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International comparisons of the home mathematics environment and relations with children's mathematical achievement

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Abstract

Background: Home mathematics environment (HME) research has focused on parent–child interactions surrounding numerical activities as measured by the frequency of engaging in such activities. However, HME survey questions have been developed from limited perspectives (e.g., *Early Childhood Research Quarterly*, **27**, 2012, 231; *Journal of Social Issues*, **64**, 2008, 95; *Early childhood mathematics education research: Learning trajectories for young children*, Routledge, New York, 2009), by researchers from a small subset of countries (15; *Psychological Bulletin*, **147**, 2020, 565), which may skew our interpretations.

Aims and Sample: This study broadened international representation by leveraging secondary data from the 2019 TIMSS to examine the variation of the frequency and reliability of the HME scale and its relation to children's mathematical achievement. Across 54 countries, 231,138 parents and children (M_{age} = 10.22 years; 51% male) participated in the larger study.

Methods: Parents completed a retrospective home environment survey and children were assessed on mathematics skills. Basic frequency descriptive statistics, Cronbach's alpha reliability coefficients, and Pearson's *r* correlation coefficients were used to assess variability across countries.

Results: Findings suggested that families in certain countries engaged in home mathematics activities more frequently than families in other countries; however, the HME scale demonstrated acceptable internal consistency across families in all countries (M α = .79; range = [.73, .89]). Further, the average relation between HME and mathematical

achievement was $r=.15$ with a range between $r=.02$ to $r=.41$.
Conclusion: Our results indicate substantial variation across countries in the HME-mathematical achievement association. These findings underscore the importance of international representation in advancing research on the diversity of a child's home environment.

KEYWORDS
home mathematics environment, international perspective, TIMSS

BACKGROUND

Research emphasizing the importance of children's early mathematical skills prior to school-based instruction (Davis-Kean et al., 2021; Watts et al., 2014) has fuelled an interest in the diverse mathematical activities that children engage with in the home environment (hereinafter the home mathematics environment (HME); LeFevre et al., 2010; Niklas et al., 2018). Most commonly, HME research has focused on parent–child interactions surrounding numerical activities as measured by the frequency of engaging in such activities (LeFevre et al., 2009). Research has identified a small, yet significant relation between the frequency of HME activities and children's mathematical understanding (Daucourt et al., 2021; Mutaf-Yıldız et al., 2020), suggesting that the home may provide the primary avenue for parents to contribute to children's mathematical skills. However, much of the published research examining the HME is comprised of samples from a limited range of countries (15 represented in Daucourt et al., 2021). In this study, we broaden international representation and address a current gap in the literature by testing to what extent, if at all, there are differences in the HME across countries—in terms of retrospective average activity reports, the reliability of measurement, and the relation between the HME and children's mathematics performance.

The home mathematics environment

Many studies have recently focused on how the HME relates to children's mathematical skills (Daucourt et al., 2021; Elliott & Bachman, 2018; Mutaf-Yıldız et al., 2020). However, findings from the existing literature are mixed (Blevins-Knabe, 2016; Mutaf-Yıldız et al., 2020), with some studies suggesting both early home mathematics and literacy activities were positively related to children's fourth-grade mathematical achievement (Gustafsson, 2013; Punter et al., 2016). Other studies indicate the HME has no relation to children's mathematical performance at age 3 and 5 (Blevins-Knabe et al., 2000; Missall et al., 2015). Most recently, a meta-analysis was conducted to synthesize the extant literature and estimate the average overall effect size of the relation between the HME and children's mathematical development (Daucourt et al., 2021). Across 15 countries, 631 effect sizes, and 68 independent samples, Daucourt et al. (2021) reported an overall small ($r=.13$, 95% CI: [.09, .17]), yet statistically significant, correlation that translates to 2% of the common variance between the HME and children's mathematical achievement. However, most of the samples included in the meta-analysis came from countries often overrepresented in the literature, most specifically the United States of America and Canada. Notably, countries overrepresented in the literature do not capture the vast differences in educational conditions, cultural values, or beliefs present across the globe, and prior research suggests interactions in the home environment vary internationally (Cahoon et al., 2021; LeFevre et al., 2010; Susperreguy et al., 2020). Thus, there is a clear need to understand child development and parenting more globally (Lansford et al., 2016, 2019).

