Efficiency of Executive Function: A Two-Generation Cross-Cultural Comparison of Samples From Hong Kong and the United Kingdom

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Abstract

Although Asian preschoolers acquire executive functions (EFs) earlier than their Western counterparts, little is known about whether this advantage persists into later childhood and adulthood. To address this gap, in the current study we gave four computerized EF tasks (providing measures of inhibition, working memory, cognitive flexibility, and planning) to a large sample (n = 1,427) of 9- to 16-year-olds and their parents. All participants lived in either the United Kingdom or Hong Kong. Our findings highlight the importance of combining developmental and cultural perspectives and show both similarities and contrasts across sites. Specifically, adults' EF performance did not differ between the two sites; age-related changes in executive function for both the children and the parents appeared to be culturally invariant, as did a modest intergenerational correlation. In contrast, school-age children and young adolescents in Hong Kong outperformed their United Kingdom counterparts on all four EF tasks, a difference consistent with previous findings from preschool children.

Executive functions (EFs), defined as the set of higher-order cognitive processes that underpin flexible, goal-directed action and adaptive responses to novel or complex situations (e.g., see Hughes, Ensor, Wilson, & Graham, 2010), have attracted remarkable interest from both cognitive and developmental psychologists. For example, meta-analytic reviews have shown that variation in executive functions are associated with individual differences in externalizing problems (Astill, van der Heijden, van IJzendoorn, & van Someren, 2012; Schoemaker, Mulder, & Deković, 2013), theory of mind (Devine & Hughes, 2013), numeracy (Bull & Lee, 2014), and literacy (Kudo, Lussier, & Swanson, 2015). Alongside this work, other studies have identified parental influences on EF skills and examined the ways social factors can influence EF development. For example, there are intergenerational correlations in EF skills (Cuevas et al., 2014) as well as beneficial effects of parental scaffolding (for a review, see Hughes, Roman, & Ensor, 2014), attachment relationships (Bernier, Beauchamp, Carlson, & Lalonde, 2015), and bilingualism (Bialystok, Craik, Green, & Gollan, 2009). Conversely, other findings indicate that family chaos (Brown, Ackerman, & Moore, 2013), maltreatment (for a review, see Belsky & de Haan, 2011), and exposure to maternal depression (Hughes, Roman, Hart, & Ensor, 2013) have adverse effects.

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Family influences, however, do not exist in a vacuum, and so cultural influences on children's executive functions also deserve attention. One striking and consistent finding is that preschoolers from Asian countries typically do better on EF tasks than their Western counterparts (e.g., Lewis et al., 2009; Sabbagh, Xu, Carlson, Moses, & Lee, 2006). This contrast has been interpreted as reflecting differences in socialization goals and practices; Asian children are more likely to be taught the importance of self-control from a very early age. To date, cross-cultural comparisons of executive function have largely been restricted to preschoolers and have been framed by a separate literature suggesting that this East-West difference is specific to executive function and does not extend to related cognitive skills, such as theory of mind. Extending the developmental scope of this research to preadolescence, Wang, Devine, Wong, and Hughes (2016) reported an advantage in executive function for children from Hong Kong (HK) relative to their peers in the United Kingdom (UK) in two separate studies involving children attending local or international schools. The same two study samples showed an advantage in the opposite direction for theory of mind, although this depended on school type: Children in the United Kingdom outperformed children in Hong Kong who attended local schools but performed similarly to children in Hong Kong attending international schools that follow UK educational practices. In other words, although general cultural differences appear to contribute to geographical contrasts in executive function, pedagogical experiences appear particularly salient for children's developing concepts of mind (see also Hughes, Devine, et al., 2014).

In another cross-cultural study that deserves note, Imada, Carlson, and Itakura (2013) found that 4- to 9-year-old children from Japan outperformed their counterparts from the United States on tests of both executive function and context sensitivity; moreover, the group difference in context sensitivity fully explained the contrast in executive function. In discussing these findings, these authors drew on adult studies demonstrating a contrast between holistic, global thinking styles and analytic, local styles of information processing that mirror the philosophical legacies of ancient China and ancient Greece (e.g., Nisbett, Choi, Peng, & Norenzayan, 2001). However, this context-sensitivity account of group differences in executive function is challenged by recent reanalyses of a previously reported Chinese advantage in perspective taking (Wu & Keysar, 2007). Specifically, by applying time-series analyses to eye-tracking data, Wu, Barr, Gann, and Keysar (2013) showed that the group contrast emerged very late in processing, which indicates a contrast in top-down suppression rather than in integration of knowledge (i.e., in executive function rather than in context sensitivity). That said, as the authors acknowledge, without direct measures of executive function, it cannot be concluded

that the East-West contrast in executive function extends beyond childhood (Wang et al., 2016). We hypothesize that the Asian advantage in executive function extends into late childhood (Hypothesis 1) and adulthood (Hypothesis 2) and that EF scores on each task are correlated across child-parent dyads (Hypothesis 3).

