bring significant

contribution to early intervention efforts to improve children at risk of reading difficulties.

Although empirical evidence shows the relationships between EF skills and word

reading (Chung & McBride-Chang, 2011; Lan et al., 2011), research on the bidirectional

associations of EF skills and word reading is relatively scarce. According to the dynamic

skills framework (Bohlmann, Maier, & Palacios, 2015), EF and academic skills, e.g., word

reading appear to be codeveloped and are dynamically affected by each other. Few recent

studies involving young children have shown the bidirectional associations of EF skills and

word reading. Particularly, Liu et al. (2019) investigated the reciprocal relationships between

EF, visual skills, and word reading of Hong Kong kindergarten children transitioning to

primary school. These results revealed that children's EF at kindergarten was predictive of

their word reading at grade one. Conversely, children's word reading at kindergarten was

predictive of their EF at grade one. As a potential explanation of why word knowledge

promotes children's development in EF, Liu et al. (2019) proposed that children who are

better in word reading may be more eager to engage in activities with high demand in

complex cognitive processing, while such experience may facilitate their growth in EF. Liu et

al. (2019) also examined EF skills of working memory and inhibitory control by combining

these two skills into one composite score. In this regard, the role of attention shifting in

addition to working memory and inhibitory control in the reciprocal associations with word reading needs to be further tested in children from the second to third year of kindergarten.

The present study

The present study investigated the bidirectionality among kindergarten children's inhibitory control, attention shifting, working memory, and their Chinese word reading by using a cross-lagged panel design. Based on the literature reviewed (e.g., Chung et al., 2018; Chung & McBride-Chang, 2011; Liu et al., 2019), it was hypothesized that a potential reciprocal relationship would be found between children's EF skills and their word reading.

Method

Participants

Participants were 523 Chinese children (277 boys, mean age at time 2 = 64.59 months, $SD = 7.18$ months) from 76 classrooms of nine local kindergartens in Hong Kong, China. The nine kindergartens were evenly distributed in the high-, middle-, and low-socioeconomic strata based on the district median household income (Hong Kong Census and Statistics Department, 2016) so as to form a socioeconomically representative sample. The children were native Cantonese speakers with no reported developmental disabilities and the attrition rate was 3.8%, which indicated a low dropout rate. Both fathers and mothers reported their education levels to serve as control variables: (1) primary, (2) secondary, (3) college, (4) university, and (5) postgraduate. Around 36.1% of the fathers completed secondary school,

whereas 41.7% of them completed college or above. For mothers, 42.1% of them completed

secondary school, whereas 40.7% of them completed college or above.

Procedure

Ethical approval was granted by the respective university. Permission was also obtained

from the principals of the nine kindergartens. Informed consent forms were sent to the

parents to invite their child's participation. At both time 1 (mean age = 52.42 months) and

time 2 (mean age = 64.59 months), the assessment measures of inhibitory control, attention

shifting, working memory, and word reading were administered individually by trained

assistants in a quiet area of each kindergarten. The assessment lasted approximately for 40

minutes and children were given a break between tasks.

Measures

Chinese Word Reading

Chinese word reading was measured by 70 items consisted of one- and two-character

words used in previous studies of Hong Kong kindergarten children (Chung, Liu, McBride,

Wong, & Lo, 2017; Ho et al., 2007). Children were instructed to read aloud the words sorted

in order of increasing difficulty. The test was terminated if children were not able to read 12

consecutive items correctly. Each correct answer was awarded one mark. Because this test

was developed for children from kindergarten through third grade, scores for younger

children were anticipated to be low on this measure. The maximum score was 70. The

Cronbach's alpha was 0.98 for both time 1 and time 2.

Inhibitory Control

Inhibitory control was measured by the NIH Toolbox Flanker Inhibitory Control and

Attention Test (Zaitchik, Iqbal, & Carey, 2014). Children were required to report the

direction of the target stimulus positioned at the center of a computer screen and ignore the

distracting stimuli positioned on the left and right of the target stimulus. The distracting

stimuli were pointing at the same or reverse direction of the target stimulus in the congruent

or incongruent trials, respectively. Children went through four practice trials and feedback

was provided to indicate the correctness of their response. If children were able to give at

least three correct responses out of the four practice trials, they proceeded to the testing trials

with a set of 20 mixed congruent and incongruent trials using fishes as stimuli and another set

of 20 mixed trials using arrows as stimuli. Each correct response was awarded one mark. The

maximum score was 40. The Cronbach's alphas were 0.82 and 0.83 at time 1 and time 2.