An international perspective

Given that prior research has been restricted by the number of countries present in the literature, the current study responds to a recent call for expanding the measurement of the HME to include more diverse and internationally representative populations (Hornburg et al., 2021). Many questions about HME activities used in prior studies were developed by researchers in the United States of America (Sarama & Clements, 2009) and Canada (LeFevre et al., 2009). This inherently sets those populations as the norm. Therefore, it is possible that certain survey questions may or may not be appropriate for capturing all international home mathematics activities. For example, a HME survey item such as, 'play board or card games' first requires board games to be a relevant activity in each country and second requires parents to understand which board or card games the question is referencing. Hence, it is essential to increase the number of countries represented in the literature to better understand the role of diverse backgrounds and experiences in the HME.

Although Daucourt et al. (2021) suggest a small, average HME-achievement relation in the existing literature, due to the small representation of countries outside of North America, the authors were unable to include country as a potential moderator of this relation. In fact, country of origin was originally a preregistered moderator that had to be excluded from analyses as to not lead to ungeneralizable findings based on skewed samples (Daucourt et al., 2021). Therefore, examining the relation between the HME and children's mathematical achievement by country would address an important gap in the literature. Importantly, analysing and descriptively reporting these relations from more countries (not included in prior research) provides opportunities for new populations to be represented and contribute to our broader understanding of the HME and children's mathematical achievement.

The present investigation

The main contribution of this study is to test to what extent there are international differences in the frequency of engagement in a specified set of HME activities. The current study was preregistered (https://osf.io/q7w3n) and utilized data from the Trends in International Mathematics and Science Study (TIMSS) 2019 wave, focusing on the mathematical questions provided in a retrospective home questionnaire. We were able to utilize data from 54 countries present in the TIMSS data set, to address our three main research questions: (1) Do families across countries differ in how frequently they participate in mathematical activities in the home? (2) Do the HME survey questions demonstrate acceptable reliability across all countries? (3) Finally, how does the overall HME activity score relate to fourth-grade mathematical achievement across different countries?

Prior studies have suggested the HME may vary across broader international contexts (Cahoon et al., 2021; Susperreguy et al., 2020), therefore, we first expect that the frequency in which parents report participating in each of these activities will differ by country. Second, based on prior work in the TIMSS data set, results have shown that the reliability of the *overall* home environment survey has been reported as acceptable across all countries (Mullis & Fishbein, 2020), which means the items are consistent with one another and measure the same construct. However, given the scale was initially developed using literacy and mathematics together, the current study examines a subset of questions from the larger survey. Thus, we found it important to examine the reliability of the subset of items as this approach was novel. We hypothesize that the HME scale will vary across countries but continue to demonstrate acceptable reliability across the subset of items. Finally, we expect that the relation between the HME and children's mathematical achievement will vary across countries but demonstrate an overall positive, small relation based on the prior HME meta-analysis ($r = .13$; based on Daucourt et al., 2021).

METHOD

Data source and sample

Data analysed in the present study were obtained from the TIMSS 2019. TIMSS includes data from children at fourth and eighth grades every 4 years since 1995 in 64 participating countries. All countries in the TIMSS data set are OECD (Organization for Economic Co-operation and Development) countries. The TIMSS data set is designed to examine trends in student mathematics and science achievement in countries around the world. Each country participating in the study develops and implements a national sampling plan with the country's National Research Coordinator and TIMSS sampling experts. The sampling procedure was upheld by Statistics Canada and advised by National Research Coordinators to ensure that the national sampling plan conformed to TIMSS standards (LaRoche et al., 2020). In addition to monitoring children's trends in mathematics and science, TIMSS also assesses children's contexts for learning through parents', teachers' and principals' questionnaires. The TIMSS data set is optimal for this study as it is the only data set that includes questions about the HME from different countries, and at the same time, provides measures of children's mathematical achievement. The sample for the present study consisted of fourth-grade children ($M_{age}[SD] = 10.22$ [.66]; 51% male) that completed the mathematical achievement test and their parents that responded to the early learning survey. The final sample consisted of 231,138 children from 54 countries across six continents.