Finally, it is worth noting that cultural influences are dynamic rather than static: In a rapidly changing world, one might expect cohort effects, such that any between-site contrasts may therefore differ across generations in magnitude or nature (or both). The current cross-cultural study of executive function is, to our knowledge, the first to adopt an intergenerational design. Previous studies have found correlations between parents and children from within the same culture group, but we do not yet know whether that is consistent across cultures. Two further strengths of this study deserve note. First, exactly the same EF tasks were administered to the parents and the children, which enabled comparisons of parents and children to be made for the first time. Second, a computerized battery was adopted that enabled testing to be conducted in whole class. As a result, our study sample is much larger than those in previous studies, which increases the reliability of our findings and enables us to compare, for the first time, age-related changes in executive function within each cultural group.

Method

Participants

In total, 886 children and 541 parents participated in this study (additional demographic details are presented in Table 1). From this overall sample, a total of 540 full parent-child dyads were available for family analyses. This sample was recruited from state and private schools in Hong Kong but only state schools in the United Kingdom. The pattern of recruitment was expected given that the percentage of school children from these ages attending private schools (i.e., those that require payment for enrollment) was about 22% in Hong Kong and about 7% in the United Kingdom. The contrasting sample size for the parents and the children in the United Kingdom reflected difficulties in recruiting parents for children attending schools in lower-income areas. It is also worth noting that the UK dyad sample included 23 pairs of siblings; for most of these, data were available from both parents, which enabled us to create separate parent-child dyad pairs. The ethics committees from all universities involved in this project reviewed and approved this research project. All parents provided written consent, and the children provided verbal assent. Families in the United Kingdom were given £20, and children received small prizes for taking part. Families in Hong Kong were given HK$300, and children received small prizes for

Table 1. Participants' Demographic Information

Statistic	Hong Kong (*n* = 262 dyads)		United Kingdom (*n* = 278 dyads)[a]	
	Children	Parents	Children	Parents
n	371	266	516	275
Age (years)	*M* = 12.21, *SD* = 0.99	*M* = 43.84, *SD* = 5.22	*M* = 11.91, *SD* = 0.93	*M* = 44.06, *SD* = 4.78
Gender (*n*)				
Female	174	189	242	186
Male	197	70	245	64
Undisclosed	0	7	29	25
Formal education (years)[b]	*M* = 7.21, *SD* = 0.83	*M* = 14.43, *SD* = 3.59	*M* = 7.68, *SD* = 0.89	*M* = 17.36, *SD* = 3.03

Note: The Hong Kong sample spoke 15 languages in addition to Cantonese, and the United Kingdom sample spoke 43 languages in addition to English.
[a]This total is slightly larger than the number of parents because in some cases, both parents or multiple children (or both) from the same family participated in the study.
[b]Completing secondary education (or starting university) was defined as 14 years of schooling, completing a bachelor's degree was defined as 18 years of schooling, completing a master's degree was defined as 20 years of schooling, and completing a doctoral degree was defined as 22 years of schooling.

taking part (except in one school that did not want to offer families any incentives). All schools were also provided a gift for their participation.

Relatively few participants had home language backgrounds that differed from the main school language. In particular, only 15 HK children spoke a language other than Cantonese at home. That said, HK children received English lessons beginning with their first year of schooling. In the UK sample, 43 children did not speak English at home. These children spoke a diverse set of languages that represented all six habitable continents.

Of the 840 children in the analyses, all but 8 UK children completed all of the EF tasks. Demographic data were missing for 16 HK parents, 25 UK parents, and 37 UK children.

Design

Our overall design had two between-subjects factors: site (United Kingdom or Hong Kong) and generation (parent or child). At both sites, the parents and the children completed the same EF tasks, which enabled direct comparisons of task performance. To avoid the complications presented by firewalls, we installed the same program on a server in the United Kingdom and a server in Hong Kong administered from the same secured Web site. The tasks' written instructions, which were very limited, were translated into Chinese for HK participants. Participants completed all four EF tasks during one session. Our performance measures were accuracy and reaction time (RT) across multiple trials. Thus, we were able to account

for speed-accuracy trade-offs by using efficiency scores, calculated by dividing the total number of correct responses by the mean RT on trials with correct responses.

The larger research project also posed questions about (a) family influences on executive function and (b) the educational impact of executive function; the results relating to these additional questions will be reported separately for reasons of space and coherence. Future reports will include trial-by-trial data for each of the EF tasks. As outlined in the application for a grant to fund this research project, we aimed to collect data from 300 parent-child dyads from each site to ensure enough statistical power to run either hierarchical regressions or structural equation models using the full data set or subsets. This target was nearly reached (*n* = 590), but some dyads were removed from the present analyses because one partner had not completed the EF-task battery.

Materials and procedure

We used an existing secured Web site, Thinking Games (for more details and example stimulus screens, see http://instructlab.educ.cam.ac.uk/TGsummary/), to administer the tasks in our EF battery. Participants completed the tasks in varied orders, with breaks between tasks if needed. In general, the children completed the EF-task battery at school (during sessions involving the whole class), and the parents completed the tasks at home. However, some families at each site chose to complete the tasks in a university lab. Participants were encouraged to respond as quickly as possible while still being accurate.

