Motor Skills and Executive Function Contribute to Early Achievement in East Asia and the Pacific

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Abstract

Research Findings: This study examined the contributions of motor skills and Executive Function (EF) to early achievement. Participants were 7,797 children (3,889 girls) aged between 36 and 72 months from six countries in East Asia and the Pacific. Fine and gross motor skills, EF, language and literacy, and mathematics achievement were evaluated using the East Asia-Pacific Early Child Development Scales (EAP-ECDS), a tool that assesses child development in seven domains. Children's caregivers provided demographic information. There were three salient findings. First, gross and fine motor skills predicted both language and literacy and mathematics achievement. Second, in general, fine motor skills contributed more to the prediction of early achievement than gross motor skills. However, there were no differences between the contribution of fine and gross motor skills to the prediction of early language and literacy in Papua New Guinea and early mathematics in Timor-Leste. Third, EF partially mediated the relation between both early achievement and gross and fine motor skills in the overall sample, Cambodia and Timor-Leste and fully mediated the association of gross motor skills and early achievement in China, Mongolia, Papua New Guinea and Vanuatu. *Practice or Policy:* Implications of the findings for early childhood education are discussed.

Keywords: motor skills, executive function, language and literacy, mathematics achievement, East Asia-Pacific Early Child Development Scales (EAP-ECDS)

Motor Skills and Executive Function Contribute to Early Achievement in East Asia and the Pacific

Children's early achievement depends on a combination of multifaceted competencies (Abenavoli, Greenberg, & Bierman, 2017; G. J. Duncan et al., 2007). Recently, increased attention has been accorded to understanding the role of motor skills and Executive Function (EF) in academic achievement (Cameron, Cottone, Murrah, & Grissmer, 2016; Davies, Janus, Duku, & Gaskin, 2016). Motor skills are closely associated with both language and mathematics achievement (Cameron et al., 2016; Carlson, Rowe, & Curby, 2013; Luo, Jose, Huntsinger, & Pigott, 2007). The core components of EF skills, including attention, working memory and inhibitory control, have also been found to predict children's learning outcomes (G. J. Duncan et al., 2007; R. J. Duncan, McClelland, & Acock, 2017). Against the background of these findings, more recent research has examined the role of EF as a potential mediator in the relation between motor development and academic achievement and found that EF is a mediator in the relation (Chang & Gu, 2018; Oberer, Gashaj, & Roebers, 2018; Schmidt et al., 2017). However, these studies have mainly focused on young children in Europe or in the U.S.

Early achievement in Low- and Middle- Income Countries

Malnutrition has a detrimental influence on children's cognitive development, motor development, and school achievement, and about 250 million children living in low- and middle-income countries (LMICs) are stunted (Lu, Black, & Richter, 2016). Despite findings from high-income countries suggesting that EF mediates the relation between motor skills and early achievement (e.g., Chang & Gu, 2018), it is not clear whether EF also mediates the relation between motor skills and early achievement in LMICs where a large number of children are stunted. Against this background, the present study considers the contributions of motor skills

and EF to early achievement in Cambodia, China, Mongolia, Papua New Guinea, Timor-Leste, and Vanuatu.

Children with a low height-for-age z score, a commonly used indicator of stunting, exhibited delay in cognitive abilities and motor scores both concurrently and longitudinally in 29 LMICs (Sudfeld et al., 2015). Similarly, analyses of data from UNICEF's Multiple Indicator Cluster Survey showed that stunting was negatively related with children's physical development and early achievement in literacy and numeracy in 15 LMICs (Miller et al., 2016). Research has shown that malnutrition or stunting in early years has a negative impact on the development of regions of brain related to motor and cognitive functioning, in terms of neuronal growth, pruning and connectivity within brain regions (Sudfeld et al., 2015). Further, such young children are also more likely to experience other disadvantages including poverty, less stimulating home environments, a limited access to early childhood settings, which lead to poor developmental outcomes (Prado & Dewey, 2014).

East Asia and the Pacific includes about 25% of the world's children under five years. In 2010, it was estimated that 20% of children under five years in East Asia and the Pacific were stunted and 29% (nearly 42 million) were at risk of not reaching their full development potential (Black et al., 2017). Many children are not ready to learn when they enter school and have low levels of reading, comprehension and mathematics skills during early primary school years (World Bank, 2018). Despite great efforts in the past decades, the stunting rate in one-third of the region's countries remains high, which will impede children's early learning and achievement (World Bank, 2018). While China is regarded as one of the top performers in early achievement in this region, over 30% of children from Cambodia, Timor-Leste and Vanuatu were not able to read a single word in Grade Two (World Bank, 2018). Low levels of early achievement, if

unaddressed, will linger on and affect later school achievement and future life success (G. J. Duncan et al., 2007). Against this background, this study examined important skills that contribute to early achievement in six LMICs in East Asia and the Pacific.

Motor skills and academic achievement

The term ‘motor skills’ describes a broad range of physical competencies including balance and stability, coordinated movement and the manipulation of objects (Griggs, 2012; Lawrence, 2012). A distinction is made between gross and fine motor skills. Gross motor skills require the coordination of the body’s larger muscles in balance, posture, orientation and movement of the trunk and limbs while fine motor skills refer to the integration of the smaller muscles for activities such as drawing, writing, reading and speaking, and usually include manual dexterity and visual-motor integration (Cameron et al., 2016).