Measures

Home mathematics environment

The HME questions were asked retrospectively and taken from the TIMSS 2019 Early Learning Survey (ELS), which was developed based on previous research documenting the importance of early childhood learning activities. To read more about the development of the TIMSS home context questionnaire, citations and outlines can be found online under the Assessment Framework chapters of the TIMSS 2019 technical report (Mullis & Martin, 2017). The ELS consists of 18 items asking parents or guardians about the home resources to support their children learning, their demographic information, their opinion about the school and pre-primary education, retrospective reports of the home activities related to literacy and numeracy before the child enters formal school and their opinion about children's literacy and numeracy abilities at first grade. The TIMSS & the Progress in International Reading Literacy Study (PIRLS) International Study centre conducted extensive analyses and reported acceptable reliability and validity across all countries (Yin & Fishbein, 2020).

For the purpose of the present study, a subset of nine of the 18 items in the ELS measuring the HME were used. When children were in fourth grade, parents were asked to retrospectively report on aspects of their home learning environment. The ELS prompts, 'Before your child began primary or elementary school, how often did you or someone else in your home do the following activities with him or her?' Items included 'say counting rhymes or sing counting songs' (ASBH01J), 'play with number toys' (ASBH01K), 'count different things' (ASBH01L), 'play games with involving shapes' (ASBH01M), 'play with building blocks or construction toys' (ASBH01N), 'play board or card games' (ASBH01O), 'write numbers' (ASBH01P), 'draw shapes' (ASBH01Q), 'measure or weigh things' (ASBH01R). Parents could respond by selecting often (1), sometimes (2), or never or almost never (3). Responses were reverse-coded such that higher scores reflected more of a given activity. Countries adapted the ELS based on their native language.

Mathematical achievement

The TIMSS & PIRLS International Study Center at Boston College developed and managed the measurement and assessments of mathematical achievement for each year of the TIMSS (Cotter et al., 2020). Children's mathematical skills were measured at fourth grade using an item response theory (IRT) scaling approach in which five plausible values were determined. The test assessed four mathematical domains: numeracy, geometry, shape and measurement, and data display (Mullis & Martin, 2017) and consisted of 175 total items. However, items were separated into 14 achievement scales with the aim that children would respond to only a subset of items (between 20 and 28 total items) and IRT would be used to provide five plausible mathematical achievement values. Items were multiple-choice (worth one point) and other constructed responses (e.g., writing words or numbers, drawing, or sorting; worth two points; Mullis & Martin, 2017). The final achievement measure accounted for sampling design, sampling weights and plausible values specific to TIMSS (International Association for the Evaluation of Educational Achievement, 2021).

Country

The TIMSS 2019 label of country identification was used as a grouping variable (IDCNTRY). The TIMSS allows all participating countries to complete the ELS. Of the 64 participating TIMSS countries, 54 countries completed the survey (see Table 2).

Analytic plan

The first research question was examined using basic frequency descriptive statistics (mean and standard deviation across each of the home mathematics items and average by country) to assess how frequently families across countries reported engaging in mathematical activities in the home. The second research question was examined using Cronbach's alpha reliability coefficient to assess to what extent the internal consistency of the HME items vary by country. Finally, the third research question was examined using Pearson's *r* correlation coefficients to assess to what extent the overall HME score was related to children's mathematical achievement by country.

The International Association for the Evaluation of Educational Achievement (IEA) International Database Analyzer (International Association for the Evaluation of Educational Achievement, 2021) software was used to create SPSS syntax. This syntax considers the sampling design, sampling weights, and plausible values reported in TIMSS. Analyses conducted using a program that does not account for the special structure of the TIMSS design would produce biased results (International Association for the Evaluation of Educational Achievement, 2021). Thus, all related syntax and analyses used SPSS version 26.0.0.0 (IBM Corporation, 2019) and are available on the OSF project page (https://osf.io/c5h7). We include Bonferroni correction for multiple comparisons given the number of estimates. Although *p*-values are reported in the manuscript, we emphasize focusing on the magnitude of effect sizes across countries.