Inhibition—the stop-signal task. This child-friendly version of the original stop-signal task (Logan, 1994) consisted of an image of a soccer field with the ball positioned in the center of either the left or the right side of the screen. For each of 108 trials (presented in three blocks), participants were instructed to press the left arrow key on the keyboard when the soccer ball was on the left side of the screen (54 trials) and the right arrow key when the soccer ball was on the right side of the screen (54 trials). However, they were to refrain from pressing when they heard the referee's whistle, which was played randomly on 20% of the trials (i.e., no-go trials). Following standard stop-signal procedures, the gap between the presentation of the picture and the presentation of the whistle was increased or decreased depending on participant accuracy. The first whistle was played 250 ms after the picture appeared. If participants successfully inhibited a response, the whistle was played 50 ms later during the next stop trial. If participants did not successfully inhibit a response, the picture of the soccer field appears 50 ms sooner on the next trial.

Working memory—a spatial span task. This modification of the Corsi blocks tasks (Corsi, 1972) was divided into two parts: forward trials (presented first) and backward trials. On each trial, the screen displayed an array of nine boxes, some of which lit up in a preselected order. Using a mouse, participants were asked to click on the boxes either in the same order (forward; short-term memory) or in the reverse order (backward; working memory). After two initial feedback items (each with two lit boxes), participants received sets of increasing length. On each forward trial, the sequence consisted of between two and nine items; on each backward trial, the sequence consisted of between two and seven items. Each number of items appeared twice, so there were 18 possible forward sequences and 14 possible backward sequences, including the sequences used on the feedback trials. Testing automatically stopped after five consecutive trials were responded to incorrectly. Only the backward items were included in the analyses reported here.

Shifting—the figure-matching task. This task was a slightly modified version of the task used by Ellefson, Shapiro, and Chater (2006). There were 128 trials, each containing four simultaneous events. A target figure in the center of the screen varied by shape (triangle or circle), color (blue or red), or both. The top of the screen displayed an instruction to sort by shape or color. In each lower corner of the screen, there was a small figure; one matched the shape of the target and the other matched the color of the target. Participants followed the instruction to sort by shape or color by pressing one of two keys on the computer keyboard; each key corresponded to one of the figures in the lower corners.

The trials were presented randomly within four 32-trial blocks (counterbalanced across participants): Two pure blocks contained either all color trials or all shape trials; two mixed blocks contained both color and shape trials, presented using an alternating-runs sequencing (Rogers & Monsell, 1995) that changed tasks every two trials (i.e., color, color, shape, shape, color, color, shape, shape, etc.). One of these mixed blocks began with a color trial and the other began with a shape trial (again, this was counterbalanced across participants). There were thus two trial types: *repeat* and *switch*. In repeat trials (included in both pure and mixed blocks), participants continued the same task as in the previous trial. In the switch trials (mixed block only), participants switched to a task different from that in the previous trial.

Planning—the Tower of Hanoi task. This was a computerized version of the task used by Welsh (1991). Participants saw two arrangements of disks on the screen and were invited to arrange the disks in the bottom set to match the top set in as few moves as possible and without placing a larger disk on a smaller disk. The minimum number of moves needed to transform the bottom set to match the top set increased with each successful solution, which increased the difficulty of the task.

After a practice 2-move, 3-disk problem (with feedback for illegal moves), participants were given six more 3-disk problems, involving 2, 3, 4, 5, 6, and 7 moves. This was followed by three additional 4-disk problems, involving 7, 11, and 15 moves. If participants erroneously placed a larger disk on a smaller disk, they were given a reminder message that the move was not allowed. This message remained on screen for 2,000 ms. The disk was then returned to its original location, but the illegal move was counted as 1 move. To continue onto the more difficult problems, participants needed to make two consecutive minimum-move solutions. On each problem, participants had a maximum of 20 moves to match the goal arrangement before being offered a new attempt; they were allowed a maximum of six attempts to achieve the two consecutive minimum-move solutions. The task ended when participants had successfully solved all problems within these constraints or when they reached two consecutive problems that they could not solve within six attempts.

Data processing and analyses

Overall accuracy and RTs on trials with correct responses were used to create efficiency scores for each of the EF tasks. Next, efficiency z scores were calculated individually for each task. Standardizations were generated using all participants. Finally, individual participants' z scores from each EF task were averaged together to create a standardized EF-efficiency aggregate score. We chose this

standardized EF aggregate score over factor scores because we wanted to facilitate comparisons with another intergenerational study of executive function (Cuevas et al., 2014) and because factor solutions were different for children and adults in this data set and in previous work (e.g., Miyake et al., 2000; Wiebe, Espy, & Charak, 2008). As a precaution, we verified our findings with analyses using factor scores and found no change in the pattern of results.

Standardized EF-efficiency aggregate scores were analyzed using a 2 × 2 analysis of variance (ANOVA) with between-subjects factors of site (Hong Kong or United Kingdom) and generation (child or parent). We focused on efficiency scores because they accounted for both accuracy and response speed and because accuracy and response speed, when analyzed separately, can show different patterns for adults and children. More specifically, previous studies with adults in these types of tasks have commonly shown ceiling effects for accuracy (e.g., Logan, 1994; Miyake et al., 2000; Rogers & Monsell, 1995), whereas studies with children have generated a wider range of accuracy scores (e.g., Akshoomoff et al., 2014; Astill et al., 2012). Age-related improvements for children in accuracy tend to positively correlate with age-related improvements in RT, but the relationship between accuracy and RT is not the same during middle adulthood: Accuracy holds steady and RT performance declines (e.g., Reimers & Maylor, 2005). Efficiency scores account for the various problems of exploring accuracy and RT independently while affording group comparisons in a single analysis. In addition, the instructions to participants (i.e., to respond as quickly as they could while still being accurate) made it appropriate to calculate efficiency scores.