Studies have uncovered relations between motor skills and academic achievement. Children with higher levels of motor skills at the beginning of school tend to achieve higher academic performance than those with lower levels (Cameron et al., 2016). Motor control, balancing abilities and the capability to explore the surrounding environment in five-month-olds indirectly predicted their academic achievement at 10 and 14 years via cognitive abilities at 4 and 10 years (Bornstein, Hahn, Suwalsky, 2013). However, when different components of motor skills are examined separately, different patterns of correlations between motor skills and academic achievement emerge. Extant research yields inconsistent findings regarding the associations between gross motor skills and both reading and mathematics achievement. When gross motor skills are considered along with fine motor skills, they have not typically contributed to prediction of academic achievement (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Kim et al., 2015; Pagani & Messier, 2012) although there have been exceptions (Son & Meisels,

2006). On the other hand, studies have consistently found that fine motor skills are strong predictors of academic achievement, even after controlling for gross motor skills (Cameron et al., 2012; Grissmer et al., 2010; Kim et al., 2015; Pagani & Messier, 2012). Researchers have further pointed out that fine motor skills underpin the relation between motor development and cognitive abilities, including academic performance, across a wide age span (Davis, Pitchford, & Limback, 2011; van der Fels et al., 2015). In addition, fine motor skills are found to be more closely linked with mathematics achievement than with literacy achievement (Murrah, Chen, & Cameron, 2013; Pitchford, Papini, Outhwaite, & Gulliford, 2016).

Researchers have articulated the potential mechanism linking motor skills with academic achievement. First, early mastery of numeracy and mathematics largely depends on the manipulation of objects which require fine motor skills (Pagani & Messier, 2012), and therefore may be more closely linked with fine motor skills than early literacy skills. Second, when children have a good mastery of fine motor skills, they are able to allocate attention to more complex academic skills that, in turn, contribute to higher levels of early achievement (Cameron et al., 2012; 2016; Pitchford et al., 2016). Third, higher levels of gross motor skills may reduce emotional distress and social difficulties in classrooms, help children to concentrate more on learning and thus promote early achievement (Pagani & Messier, 2012; Pitchford et al., 2016). Despite the evidence, studies have not adequately examined the relation between motor skills and academic achievement (Cadoret et al., 2018; Cameron et al., 2016), especially in LMICs. Hence, it is not clear whether the same relation between motor skills and achievement will be found among children in LMICs as those living in western countries.

Motor skills, Executive Function, and academic achievement

Given associations between EF, motor skills and academic achievement, an increasing number of studies are probing the nature of the relation between these three variables (Sulik, Haft, & Obradović, 2018). Generally, these studies have explored the simultaneous prediction of academic achievement from motor skills and EF, or the mediating role of EF in the motor-academic performance link. Findings show that both motor skills and EF are strong predictors of reading and/or mathematics achievement and the growth of academic performance between kindergarten and middle school years (Brock, Kim, & Grissmer, 2018; Cameron, et al., 2012; Carlson, 2014). The significant contributions of both early fine motor skills and EF to later school achievement were also detected in a cross-cultural study conducted in the U.S. and the U.K. (Grissmer et al., 2010). However, when analyzed together with fine motor skills and EF, gross motor skills did not contribute to the development of school outcomes (Cameron et al., 2012). Further, visuomotor skills, an important component of fine motor skills, were differentially correlated with different aspects of academic achievement when considered together with behavioral self-regulation and EF (Becker, Miao, Duncan, & McClelland, 2014). While behavioral self-regulation, visuomotor skills and EF were significantly associated with emergent literacy, EF was not related to mathematics and visuomotor skills were not related to vocabulary scores (Becker, Miao, et al., 2014).

Several other studies report that EF mediates the relation between academic achievement and motor skills in terms of fine motor skills (Cadoret et al., 2018; Roebers et al., 2014), visuomotor integration skills (Chang & Gu, 2018), and physical activity or active play (Becker, McClelland, Loprinzi, & Trost, 2014; Cadoret et al., 2018; Chang & Gu, 2018; Oberer et al., 2018). Few have examined whether EF mediates the relation between gross motor skills and

academic achievement. A large-scale longitudinal study of early primary school children in Norway demonstrated that physical activity involving gross motor skills did not predict EF and academic performance in numeracy, reading and English, and EF was not a mediator in the relation between gross motor skills and school achievement (Aadland, Ommundsen, et al., 2017).

Neuroimaging studies indicate that the rostral premotor cortex serves as a link between motor and cognitive networks and brain regions previously thought to be involved only in motor activities (cerebellum and basal ganglia) or cognitive activities (prefrontal cortex) are co-activated during certain motor or cognitive tasks (Diamond, 2000; Hanakawa, 2011). Evidence from longitudinal studies demonstrate that early motor development predicts adult EF (Carlson, Zelazo & Faja, 2013). This may explain the close relation between motor skills and EF, the higher order cognitive skill (Ackerman & Friedman-Krauss, 2017; Blair & Razza, 2007; Diamond, 2000; McClelland et al., 2007). At the same time, findings from studies with children and adolescents suggest that EF is a domain-general skill that facilitates both reading/language and mathematics achievement (Best, Miller, & Naglieri, 2012; Bull, Espy, & Wiebe, 2008). The findings are culturally robust in the U.S., European and Asian contexts (G. J. Duncan et al., 2007; Lan, Legare, Cameron, Li, & Morrison, 2011; Thorell, Veleiro, Siu & Mohammadi, 2013). Therefore, it is likely that EF plays a mediating role between motor skills and academic achievement.