Attention Shifting

Attention shifting was measured by the NIH Toolbox Dimensional Change Card Sort

Test (Zaitchik et al., 2014). Two target photos showing information in two varying

dimensions were presented to the children (i.e., yellow color vs blue color, a ball vs a truck).

Children were then required to sort a series of photos showing information in the two varying

dimensions (e.g., a blue ball or a yellow truck) according to the reference dimension. The

reference dimension changed periodically and was signaled to the children by visual (i.e.,

showing the word of "shape" or "color") and audio (i.e., playing an audio file of the word of

"shape" or "color") cues. Children had three chances to go through a set of four practice trials

for each dimension. Feedback was provided to indicate the correctness of their response. If

children were able to give at least three correct responses out of the four practice trials, they

proceeded to the next practice trials and then to the testing trials. In the testing trials, children

needed to sort five trials for the color dimension and five trials for the shape dimension. The

task terminated if they gave more than one incorrect response. In the case that children met

the passing benchmark for both dimensions, they further proceeded to the mixed block

consisting of 30 shape/color trials. Each correct response was awarded one mark. The

maximum score was 40. The Cronbach's alphas were 0.77 and 0.86 at time 1 and 2.

Working Memory

Working memory was measured by the Wechsler Intelligence Scale for Children (3rd)

backward digit span task (Wechsler, 1991). Children heard a sequence of digits presented at a

rate of one per second and then reversely repeated that sequence when prompted by a signal.

The number of digits increased from two to nine, with two different sequences on each span

level. The task terminated if children wrongly recalled both sequences at a level. Each correct

answer was awarded one mark. The maximum score was 16 and the Cronbach's alphas were

0.63 and 0.72 at time 1 and 2.

Data analysis plan

Cross-lagged panel model examining the bidirectionality between children's word

reading, inhibitory control, attention shifting, and working memory across two time points

was estimated with the lavaan package (version 0.6-1) in R (version 3.5.0; R Core Team,

2018), with child's age, gender, and parental education levels statistically controlled. Model

fit was evaluated by the Chi-square index (χ^2), comparative fit index (CFI), non-normed fit

index (NNFI), root mean square error of approximation (RMSEA), and standardized root

mean square residual (SRMR). A non-significant χ^2 value, CFI and NNFI values over .95,

and RMSEA and SRMR values below .05 represent a good model fit (Hu & Bentler, 1999).

Results

Preliminary analyses

Table 1 displays the descriptive statistics and bivariate correlations of the study

variables. The fractions of missing data for the variables ranged between .048 and .184 with

Little's (1998) test value indicating that the data was missing completely at random (χ^2 (210)

= 235.44, p = .11). Thus, path analysis was conducted with full information maximum

likelihood estimation with robust standard errors (i.e. estimator MLR), which is robust to

non-normality.

<Table 1 about here>

Cross-lagged path analysis

Figure 1 shows the parameter estimates and model fit statistics for the cross-lagged

panel model, which demonstrated a good fit to the data χ^2 (5, $N = 523$) = 6.72, $p = .24$, CFI =

1.00, NNFI = .99, RMSEA = .03 (90% CI: .00, .07), SRMR = .02, $R^2_{Word\ Reading} = .73$, $R^2_{Inhibitory\ Control} = .24$, $R^2_{Attention\ Shifting} = .10$, $R^2_{Working\ Memory} = .25$. The three EF skills were

significantly associated with each other at both time 1 ($r = .18$ to .30, $p < .001$) and time 2 (r

= .09 to .14, $p < .05$). Moreover, the three EF skills were positively related to word reading at

both time 1 ($r = .11$ to .50, $p < .05$) and time 2 ($r = .09$ to .26, $p < .05$). The autoregressive

paths of word reading ($\beta = .78$, $SE = .04$, $p < .001$), inhibitory control ($\beta = .16$, $SE = .04$, p

< .001), attention shifting ($\beta = .16$, $SE = .05$, $p < .01$), and working memory ($\beta = .20$, SE

= .06, $p < .001$) were all significant. The cross-lagged paths from word reading at time 1 to

working memory at time 2 ($\beta = .15$, $SE = .01$, $p < .05$) and from inhibitory control at time 1 to

attention shifting at time 2 ($\beta = .13$, $SE = .06$, $p < .05$) were significant. Additionally, the

cross-lagged paths from attention shifting at time 1 to both inhibitory control ($\beta = .20$, SE

= .04, $p < .001$) and working memory at time 2 ($\beta = .10$, $SE = .01$, $p < .05$) were significant.