However, efficiency scores can mask response patterns. There could be differences in response strategies across the generations and sites, and efficiency scores might not be a true reflection of the underlying accuracy and RTs, To investigate these ideas, we followed up our initial analysis with similar ANOVAs that used standardized aggregate z scores for accuracy and RTs on trials with correct responses as dependent variables. The standardized aggregates for accuracy and RT were calculated using the same procedures as the standardized EF-efficiency aggregate score. To make sure that the standardized aggregate scores were not biased by one or more of the individual EF tasks, we ran the same ANOVAs described in the previous paragraph; a separate ANOVA was run for each EF task, and the standardized scores for that EF task were used as the dependent variable.

Several verification checks were conducted to eliminate the potential contribution of various biases on the main findings. We evaluated the potential influence of two core demographic variables (age and education) on the overall findings by conducting a 2 (site: Hong Kong or United Kingdom) × 2 (generation: child or parent) analysis of covariance (ANCOVA) with age as a covariate. When appropriate, significant effects and interactions were followed up using Tukey's post hoc test to control for Type I error. We report effect sizes using η_p^2. Our child sample provided 80% power to detect a small-size effect ($\eta_p^2 = .01$), and the parent sample provided 80% power to detect a medium-size effect ($\eta_p^2 = .09$), which substantially reduced the risk of Type II error.

Results

We first examined the effects of site (United Kingdom or Hong Kong) and generation (parent or child), and their interaction, on EF performance. We analyzed overall task performance and within-task contrasts in participants' performance using performance-cost metrics. Capitalizing on the large sample size for the current study, we then examined the relationship between age and executive function in each generation. Finally, building on this study's two-generation design, we examined the association between parents' and children's EF performance (both overall and within each site).

EF scores differed by site and generation

The mean z scores for efficiency of overall EF-task performance showed a significant effect for site, $F(1, 1423) = 102.26$, $p < .001$, $\eta_p^2 = .07$; efficiency was higher in Hong Kong than in the United Kingdom (Fig. 1). The effect of generation was also significant, $F(1, 1423) = 16.35$, $p < .001$, $\eta_p^2 = .01$; efficiency was higher for children than for parents. There was also a significant interaction between site and generation, $F(1, 1423) = 74.76$, $p < .001$, $\eta_p^2 = .05$; efficiency differed between the United Kingdom and Hong Kong for children but not parents. On average, HK children performed as well at age 10 as their UK counterparts did at age 12; this 2-year lag appeared across the age span of the study sample. These findings extend the developmental scope of findings from previous studies in which Asian preschoolers showed better EF skills than their Western counterparts. Our results indicate that in middle childhood and early adolescence, HK children outperformed their UK peers—but this effect was not evident for the parents.

The results for the aggregate efficiency score were corroborated by similar analyses conducted on aggregate accuracy and aggregate RTs on trials with correct responses. For accuracy, there was a significant effect of generation, $F(1, 1423) = 186.70$, $p < .001$, $\eta_p^2 = .12$; parents were more accurate than were children. The effect of site was not significant, $F(1, 1423) = 0.02$, $p = .89$, $\eta_p^2 = .00$.
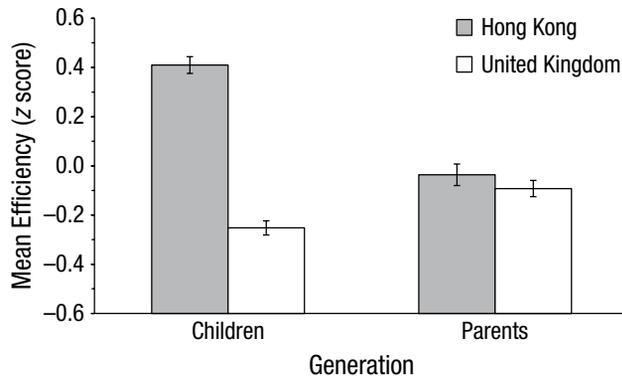
Fig. 1. Mean efficiency score as a function of participants' generation and the site at which they were tested. Error bars indicate ±1 *SEM*.

However, there was a significant interaction between site and generation, $F(1, 1423) = 27.69$, $p < .001$, $\eta_p^2 = .02$. Follow-up tests indicated that UK parents had the highest accuracy, followed by HK parents, then HK children, and then UK children. For RTs on trials with correct responses, there were significant effects of site, $F(1, 1422) = 42.86$, $p < .001$, $\eta_p^2 = .03$; HK children were faster than UK children. There was also a significant effect of generation, $F(1, 1422) = 141.48$, $p < .001$, $\eta_p^2 = .09$; the children were faster than the parents. In addition, the Site × Generation interaction was significant, $F(1, 1422) = 31.86$, $p < .001$, $\eta_p^2 = .02$; HK children had the fastest RTs on correct trials, followed by UK children, who were faster than both HK parents and UK parents.