The Present Study

Previous studies have shown that motor skills are closely related to academic achievement and suggest that EF is a promising mediator to account for the relation between motor skills and academic achievement. However, to date, much of the research has been conducted in rich Western countries (Nielsen, Haun, Kärtner & Legare, 2017) and there is a

question over whether the findings will be equally valid in LMICs. Using data from the validation sample of the East Asia-Pacific Early Child Development Scales (EAP-ECDS), the current study explored whether EF mediated the relation between motor skills and early achievement in Cambodia, China, Mongolia, Papua New Guinea, Timor-Leste, and Vanuatu.

We considered the relations between early achievement and both gross motor skills and fine motor skills, and additionally examined the role of EF in these relations. Analyses were conducted both using a sample of all countries together, and also separately for each of the six countries. This allowed further investigation of commonalities and differences in the relation between motor skills, EF and early achievement in countries that vary markedly in economic development as well as in early childhood education.

The present study addressed two research questions: (i) Do fine motor skills and gross motor skills predict early language and literacy and early mathematics across the six countries? (ii) Does EF mediate the relation between motor skills and early achievement across the six countries? We hypothesized that both gross and fine motor skills would contribute to achievement in mathematics and language and literacy in all the six countries. We expected that fine motor skills would have larger associations with achievement than gross motor skills, based on earlier research (Grissmer et al., 2010). Further, based on Becker, McClelland et al. (2014), we anticipated that EF would mediate the relation between fine and gross motor skills and early achievement in language and literacy and mathematics. We had no empirical basis to expect that there would be differences across the six countries.

Method

Participants

Data for the present study were from the validation study of the East Asia-Pacific Child Development Scales (EAP-ECDS) conducted between 2013 and 2014. Participants were 8,439 children from six countries, including Cambodia, China, Mongolia, Papua New Guinea, Timor-Leste, and Vanuatu. The final analytic sample excluded children who were initially sampled but were outside the intended age range of 36 to 72 months, and also excluded ethnic minority children since sampling of ethnic minorities was insufficiently representative. After these exclusions, the present study included 7,797 children aged 36 to 72 months (3,889 girls) and their parents from the six countries.

The sampling plan in five countries was developed in conjunction with the country's National Census Department or Statistics Institute. The objective was to obtain a nationally representative sample using multistage sampling with the last stage at the community level. Stratified random sampling by urban/rural location, gender, and age in years (3, 4, and 5) was conducted to achieve a minimum sample of 100 children in each of the 12 categories. This was considered sufficient to detect a difference between subgroups of 0.25-0.3 SD with 0.80 power, alpha of 0.05, and 24 children per community, unadjusted for covariates. The exception was the sample in China, which was drawn from five provinces chosen for their divergent levels of economic development. Further, in China, an additional stage was added to sample kindergartens within communities.

Country context

There are great variations in contexts and in early childhood education (ECE) among the six countries. For example, country population varied from 1.4 billion in China to 0.27 million in

Vanuatu; gross domestic product per capita income in 2014 ranged from US$1094.60 in Cambodia to US$7590 in China; stunting rates varied from 9% in China to 58% in Timor-Leste and the gross enrolment ratio for pre-primary education in 2012 ranged from 15% in Cambodia to 85% in Mongolia (see Rao et al., 2018 for details).

Among the six countries, China has been acknowledged as the world leader in educational achievement due to distinguished performance in international achievement tests (OECD, 2014; 2016). Chinese culture stresses the importance of propriety, discipline, self-control, and the exertion of effort, and parents emphasize school learning (Rao, Sun, & Zhang, 2014). Mongolian people also highly value education and prioritize children's education (Gundenbal & Salmon, 2011). In Vanuatu, due to financial constraints, parents tend to defer children's enrollment in formal education until primary school (Ministry of Education, Government of Vanuatu, 2013). There is a low quality of ECE due to a lack of educational resources and qualified teachers in centers and Kindys (kindergartens in Vanuatu) (Ministry of Education, Government of Vanuatu, 2013). In Papua New Guinea, the quality of pre-primary education is not deemed to be high because of low levels of teacher qualifications, a low teacher-child ratio (about 1:47 in 2013), and the lack of a national Early Childhood Care and Education (ECCE) curriculum (Department of Education, Papua New Guinea, 2015). Cambodia is expanding preschool access but has significant urban-rural disparities. Children from poor families, with less educated mothers and those from ethnic minority groups in rural areas have very limited preschool access (Rao, Sun, Ng., et al., 2014). In Timor-Leste, challenges to the provision of ECE include the concern that some parents may not be aware of the importance of early learning and education (Democratic Republic of Timor-Leste, 2015).

Procedure

The present study uses data from the validation study of the EAP-ECDS. At the initial stage, core members of research teams from the six countries received training from a university-based technical support group in the Region. During training, items requiring country adaption and cultural-specific adaption were discussed. After training, each research team followed standard translation and back-translation procedures to ensure the equivalence of the English and local versions of the EAP-ECDS. In each country, two local persons who were bilingual (local language and English) and who had expertise in the area of ECE, but were not familiar with the Scales, were invited to translate the assessment and questionnaire forms. The first person translated the original English version to the local language while the second person translated the local version back to English. Each country team discussed with the technical support group any differences or revisions for the measures. In addition, each country research team recruited assessors who are university faculty members, local officers, and graduate students in the area of ECE. All the assessors received in-country training from the university-based technical support group and several rounds of training from core members of the country team. After that, the assessors conducted pilot assessments, videotaped the assessment process and sent the videos to the technical support group for feedback. These procedures were followed to ensure standardized administration and scoring procedures (Rao et al., 2018).