<Figure 1 about here>

Discussion

This study investigated the bidirectionality between the EF skills of inhibitory control, attention shifting, working memory and word reading among Hong Kong Chinese-speaking kindergarten children. The results reveal that children's early word reading and attention shifting may foster later working memory and that their inhibitory control and attention shifting may contribute to each other over time. However, bidirectionality between EF skills and word reading was not found. The present findings have expanded the existing studies by demonstrating the facilitative role of word reading in children's development in working memory (e.g., Chung & McBride-Chang, 2011; Liu et al., 2019). These results also support the universality of association between EF skills particularly in working memory and word reading in young children.

Bidirectional relationships between EF and word reading

The present results suggest that children's early word reading was predictive of their working memory one year later with corresponding autoregressive effects and demographic variables controlled. However, children's EF skills were not predictive of their prospective word reading. At both time points, children's EF skills were significantly associated with their concurrent word reading, while the strongest relationships were obtained between working memory and word reading. These findings are in line with previous evidence suggesting the importance of working memory (especially in the verbal domain) in children's reading development (Carretti et al., 2009).

Contrary to Liu et al.'s (2019) findings demonstrating the bidirectionality between word reading and EF across children's formal school transition, the present results do not support the bidirectionality between word reading and EF in earlier kindergarten years. Yet, the non-significance of the cross-lagged paths from EF skills to word reading aligned with previous findings that kindergarten children's working memory and inhibitory control were not predictive of later word reading after controlling for the initial level of word reading (Chung & McBride-Chang, 2011). One of the plausible explanations may be the differences in curriculum design across kindergartens and primary schools. Specifically, children's word acquisition process during the kindergarten years may be more step-by-step and topic-driven. Accordingly, children's word reading may be mainly determined by their prior level of word reading (as reflected by the strong autoregressive path) but not their previous EF skills. In contrast, when children are transitioning from kindergarten to the first grade, the discontinuity in pedagogical method and the sharp increase in the number of new Chinese characters acquired may make EF especially important in their day-to-day learning, as reflected by the significant cross-lagged path from early EF to later word reading but non-significant autoregressive path in word reading (Liu et al., 2019). Perhaps the stability of word reading in the present study is so strong that there may not be enough variance left over for EF to predict, which leads to the non-significance of the cross-lagged paths from EF skills to word reading. Nevertheless, future studies with three or more time points are necessary to

assess the directionality of these relationships in order to further investigate the directions of

effect and the associations between EF skills and word reading. Future research may also

consider including children in a wider age range to examine if age or class levels might

moderate the relationships.

The present finding also indicates that children's early word reading may influence their

subsequent working memory. In line with Liu et al.'s (2019) contention, it is possible that

children with advanced word knowledge may engage in more reading activities, while the

extensive reading experience requires children to actively recall and manipulate information

stored in the long term memory and, in turn, strengthens their working memory capacity.

Given that working memory was the main correlate of children's concurrent word reading,

early word reading may affect later word reading indirectly through children's working

memory and future work is needed to examine this possibility.

Bidirectional relationships among the three EF skills

In addition, the results reveal the reciprocal relationships between inhibitory control and

attention shifting and the cross-lagged path from attention shifting to working memory. The

pattern of results points to the importance of kindergarten children's attention shifting, which

may contribute to subsequent development in inhibitory control and working memory.

Although working memory and inhibitory control were suggested as the major aspects of EF

contributing to kindergarten children's early academic achievement (Chung & McBride-

Chang, 2011), attention shifting may possess a subtle role in supporting the growth in

working memory and inhibitory control. These findings are in line with the contention that

EF exhibits both unity and diversity (Miyake & Friedman, 2012) and different EF skills may

contribute to each other over time. Moreover, the results augment previous findings in

relation to the concurrent relationship between attention shifting and word reading (Lan et al.,

2011) by exploring how attention shifting may influence prospective word reading through its

impacts on working memory and/or inhibitory control indirectly.