Taken as a whole, the aggregate efficiency score reflected the very fast, correct responses of the HK children, who showed performance advantages over the UK children in both accuracy and RT. Both groups of parents were more accurate than both groups of children, but this was paired with a slow RT.

The UK parents were significantly more accurate than the HK parents, but they did not have a significantly higher efficiency score because they had a slower (albeit nonsignificantly slower) RT than the HK parents. This pattern of overall performance was replicated for the individual EF tasks and was supported by the correlations among the tasks. As shown in Table 2, efficiency scores on the four EF tasks, as well as the aggregate score, showed consistent correlations with one another for the full sample as well as for each generation separately; the correlations ranged from .12 to .42. However, the correlational patterns were not the same across the two generations and sites. In addition, the associations between these aggregate EF scores and children's nonverbal IQ (as indexed by Raven's Progressive Matrices scores; Raven, Raven, & Court, 1998) were .34 (Hong Kong) and .40 (United Kingdom); the correlations did not differ significantly across the two samples of children ($z = 1.02$, $p = .31$).

Table 2. Correlations Among the Efficiency Scores for the Full Sample, for Parents, and for Children, After Controlling for Age and Education

Sample and task	1	2	3	4
Full sample				
1. Inhibition	—			
2. Working memory	.25**	—		
3. Shifting	.42**	.37**	—	
4. Planning	.18**	.32**	.30**	—
5. Aggregate score	.68**	.71**	.76**	.64**
Children				
1. Inhibition	—			
2. Working memory	.25**	—		
3. Shifting	.40**	.32**	—	
4. Planning	.14**	.26**	.21**	—
5. Aggregate score	.69**	.70**	.72**	.59**
Parents				
1. Inhibition	—			
2. Working memory	.12*	—		
3. Shifting	.37**	.31**	—	
4. Planning	.15**	.30**	.29**	—
5. Aggregate score	.64**	.63**	.74**	.66**

*$p < .01$. **$p < .001$.

Each dyad consisted of a child and his or her parent, so generation might not be a fully independent variable. We fully replicated results with additional analyses treating generation as a within-subjects variable. There were a larger number of children in the UK sample whose parents did not complete the EF tasks. To test for potential biases in the data, we reran the analyses only when data were available for both the child and the parent in a given dyad. The results for efficiency and RTs were the same. Although the overall effects and interactions were the same for accuracy, the post hoc tests were slightly different; the gap between the HK and UK children narrowed and was no longer significant.

Associations of age and education with executive function

Age. The HK and UK children's ages were not identical, and neither were HK and UK parents' ages. This raises the possibility that the difference in results between sites could be accounted for by age differences among parents and among children. The results did not support this hypothesis: A 2 (site) × 2 (generation) ANOVA on participant's age indicated only a significant main effect of generation, $F(1, 1345) = 32,293.64$, $p < .001$. Neither the main effect of site, $F(1, 1345) = 0.05$, $p = .82$, nor the Site × Generation interaction, $F(1, 1345) = 2.15$, $p = .14$, was significant, which confirms that neither the children's

ages nor the parents' ages were significantly different at the two sites.

The Site × Generation interaction effect reported for EF efficiency raises the possibility that the UK children might eventually catch up with their HK peers. However, the results do not indicate that this is likely. Age was a significant predictor of EF performance for both groups of children—Hong Kong: $R^2 = .12$, $F(1, 369) = 50.69$, $p < .001$; United Kingdom: $R^2 = .14$, $F(1, 476) = 76.19$, $p < .001$. In regression analyses, the intercept was higher for the HK children ($y = -2.45$) than for the UK children ($y = -3.17$), but the coefficients indicated similar age-related improvements in the two groups. For each year of age, the improvement was about 0.23 *SD* for HK children and 0.25 *SD* for UK children. As shown in Figure 2a, the average EF score for HK children at age 10 was similar to that for UK children at age 12; likewise, the average EF score for HK children at age 12 was similar to that for UK children at age 14. That is, across the age span of the children in the current study, there was no evidence of a catch-up effect by early adolescence.

Figure 1 shows that the mean efficiency scores for HK and UK parents were lower than the mean efficiency score for HK children. Additional analyses indicated that the parents had higher mean accuracy but slower mean RTs compared with the children. These results could have been driven by the slow age-related declines in RT that started in middle adulthood. Age was a significant predictor of EF efficiency for both groups of parents—Hong Kong: $R^2 = .03$, $F(1, 248) = 6.52$, $p = .01$; United Kingdom: $R^2 = .04$, $F(1, 248) = 9.65$, $p = .002$ (see Fig. 2a). In regression analyses, the intercept was nearly the same for the HK parents ($y = 0.91$) and the UK parents ($y = 0.89$), and the coefficients indicated small, similar age-related performance decline in the two groups. For each year of age, the decline was about 0.02 *SD* for both HK parents and UK parents. A test for homogeneity of regression slopes indicated that they were significantly different between the two generations, $F(1, 1345) = 171.32$, $p < .001$, $\eta_p^2 = .11$.

We used ANCOVAs with age as a covariate and separate slopes for the two generations as well as ANOVAs with age as a continuous factor, and we were able to replicate the main site and cohort findings. Most important, the differences across sites for the children's EF efficiency and the similarities across sites for the parents' EF efficiency remained even when the aggregate EF scores were adjusted for age.