Trained assessors in each country team administered the EAP-ECDS to children in individual sessions after obtaining consent from parents. To ensure reliability in data collection each assessor conducted tests together with a supervisor. The inter-rater reliability was at least 85% between the assessor and supervisor before the commencement of formal assessment, and

regular monitoring of inter-rater reliability was undertaken (Rao, Sun, Ng, et al., 2014; Rao et al., 2018).

Parents provided standard demographic information through individual interviews in five countries. The exception was China where parents completed questionnaires in small groups under the supervision of a research assistant, who was also able to answer any queries. This was done because of the relatively high literacy rate in China compared to the other countries.

Measures

All the measures of gross and fine motor skills, EF and early achievement in early language and literacy and early mathematics were from the EAP-ECDS. The Scales are an 85-item psychometrically robust tool that assesses child development in the following seven domains: Cognitive Development, Language and Emergent Literacy, Socio-emotional Development, Motor Development, Cultural Knowledge and Participation, Health, Hygiene and Safety, and Approaches to Learning (Rao, Sun, Ng, et al., 2014). All the items were developed based on the Early Learning and Development Standards (ELDS) from seven countries in East Asia and the Pacific (Rao, Sun, Ng., et al., 2014). The selected items for each measure were commonly used in prior studies and were agreed upon by the technical support group as typical tasks to address each developmental domain. More details on the Scales can be found in the technical report on the validation study (Rao, Sun, Ng., et al., 2014).

Motor skill assessment. A total of 10 items in the EAP-ECDS were selected from the sub-scales of Motor Development and Language and Emergent Literacy to assess motor skills. These included five items for fine motor skills and five items for gross motor skills. Cronbach's alpha scores (α) were calculated to assess the reliability of each measure and, because of clustering in the sample design, intracluster correlations (ICC) were calculated to compare the

within-province and between-province variances. The fine motor assessment (α = .88, ICC = .10) included folding a paper plane following a demonstration; using a pencil to copy three shapes; drawing a person; stringing beads; and buttoning and unbuttoning a vest. The gross motor assessment (α = .75, ICC = .08) included walking forwards and backwards on a narrow strip; pouring water into a cup and laying down the cup to a designated place; throwing the ball to a target; and catching a ball. Some items are composed of several sub-items. All the sub-items or items with no sub-items were scored 0 or 1 (see Appendix 1).

Early achievement measures. The language and literacy test contained 12 items from the domain of Language and Emergent Literacy (α = .92, ICC = .14) in the EAP-ECDS. The test examined children's receptive and expressive language (e.g. recognizing and naming actions and telling a story according to pictures), pre-reading skills (e.g., recognizing simple written information and reading a book), and pre-writing skills (e.g., writing own names). The mathematics test comprised 11 items from the Cognitive Development domain of the EAP-ECDS (α = .93, ICC = .10). These items assess children's command of concepts of time, quantity, numeracy and counting, simple computation, shape, pattern, and classification (see Appendix 1).

Executive Function tasks. All five items tapping three components of EF, including working memory, inhibitory control, and attention skills, were selected from the EAP-ECDS subscales of Cognitive Development, Language and Emergent Literacy and Approaches to Learning (α = .88, ICC = .10). Two items requiring children to repeat multi-word sentences (from five words to seven words) and act according to a three-step instruction examined children's working memory. The basic version of Dimensional Change Card Sort (Zelazo, 2006) is commonly used as a measure of cognitive flexibility or set-shifting (Doebel & Zelazo, 2015)

and was used to assess attentional skills in the present study. In the task, children were presented with two target cards (e.g., a blue rabbit and a red boat) and a series of test cards (e.g., red rabbits and blue boats). They were instructed to sort the test cards according to one dimension (e.g., by color) and then according to another dimension (e.g., by shape) without any pause in between. The tapping game (Diamond & Taylor, 1996) and the gift delay task (Carlson & Wang, 2007) explored children's inhibitory control. The tapping game included six trials and required children to tap once while the assessor tapped twice and vice versa. The gift delay task was conducted at the end and children were told that they would be given a surprise gift, but would have to wait for a moment (a minute). Children would get a score of 1 if they got a correct response in each step/trial or were able to wait for a minute (see Appendix 1).

Parent survey. A variable for maternal education was constructed using the mother's highest qualification across 9 levels from no formal education to postgraduate, and was operationalized as a continuous variable. An indicator of household wealth was constructed based on standard questions on household asset ownership from the Multiple Indicator Cluster Survey (UNICEF, 2005) and, following Filmer and Pritchett (2001), a composite variable was created using Principal Component Analysis. Similar techniques have been used extensively elsewhere to represent household wealth (Schady et al., 2015). A country-specific standardized variable was created such that a score of 0 indicates mean wealth compared to other within-country households, and a score of 1 indicates wealth of 1 SD above the average for that country.

Analytical Plan

Missing values. The following steps were taken to deal with missing values. Dummy variables for missingness were created for each of the variables used for analysis. Country, age, household wealth and gender had no missing values. Missing values were found for language

and literacy (7 cases), mathematics (2 cases), gross motor skills (12 cases), fine motor skills (7 cases), EF (3 cases), maternal education (170 cases), and urban-rural residence (13 cases).

For these variables, associations were examined between missingness and scores in language and literacy, mathematics, gross motor skills, fine motor skills, EF, maternal education, and household wealth. Missingness in mathematics, maternal education, and urban-rural residence was not associated with scores for any of the key variables, so missing values for mathematics and maternal education were imputed using the province means, and where urban-rural residence was missing cases were randomly allocated either urban or rural residence weighted by the proportion of urban or rural cases in that province.