Limitations

This study has at least four limitations. First, this study only focused on the relationships

between EF skills and children's reading performance at word level. In order to have a more

comprehensive understanding of children's reading development, reading performance

should also include sentence reading and passage reading. Second, future work should

consider including reading-related cognitive skills (e.g., vocabulary knowledge, phonological

awareness, and morphological awareness) together with EF skills and examine the specific

roles of these skills in children's reading performance given that these skills have been

identified as strong correlates of Chinese word reading in earlier studies (e.g., Chung &

McBride-Chang, 2011). Relatedly, although the backward digit span, dimensional card sort,

and Flanker tasks were designed by Wechsler (1991) and Zaitchik et al. (2014) to measure

working memory, inhibitory control, and attention shifting, respectively, in reality children

probably needed to activate multiple skills of EF to perform these tasks. The working

memory task probably required the use of inhibitory control, and the inhibitory control and

attention shifting tasks probably required the use of working memory. In fact, some cross-

time correlations of the same EF measure were weaker than the cross-sectional correlations

among different EF measures, indicating not only the potential overlapping among these

constructs, but also the dynamic development of EF during the early years (Bull & Lee, 2014;

Friedman & Miyake, 2017). Therefore, future researchers should use a wide range of EF

measures, including adult reports and child behavioral tasks, to capture the potential changes

in the latent structure of EF in different stages of child development.

Third, participating children were Hong Kong Chinese kindergarteners who read

traditional Chinese characters. Therefore, the generalizability of the findings to other Chinese

and Asian societies cannot be assumed and further studies are needed to test the replicability.

Finally, this longitudinal study was correlational and provided no causal inference to its

findings. Future studies using multi-waves longitudinal or experimental design are needed to

validate the present results.

Conclusions and Implications

Despite its limitations, the present study contributed to theory by suggesting the

facilitative role of word reading in kindergarten children's working memory and highlighting

working memory as the predominate correlate of children's concurrent word reading.

Practically speaking, the results highlighted the importance of early word reading experience in the development of working memory and suggested the utility of improving kindergarten children's working memory to foster their Chinese word reading.

Compliance with Ethical Standards: This manuscript was prepared in accord with the ethical standards of the American Psychological Association

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all participants' legal guardians included in the study.

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Table 1

Mean (M), standard deviation (SD), range, and bivariate correlations of study variables.

Variables	M	SD	Range	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1. Child Gender	--	--	--	--										
2. T2 Child Age	64.59	7.18	52.00-82.00	.06	--									
3. Paternal Education	2.92	1.136	1.00-5.00	.01	-.01	--								
4. Maternal Education	2.84	1.076	1.00-5.00	.08	-.03	.64**	--							
5. T1 Word Reading	15.32	16.66	0.00-67.00	.03	.56**	.04	.06	--						
6. T1 Inhibitory Control	23.71	12.90	0.00 – 40.00	.13**	.45**	.01	.06	.49**	--					
7. T1 Attention Shifting	22.50	13.90	0.00 – 40.00	.12**	.41**	.07	.08	.32**	.41**	--				
8. T1 Working Memory	1.02	1.32	0.00-6.00	.09*	.51**	.09	.13**	.64**	.47**	.36**	--			
9. T2 Word Reading	33.97	19.53	0.00-70.00	.08	.52**	.12*	.16**	.85**	.46**	.33**	.57**	--		
10. T2 Inhibitory Control	32.33	11.12	6.00-40.00	.09	.37**	.13*	.13**	.28**	.36**	.37**	.32**	.33**	--	
11. T2 Attention Shifting	27.41	13.33	2.00-40.00	.16**	.08	.13**	.17**	.11*	.20**	.22**	.16**	.19**	.24**	--
12. T2 Working Memory	2.21	1.49	0.00-6.00	.07	.37**	.05	.12*	.42**	.33**	.31**	.43**	.49**	.30**	.18**

Note: * $p < .05$; ** $p < .01$. T1 = Time 1; T2 = Time 2.

Figure Legends

Figure 1. Cross-lagged panel model of children's word reading, inhibitory control, attention shifting, and working memory across time 1 and time 2. Control variables include child age, gender, and paternal and maternal education levels. Standardized coefficients are reported. Solid paths are statistically significant. Non-significant paths are not shown. WR = word reading; IC = inhibitory control; AS = attention shifting; WM = working memory; T1 = time 1; T2 = time 2. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. Fit indices χ^2 (5, $N = 523$) = 6.72, $p = .24$, CFI = 1.00, NNFI = .99, RMSEA = .03 (90% CI: .00, .07), SRMR = .02, $R^2_{Word\ Reading} = .73$, $R^2_{Inhibitory\ Control} = .24$, $R^2_{Attention\ Shifting} = .10$, $R^2_{Working\ Memory} = .25$.

Figure 1.