Education. Next, we used a 2 (site) × 2 (generation) ANOVA to test whether participants' education levels varied across the groups. The results indicated significant main effects of site, $F(1, 1345) = 202.26$, $p < .001$, and generation, $F(1, 1345) = 5,059.39$, $p < .001$, and a significant Site × Generation interaction, $F(1, 1345) = 107.06$,

$p < .001$. Post hoc tests indicated that the UK parents had higher education levels than the HK parents and that the UK children had more formal schooling than HK children. The difference for the children was due to the later age at which children begin to attend school in Hong Kong. The different levels in educational experience across the two sites raise the possibility that the EF differences were driven by educational experience.

As would be expected, educational experience and age were highly correlated for the children at both sites—Hong Kong: $r(371) = .85$, $p < .001$; United Kingdom: $r(478) = .93$, $p < .001$. Given these high correlations, it is unsurprising that education level was a significant predictor of EF performance—Hong Kong: $R^2 = .12$, $F(1, 369) = 48.08$, $p < .001$; United Kingdom: $R^2 = .12$, $F(1, 512) = 68.13$, $p < .001$ (see Fig. 2b). In regression analyses, the intercept was higher for the HK children ($y = -1.54$), than for the UK children ($y = -2.19$), but the coefficients indicated similar education-related improvements in the two groups. For each year of education, the improvement was about 0.27 *SD* for HK children and 0.25 *SD* for UK children. As shown in Figure 2b, the average EF score for HK children with 6 years of formal education was similar to that for UK children with 9 years of formal education. In sum, across the education span of the children in the current study, there was no evidence of a catch-up effect by early adolescence.

The education level of the parents in the study varied between the two sites. The UK parents had higher education levels than the HK parents. In addition, education level and age were not correlated for the HK parents, $r = (250) = .03$, $p = .61$; however, there was a small but significant correlation for the UK parents, $r = (250) = .20$, $p = .002$. Older UK parents had higher levels of education than younger UK parents. Somewhat surprisingly, education level was not predictive of EF performance at either site—Hong Kong: $R^2 = .00$, $F(1, 257) = 0.23$, $p = .63$; United Kingdom: $R^2 = .00$, $F(1, 248) = 0.32$, $p = .57$ (see Fig. 2b). In regression analyses, the intercept was higher for HK parents ($y = -0.12$) than for UK parents ($y = -0.20$), but the coefficients indicated only small opposite effects of age in the two samples. For each year of education, the HK parents' performance improved by about 0.006 *SD*, and the UK parents' performance declined by 0.006 *SD*. The older UK parents had higher education levels, but this educational advantage was not predictive of improved performance on the EF task. Again, the test for homogeneity of regression slopes indicated that they were significantly different between the two generations, $F(1, 1390) = 28.73$, $p < .001$, $\eta_p^2 = .02$.

It could be that education level was not predictive for the UK parents because the older parents had higher education levels, which suggests that any advantage of increased education was counteracted by the disadvantages of increased age. Hierarchical regressions confirmed
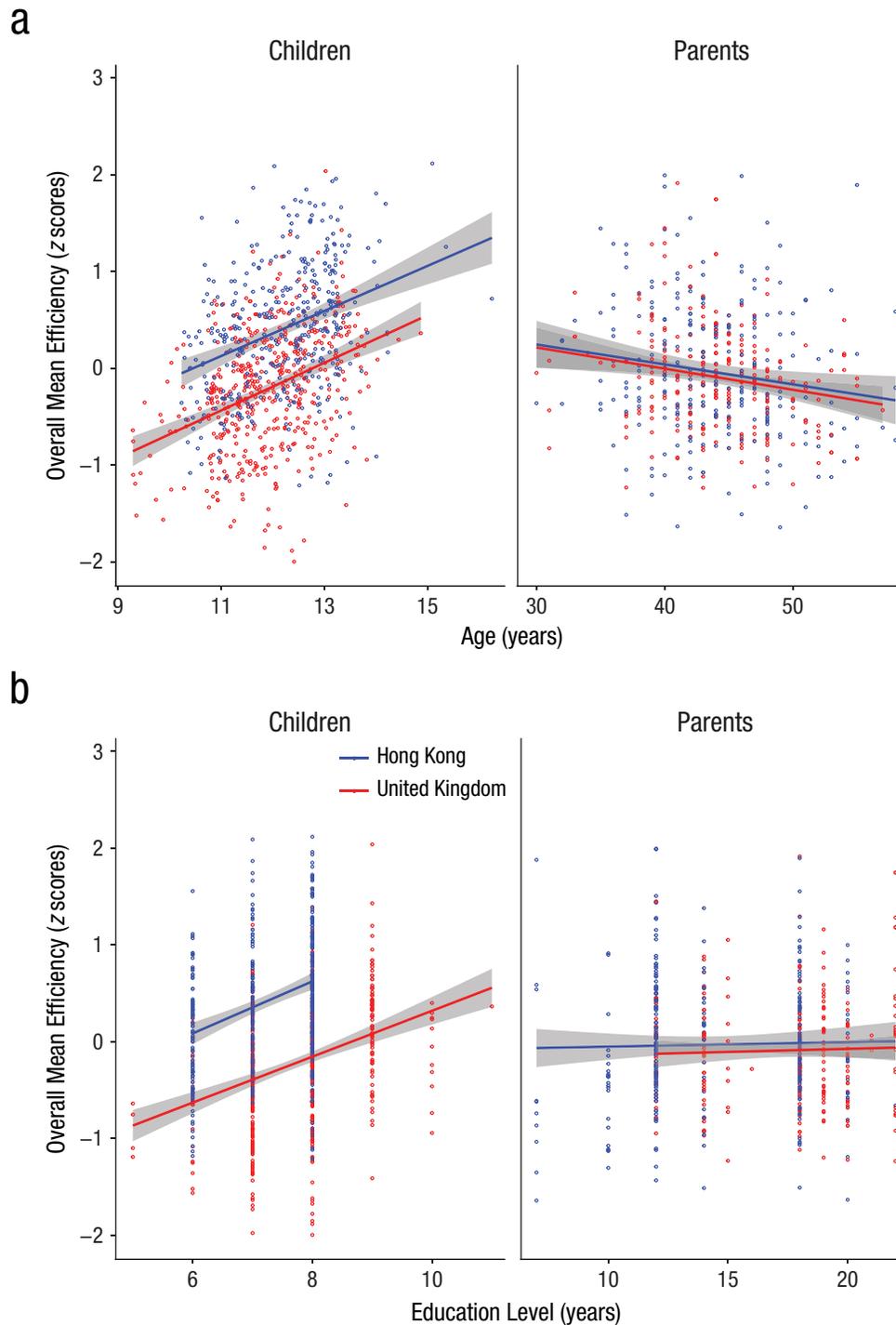
Fig. 2. Scatterplots (with best-fitting regression lines) showing the relationship between overall mean efficiency and (a) age and (b) education level for each site, presented separately for the children and the parents. The gray areas around the regression lines indicate 95% confidence intervals.