Missingness in language and literacy was associated with fine motor scores and with EF scores; missingness in gross motor skills was associated with language and literacy, fine motor, and EF scores; missingness in fine motor skills was associated with early literacy, gross motor and EF scores; and missingness in EF was associated with mathematics scores. For these variables, where available, scores were imputed using means that were specific to the province, maternal education level, household wealth quintile, and gender of each missing case. We did not use more computationally demanding methods such as multiple imputation to deal with missing values. This was because the advantages of such methods would be small given our data met the criteria of: (i) having a large sample size (>1000 cases, overall and in 5 of 6 countries individually); and (ii) having a low proportion of missing values (less than 5% for all variables) (Cheema, 2014).

Transforming scores. A series of descriptive, regression and Structural Equation Modelling (SEM) analyses were conducted using Stata 13.1. In the regression and SEM analyses, all the original total scores of motor skills, EF and early achievement were transformed

to country-specific month-of-age-adjusted z-scores, in order for children's scores to be compared with those of their within-country same-age peers.

Descriptive statistics. Means and standard deviations were calculated for key variables for each of the six countries. Demographic statistics were also generated for the control variables including child age, gender, urban-rural residence, maternal education, and country-specific household wealth.

Motor Skills, EF and early achievement. Hierarchical linear modelling (HLM) considers and explores the structure of hierarchical populations (Bartholomew, Steele, Galbraith, & Moustaki, 2008). It is appropriate for analyzing data from clustered samples as it accounts for potential similarities between children residing in the same area. Due to the clustered sampling design in our study, we used HLM to examine associations between gross and fine motor skills and early achievement in both language and literacy and mathematics, by including either gross motor or fine motor skills as an independent variable, and either early language and literacy or early mathematics as a dependent variable in separate regression models. HLM was then used to analyze associations between motor skills and early achievement by including fine and gross motor skills as two independent variables in the same regression model. Differences in the magnitudes of associations between gross motor skills and early achievement and those between fine motor skills and early achievement were then tested for statistical significance. In each case, regressions were run once for the overall sample and again for each country separately, and control variables were included for child age, gender, urban-rural residence, maternal education, country-specific household wealth, and country (for the overall sample regressions only). The clustering variable used was an indicator of the province in which assessments were conducted. In all HLM regressions, province was used as the level 2 variable.

Structural Equation Modelling (SEM) was used to examine whether EF mediated the association between gross and fine motor skills and early language and literacy and mathematics scores, after controlling for the same variables used in the HLM analyses. Two sets of SEM models were constructed, analyzing the mediating effect of EF for: (i) the relations between fine and gross motor skills and early language and literacy; and (ii) the relations between fine and gross motor skills and early mathematics. In both sets of SEM analyses province was used as the variable that adjusted the robust standard errors for clustering. Our approach to mediation analysis followed that outlined by Hayes (2009) whereby it is not necessary for a total effect to be statistically significant in order to conclude that a significant indirect effect can be considered evidence of mediation.

Results

The mean developmental scores and demographic statistics for each of the six countries are presented in Table 1. Means and standard deviations are shown for gross motor skills, fine motor skills, EF, early language and literacy and early mathematics. On average, children in China had the highest EF, early language and literacy and mathematics scores, but relatively low scores in gross motor skills; children in Mongolia had the highest fine motor scores; children in Vanuatu had the highest gross motor scores; children in Timor-Leste had the lowest early language and literacy scores; and children in Papua New Guinea had the lowest scores in fine motor skills and early mathematics. Descriptive statistics are also shown for control variables including country wealth, maternal education, the average age in months, and the percentage of girls and of urban children in each country's sample.

Motor skills and early achievement

Four series of HLM regressions were performed with gross motor skills or fine motor skills as a separate independent variable, and early language and literacy or early mathematics achievement as a dependent variable, after controlling for the above-mentioned variables, for the overall sample and for each country individually. For the overall sample, gross motor skills ($\beta_{\text{language and literacy}} = .27$, $p < .01$; $\beta_{\text{mathematics}} = .24$, $p < .01$), and fine motor skills ($\beta_{\text{language and literacy}} = .43$, $p < .01$; $\beta_{\text{mathematics}} = .37$, $p < .01$) were all significantly associated with early achievement in both early language and literacy and early mathematics (Supplemental Figures 1a and 1b). Significant associations between gross motor skills ($\beta_{\text{language and literacy}} = .14\text{-}.41$, $p_s < .01$; $\beta_{\text{mathematics}} = .11\text{-}.31$, $p_s < .01$) or fine motor skills ($\beta_{\text{language and literacy}} = .30\text{-}.60$, $p_s < .01$; $\beta_{\text{mathematics}} = .24\text{-}.50$, $p_s < .01$) and early achievement were found across all the six countries individually (see Supplemental Figures 1a and 1b).

Further, another two separate series of HLM regressions, one with early language and literacy and the other with early mathematics as the dependent variable, and with both gross motor skills and fine motor skills included as independent variables, were run for the overall sample and for each country to show the relative magnitudes of gross motor skills and fine motor skills coefficients. Table 2 indicates that for the overall sample, gross motor ($\beta_{\text{language and literacy}} = .16$, $p < .01$; $\beta_{\text{mathematics}} = .14$, $p < .01$), and fine motor ($\beta_{\text{language and literacy}} = .38$, $p < .01$; $\beta_{\text{mathematics}} = .33$, $p < .01$) were all significantly associated with both language and literacy and mathematics. Both fine motor skills ($\beta_{\text{language and literacy}} = .28\text{-}.55$, $p_s < .01$; $\beta_{\text{mathematics}} = .23\text{-}.44$, $p_s < .01$) and gross motor skills ($\beta_{\text{language and literacy}} = .09\text{-}.26$, $p_s < .05$; $\beta_{\text{mathematics}} = .07\text{-}.19$, $p_s < .05$) were also significant predictors of early achievement across the six countries individually (see Table 2). As shown in Figures 1a and 1b, after the fine motor skills variable was included in the

regression models, the magnitude of the relation between gross motor skills and early achievement in both language and literacy and mathematics decreased to a large extent for the overall sample and for each country individually.

Further analyses showed that fine motor skills had larger associations than gross motor skills with early language and literacy ($\beta = .22$, $p < .01$) and with early mathematics ($\beta = .19$, $p < .01$) for the overall sample (see Table 2). Fine motor skills had a larger association than gross motor skills with early language and literacy in Cambodia ($\beta = .19$, $p < .01$), China ($\beta = .19$, $p < .01$), Mongolia ($\beta = .25$, $p < .01$), Timor-Leste ($\beta = .28$, $p < 0.01$), and Vanuatu ($\beta = .40$, $p < .01$), but no significant difference was found in Papua New Guinea ($p > .05$) (see Table 2). The finding that fine motor skills had a larger association than gross motor skills with early mathematics was replicated in Cambodia ($\beta = .13$, $p < .05$), China ($\beta = .15$, $p < .01$), Mongolia ($\beta = .21$, $p < .01$), Papua New Guinea ($\beta = .26$, $p < .01$), and Vanuatu ($\beta = .30$, $p < .01$). However, for children from Timor-Leste there was no significant difference ($p > .05$).

Motor skills, Executive Function and early achievement

To investigate whether EF mediates the relation between motor skills and early language and literacy and mathematics, two sets of SEM analyses were constructed, with one set including the early language and literacy variable and the other set including the early mathematics variable. Each set of SEM analysis was run for the overall sample and for each country individually. Table 3 shows total effects between motor skills and early achievement, and splits these total effects into direct effects between motor skills and early achievement, and indirect effects via EF. Two sets of results are shown for early language and literacy and early mathematics separately. Results are also presented for the six countries together and for each country individually.

Generally, EF mediated the relation between motor skills and early achievement both for the overall sample and for each country (see Table 3). All direct, indirect and total effects between fine motor skills and early achievement via EF were statistically significant in every model ($p_s < .01$, see Table 3). EF mediated the relation between fine motor skills and early achievement in both language and literacy and mathematics for the six countries as a whole and for each country individually. Across the six countries combined, EF accounted for 27.2% of the total effect of fine motor skills on early language and literacy and 37.7% of the total effect of fine motor skills on mathematics.

The indirect effects between gross motor skills and early achievement via EF were significant in every model. Across the six countries combined, EF accounted for 41.5% of the total effect of gross motor skills on early language and literacy, and 53.8% of the total effect of gross motor skills on early mathematics. However, the direct effects of gross motor skills on early language and literacy and early mathematics were not significant in China ($\beta_{\text{early language and literacy}} = .08$, $p > .05$; $\beta_{\text{early mathematics}} = .02$, $p > .05$), Mongolia ($\beta_{\text{early language and literacy}} = -.01$, $p > .05$; $\beta_{\text{early mathematics}} = .04$, $p > .05$), Papua New Guinea ($\beta_{\text{early language and literacy}} = .09$, $p > .05$; $\beta_{\text{early mathematics}} = .02$, $p > .05$) and Vanuatu ($\beta_{\text{early language and literacy}} = .05$, $p > .05$; $\beta_{\text{early mathematics}} = .10$, $p > .05$), suggesting that, for children in these four countries, EF played a full mediating role between gross motor skills and early achievement. For the overall sample and Cambodia, and Timor-Leste, the direct effects remained statistically significant suggesting that in these cases, EF mediated only part of the relation between motor skills and early achievement. The magnitudes of the coefficients are illustrated in Supplemental Figures 2a and 2b.

Discussion

This study examined (i) associations between motor skills and early academic achievement; and (ii) whether EF mediates relations between motor skills and early academic achievement in young children from six developing countries in East Asia and the Pacific. A burgeoning literature has shown that motor skills, and fine motor skills in particular, are strong predictors of academic attainment (Cameron et al., 2016; Grissmer et al., 2010; Murrah et al., 2013; Pagani & Messier, 2012; Pitchford et al., 2016). However, little is known about the interplay between motor skills, EF, and academic achievement in LMICs. The present study contributes to the emerging evidence from LMICs.

Prediction of early achievement from motor skills

Associations between motor skills and academic achievement were examined using a series of HLM regressions. The findings upheld the expectation that motor skills are strong predictors of early achievement in early language and literacy and mathematics. Comparatively, motor skills are usually neglected in studies of early learning (Pagani & Messier, 2012). The current study found that both gross and fine motor skills were significantly related with early achievement in both language and literacy and mathematics. The finding corroborates studies indicating that motor skills are an important contributor to school outcomes (Becker, McClelland, et al., 2014; Cameron, et al., 2012; 2016; Luo et al., 2007; Murrah et al., 2013; Pagani & Messier, 2012). Specifically, researchers consider fine motor skills as an important indicator of school readiness and early achievement and advocate the promotion of these skills in the early years (Carlson, 2014; Grissmer et al., 2010). Gross motor skills are generally thought to be related to social skills or physical well-being and to have a weaker association with academic achievement than fine motor skills (Cameron et al., 2016; Grissmer et al., 2010; Kim et al.,

2015). However, our study found that even after controlling for fine motor skills, associations between gross motor skills and early academic achievement remained significant. The notable associations of early achievement to fine motor skills and gross motor skills are not only evident for the large, combined sample, but also robust in each individual country. This implies that both fine motor skills and gross motor skills are closely related to early achievement and the finding is consistent across countries.