this idea. Age was a significantly negative predictor of the parents' EF-task performance when we controlled for education level, but education was not a significant predictor regardless of whether we controlled for age.

Finally, given the differences in education level and parental participation across the two sites, we checked whether parental education influenced the children's data. We averaged the education level of each participating parent with the education level he or she reported for the child's other parent and tested whether this was predictive of EF-task performance. The results confirmed that parents' education was not a significant predictor of

the children's EF-task performance at either site—Hong Kong: $R^2 = .001$, $F(1, 273) = 0.38$, $p = .54$; United Kingdom: $R^2 = .009$, $F(1, 232) = 2.10$, $p = .15$. In regression analyses, the intercepts were of similar magnitude but opposite direction for Hong Kong ($\gamma = 0.45$) and for the United Kingdom ($\gamma = -0.47$), and the coefficients indicated similar but opposite education-related effects in the two groups. For each year of education, the HK sample's performance worsened by 0.01 *SD*, and the UK sample's performance improved by 0.02 *SD*. When we used only the education level of the participating parent, the findings were similar.

Verification checks. We used ANCOVAs with education as a covariate and separate slopes for the two generations as well as ANOVAs with education as a continuous factor, and we were able to replicate the main site and cohort findings. Most important, the differences between sites for the children's EF-task performance and the similarities between sites for the parents' EF-task performance remained even when aggregate EF scores were adjusted for education. These findings were replicated when we ran additional ANCOVAs and ANOVAs controlling for both age and education.

Relation between parents' and children's EF scores

In total, 541 parent-child dyads completed the EF tasks. Overall efficiency *z* scores across the four EF tasks showed a significant (but small) correlation between the parents and the children, both across the two sites, $r(540) = .21$, $p < .001$, and separately in Hong Kong, $r(262) = .26$, $p < .001$, and the United Kingdom, $r(278) = .13$, $p = .04$. These correlations remained relatively unchanged when we controlled for participant's age—combined across the sites: $r(500) = .22$, $p < .001$; Hong Kong: $r(242) = .28$, $p < .001$; United Kingdom: $r(254) = .14$, $p = .03$. The correlations were similar whether they were conducted using accuracy data or RT data.

Finally, to investigate whether the typically different formats for data collection between the parents (at home, alone and unsupervised) and the children (at school, in large groups supervised by researchers) influenced EF-task performance, we ran the same correlations for parents and children who had a researcher supervising the data collection and again for parents and children who completed the task individually. The results confirmed that the different supervision formats were not an explanation for the findings.

Results summary

This study is methodologically innovative in its two-generation design (which enabled the integration of developmental and cultural perspectives) and its use of online EF tasks (which enabled efficient data collection from a large sample). The study results can be summarized by three main findings. At both sites, the East-West contrast in EF efficiency was evident in early adolescence, but not in middle adulthood. Second, at both sites, children's EF efficiency scores increased substantially with age; in contrast, parents' EF scores showed a small negative association with age. Third, within child-parent dyads, the intergenerational association in EF performance was modest but significant.