Further, we found that in comparison with gross motor skills, fine motor skills were a better predictor of both early language and literacy and mathematics achievement in the overall sample and in individual countries, except for Timor-Leste and Papua New Guinea. Researchers point out that in education settings that include early childhood education programs, children spend a considerable amount of time in fine-motor related activities including drawing, cutting, folding, stringing beads and object manipulation (Cameron, et al., 2012; Pitchford et al., 2016). Such activities require visual-motor integration and mapping visual representations to concepts, which are important for early learning and cognitive processes (Cameron et al., 2016; MacDonald et al., 2016). When children are skilled enough to evidence automaticity in these activities, they will be capable of higher levels of conceptual processing, including connecting symbols with meaning and this, in turn, promotes early achievement (Cameron, et al., 2012; Pitchford et al., 2016). Relatively, gross motor skills require less involvement of cognitive processes and may not contribute to early achievement as much as fine motor skills (Westendorp et al., 2011).

It is notable that there was no significant difference in the associations of gross motor skills and fine motor skills with early language and literacy in Papua New Guinea, and with early mathematics in Timor-Leste. These two countries are among those with the lowest levels of economic development among the six countries studied (Rao, Sun, Ng, et al., 2014). The finding

could be related to limited pre-school opportunities for children in these two countries, both in terms of participation and quality. Further, children in these two countries may have many opportunities to engage in gross motor activities while few in fine motor activities. The descriptive analyses further showed that children in these two countries had lowest scores in fine motor skills. This may be why there were no significant differences between gross and fine motor skills in contributing to the prediction of early academic achievement.

Mediation of Executive Function in the relation between motor skills and early achievement

The study also examined the role of EF in the relation between motor skills and early achievement. By extending the existing literature and including both gross and fine motor skills, our study showed that EF mediates the association between early achievement and both gross and fine motor skills, and the finding is consistent across all the six countries in East Asia and the Pacific. The result echoes findings of similar studies in children from different cultural backgrounds (Becker, McClelland, et al., 2014; Chang & Gu, 2018; MacDonald et al., 2016; Roebers et al., 2014). Relations between gross motor skills and early achievement have received less attention in existing research, and our study adds to the extant literature by showing that EF also mediates the relation between gross motor skills and academic achievement. Researchers suggest that the initiation of motor activities triggers the execution of EF skills, and then affects children's school performance (Becker, McClelland et al., 2014; Cameron et al., 2012; MacDonald et al., 2016).

The completion of both fine and gross motor skill assessment tasks in the current study required children to focus their attention (e.g., walking on a thin strip without significant deviation), rely on working memory (e.g., remembering the steps of folding a plane), and engage

in inhibitory control (e.g., tapping task). All these three components of EF have been shown to predict school performance both concurrently and longitudinally (G. J. Duncan et al., 2007; Jacob & Parkinson, 2015; Zhang & Rao, 2017). Our results show that motor skills significantly contribute to language and literacy and mathematics achievement through EF. Therefore, it is possible that motor activities augment the cognitive and learning process in young children, and then enhance school achievement.

Although EF was a partial mediator between fine motor and gross motor skills and early achievement in the overall sample and in Cambodia and Timor-Leste, it played a full mediating role in the relation of gross motor skills with early achievement in language and literacy and mathematics in China, Mongolia, Papua New Guinea and Vanuatu. The finding in the four countries is consistent with that in the U. S. showing that gross motor skills did not predict academic achievement when fine motor skills and EF were considered (McClelland et al., 2012). This also implies that when EF is included, fine motor skills make more contribution to early achievement than gross motor skills. Both China and Mongolia lay high value on education (Gundenbal & Salmon, 2011; Rao, Sun, & Zhang, 2014). Parents and teachers may organize different forms of activities in addition to gross motor activities to facilitate children's early learning, such as in-hand manipulation activities and early academic learning, and thus may reduce the effect of gross motor skills on early achievement. Children from Papua New Guinea and Vanuatu achieved relatively high gross motor scores, but relatively low scores in fine motor skills, EF and early achievement. It is interesting that the relatively higher level of gross motor scores did not correspond to benefits in early achievement for children in these two countries. Further studies are required to explore the underlying mechanism.

Despite the fact that the six countries differed in gross and fine motor skills, EF and early achievement, the study found consistently that motor skills contribute to early achievement in language and literacy and mathematics, and EF mediates the relation between both fine motor skills and gross motor skills and early achievement. This means that the path of motor skills→ EF→ early achievement is universal across different LMICs in the East Asia and the Pacific.

Implications

This study is one of the few to focus on the relations between fine and gross motor skills, executive function and early achievement in language and literacy and mathematics in developing countries. Generally, many studies in developmental psychology are conducted in Western contexts and researchers have called for more diverse samples to avoid biased conclusions (Nielsen et al., 2017). By drawing on a large and representative sample from six different countries in East Asia and the Pacific, our study seeks to address this sampling gap. We found that both fine motor and gross motor skills and EF are important for early achievement. Fine motor skills made a greater contribution to early achievement than gross motor skills. Further, EF fully or partially mediated the relation between motor skills and early achievement. Although the countries differed in child outcomes, the findings are generally consistent across East Asia and the Pacific.