Discussion

This study is the first to explore (a) cross-cultural contrasts in adults' executive function and (b) cultural universality of both age-related improvements in executive function and parent-child associations in executive function. Demonstrating that online EF testing is feasible and valid is a further contribution to the field, particularly because this methodology facilitates the recruitment of large samples that include parents, which enables performance on the same task battery to be compared across generations. By reducing verbal demands, these tasks also minimize the role of the researcher (and attendant biases), and they facilitate standardized testing across different language groups. Building on these methodological innovations, the findings highlight the value of combining cultural and developmental perspectives. Specifically, our results show both a Site × Generation interaction for executive function and the cultural universality of associations between executive function and key participant characteristics (i.e., age and education). Thus, we extend existing findings that show a clear East-West contrast in preschool children's executive function: The 6-month difference for preschool children (Sabbagh et al., 2006) was expanded to 2 years by late childhood and early adolescence. This contrast may reflect socio-developmental factors (e.g., self-control as a key socialization goal) or educational experiences (e.g., increased bilingualism for HK children). However, given that Chinese adults appear to show better perspective-taking and response control than American adults (Wu & Keysar, 2007; Wu et al., 2013), our null results for parents are surprising.

A key methodological innovation in this study was the use of an online platform to administer EF tasks, which enabled detailed task data to be collected from large samples at each site. Given the novelty of this approach, it is reassuring that efficiency scores indicated good internal consistency. Note that correlations between individual tasks and between EF aggregate scores and nonverbal IQ were similar in magnitude to those in studies involving one-on-one testing (e.g., Carlson, Mandell, & Williams, 2004; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Wiebe et al., 2008). Together, these findings suggest that the data gathered from these whole-class sessions was as reliable or valid as individual assessments.

The online format, however, might have affected the two generations differently, which suggests a possible explanation for the modest association in executive function between children and their parents. Previous intergenerational work (Cuevas et al., 2014) used manual and computer tasks but focused primarily on accuracy instead of RTs. Future work should include both manual and computerized tasks and should account for both accuracy and RTs and control for the age-related declines in RT performance on EF tasks that begin before middle adulthood (e.g., Reimers & Maylor, 2005). The current work includes a wider span of ages for the children and the parents than reported previously. The participants' age does seem to have an impact on EF performance for both parents and children. A more precise exploration of genetic contributions to executive function would require a more constrained range of ages for both children and parents. Alternatively, the contrast between the relatively strong intergenerational association in executive function reported previously for preschool children (Cuevas et al., 2014) and the weaker results that we observed may reflect a genuine waning in parental influences on children's EFs. Existing work has focused heavily on toddlers and preschool children (Hughes, 2011), but children become more independent and spend much less time with their parents by middle to late-childhood, which makes it possible that other socializing forces eclipse parental influences. Longitudinal data straddling preschool and middle childhood are needed to test this hypothesis.

How should the divergent results from the cross-cultural comparisons of children and parents be explained? One possibility is that the relevant cultural differences are specific to norms regarding children. For example, the emphasis on order and harmony within Confucian cultures means that HK children receive frequent guidance regarding the need to inhibit individual desires (Tardif, Wang, & Olson, 2009); this explicit socialization may mean that compliance with collectivist norms requires less effortful control in adulthood. For example, a recent cross-cultural study found that UK parents showed greater awareness of their children's desires and interests compared with HK parents (Hughes, Devine, & Wang, 2017). An alternative possibility is that the discrepant findings from the parents and the children reflect the dynamic nature of culture. In particular, a series of educational reforms in Hong Kong in the past two decades has led to major changes in the education system, such that HK children could have learning experiences different from those of their parents, including heightened pressure for students to achieve in both academic and extracurricular activities. Additional work is needed to confirm the influence of parental attitudes and changes in the education system as potential explanations of the current findings.

Studies of adult cognition have reported cross-cultural contrasts in attention style or context sensitivity (e.g., Imbo & Lefevre, 2009; Kuwabara & Smith, 2012), described metaphorically as the contrast between a wide-angle lens and a telephoto lens for a camera (Nisbett et al., 2001). Neurophysiological research also highlights the value of considering context sensitivity and executive function in tandem. For example, in a review of changes across adolescence in the neurological and functional maturity of the rostral prefrontal cortex (traditionally viewed as a neural substrate for executive function), Dumontheil, Burgess, and Blakemore (2008) argued that this region is also critical for relational reasoning. As noted earlier, recent findings from both adults and children also suggest an intriguing overlap between context sensitivity and executive function, although the causal direction of this association remains controversial. Specifically, Wu et al. (2013) argue that Chinese adults' superior perspective-taking skills (i.e., context sensitivity) reflect an advantage in the suppression of irrelevant information (i.e., executive function). In contrast, Imada et al. (2013) argue that Japanese children's EF development is facilitated by a cultural emphasis on context.

Although longitudinal designs are needed to test these hypotheses, our findings indicate that cultural contrasts may differ in nature as well as magnitude at different points along the life span. We aim to increase the scope of this research by examining the correlates of individual differences in executive function among the children in this study. To our knowledge, the current study is the first published study of executive function to include both intergenerational and cultural comparisons. Clearly, then, our findings require both independent replication and extension to other cultures.

Declaration of Conflicting Interests

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Open Practices

All data and materials have been made publicly available via the UK Data Service and can be accessed at http://reshare.ukdataservice.ac.uk/852658/. The complete Open Practices Disclosure for this article can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797616687812. This article has received badges for Open Data and Open Materials. More information about the Open Practices badges can be found at https://www.psychologicalscience.org/publications/badges.

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