Neuroimaging studies indicate that the brain regions mainly involved in motor activities or cognitive activities are coactiviated (Diamond, 2000; Grissmer et al., 2010), which suggests that motor skills and cognitive skills develop together. Together with our study, these studies suggest that the enhancement of motor skills might be a pathway to boost school attainment for children from LMICs.

Physical activities provide children with abundant opportunities to learn and practice motor skills. Studies have shown that physical activities such as aerobic exercise, martial arts, yoga and tennis are effective in enhancing EF (Davis et al., 2011; Diamond & Lee, 2011; Westendorp et al., 2014). In addition, fine motor activities such as design copy are likely to improve specific components of EF (e.g., attention) (Kim et al., 2015; van der Fels et al., 2015). Our findings support the move to increase motor activities in early childhood education in East Asia and the Pacific. However, there is typically relatively little time in the daily schedule of program activities in ECE for physical activities (Cameron et al., 2016; Pagani & Messier, 2012). Therefore, it is recommended that teachers and parents provide children with substantial opportunities of physical games and motor activities to facilitate their gross motor skills, and use manipulatives to promote fine motor skills. In addition, although the present study did not primarily aim to address cultural differences in exploring the relation between motor skills, EF and early achievement, there are minor differences between the countries that are worth mentioning. For instance, while associations between fine motor skills and early achievement are significantly larger than associations between gross motor skills and early achievement in the majority of countries, for children in two lower income countries - Timor-Leste and Papua New Guinea – there was no significant difference in coefficients for gross motor skills and fine motor skills. This implies that we should give particular importance to the development of fine motor skills in children from more economically disadvantaged countries. At the same time, while gross and fine motor skills significantly predicted early achievement even after controlling for EF in the overall sample and in Cambodia and Timor-Leste, the gross motor-achievement link was not significant in China, Mongolia, Papua New Guinea and Vanuatu. Gross motor scores in China and Mongolia were relatively low. Therefore, both countries may provide children with

more gross motor activities to promote their early achievement. The provision of more gross motor and physical activities may also prevent childhood obesity in both countries. Children from Papua New Guinea and Vanuatu had relatively low scores in fine motor skills and their development of fine motor skills should be promoted. These cultural differences pose the need for further studies to uncover the influences of culturally-specific practices in early childhood education on the relation between motor skills, EF and academic achievement.

In addition, our study also revealed the mediating role of EF on the association between motor skills and early achievement. Except for the enhancement of motor skills, the facilitation of EF may also promote children's early academic learning. Research indicated that education and schooling is significantly associated with cognitive skills especially at earliest ages (Burrage et al., 2008; Gurven et al., 2017). Classroom practices such as teachers' proactive regulatory instructions and group work help to engage children in classroom activities, improve their attentional control, self-regulation abilities and EF, and bring about benefits to academic learning (Lan et al., 2009). Further, some curricula and activities that specifically focus on different or specific components of EF have been shown to improve children's EF skills and their academic performance (Diamond, Barnett, Thomas & Munro, 2007; Jacob & Parkinson, 2015; Tominey & McClelland, 2011). Therefore, we should strengthen the quality of early childhood education and support EF skills in preschool programs by embedding different components of EF into curriculum and educational activities.

While this study extends the prior literature on the contribution of motor skills and EF to early achievement, it has several limitations. First, all measures in the study are from one instrument that is used to assess holistic development of children instead of specific components of child development. Although the scale is psychometrically robust, not all aspects of different

domains are included (Rao, Sun, Ng, et al., 2014). For instance, the gross motor items requiring balancing and body orientation, such as hopping on each foot, and skipping, were not included. In addition, there are limited items in the early achievement tests of language and literacy and mathematics. Second, although we found that EF mediated the relation between motor skills and early achievement in language and literacy and mathematics, caution should be exercised in interpreting the findings given the cross-sectional design of the study. An experimental study should be conducted in order to better understand causal links between different child outcomes. Third, cultural differences in terms of child rearing and education may have an impact on early learning and development in children from different countries. The current study found minor differences among the countries. However, as we do not have data on relevant factors such as parenting practices and educational practices in early childhood education programs, we are not able to explain the reasons for the differences. Similarly, although malnutrition or stunting has a detrimental impact on child development and its prevalence is high in LMICS including some countries from East Asia and the Pacific (Lu et al., 2016; Miller et al., 2016; Sudfeld et al., 2015), our study did not include such data. The inclusion of malnutrition and stunting status of the participant children might help improve our understanding of the differences in child development among the countries. Therefore, further studies may examine how factors such as parenting and educational practices as well as child nutritional status influence the development of motor skills, EF and early achievement and the interplay between these three child outcomes among different countries.

To conclude, we found that fine motor skills and gross motor skills are strong predictors of early achievement in language and literacy and mathematics in young children in East Asia and the Pacific. Fine motor skills are more important in facilitating early achievement than gross

motor skills. At the same time, gross motors skills contribute significantly to early achievement even after controlling for fine motor skills. Further, EF mediates the links between motor skills and academic achievement. There are minor differences among the countries. By extending the sample and adopting different measures, the findings of our study are generally consistent with the existing literature. Findings suggest that we should attach importance to children's motor development and provide them with adequate opportunities for motor activities to promote their EF and ensure a good start for school.

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