RESULTS

Global HME

Separating the nine items that focused on home mathematics activities from the larger ELS, we calculated the means and standard deviations for each of the nine items across all countries (Table 1) and each country across all nine items (Table 2). Across the nine items, we found that the most common

TABLE 1 Average global descriptive statistics of the HME items.

	M (SD)	Min	Max
Count things	2.55 (.57)	1.95	2.81
Building blocks	2.53 (.60)	1.84	2.85
Games with shapes	2.50 (.60)	1.78	2.79
Write numbers	2.43 (.61)	2.07	2.79
Draw shapes	2.41 (.63)	1.97	2.68
Board or card games	2.30 (.64)	1.68	2.73
Number toys	2.29 (.67)	1.79	2.65
Counting songs	2.25 (.68)	1.79	2.73
Weigh or measure things	1.79 (.69)	1.40	2.07
HME total	**2.34 (.39)**	**1.86**	**2.54**

activity parents reported engaging their children in when pooled was counting things in the home (M [SD] = 2.55 [.57]), and the least common activity parents engaged their children in was weighing or measuring things (M [SD] = 1.79 [.69]). Overall, most parents participated in home mathematics activities with their children between sometimes and often (M [SD] = 2.34 [.39]). However, there was substantial variation in the frequency of activities across countries. For example, families in Morocco engaged in home mathematics activities the least often (M [SD] = 1.86 [.55]), whereas families in Northern Ireland engaged in home mathematics activities the most often (M [SD] = 2.54 [.37]), and these were significantly different (t[8330] = 49.71, $p < .001$).

Reliability of the HME

Table 2 displays the reliability of the HME across each country for the nine home mathematics activities. The results suggest that items for all 54 countries demonstrated acceptable ($\alpha > .70$; DeVellis & Thorpe, 2021) internal consistency ($M\alpha = .79$) suggesting that the nine HME items are closely related as a group regardless of country. Notably, HME survey items for families in Georgia, Italy, Kosovo and Oman demonstrated the lowest, yet still acceptable Cronbach's alpha coefficient ($\alpha = .74$), and survey items for families in Turkey demonstrated the highest coefficient ($\alpha = .90$).

Relation between the HME and mathematical achievement

Examining the correlation between preschool home mathematics activities and children's mathematical achievement in fourth grade, we found a small, positive average relation across the included countries ($r = .15$) that was consistent with the meta-analytic effects reported by Daucourt et al. (2021), albeit representing a much wider geographical spread. Table 2 also displays Pearson's r coefficient for each country. Due to the large sample size and sampling weights applied in IDB Analyzer, all but one correlation was statistically significant in Table 2 ($p < .05$). Children in Turkey and Bulgaria demonstrated the strongest relation between home mathematics activities and mathematical achievement ($r = .41$, $p < .001$), and children in Georgia demonstrated the smallest positive correlation between home mathematics activities and achievement ($r = .02$, $p = .25$).

The substantial variation in the HME-mathematical achievement relation led us to conduct sensitivity analyses to examine item-level HME-mathematical achievement correlations across countries. A heatmap of these individual correlations can be seen in Table 3. Results showed that all items tended to be moderately related to mathematics for children in Bulgaria and Turkey, suggesting the larger correlations in these countries ($r = .41$) are a product of generally stronger relations across items rather than a

TABLE 2 Country HME and mathematical achievement statistics.

Country	Country ID	HME *M* (*SD*)	*N* observations	HME rank	Cronbach's alpha	Alpha rank	HME-math achievement correlation	Correlation rank
Albania	ALB	2.45 (.40)	3957	14	.79	24	.22*	4
Armenia	ARM	2.38 (.40)	4835	25	.77	35	.11*	41
Austria	AUT	2.35 (.36)	3854	29	.75	46	.13*	29
Azerbaijan	AZE	2.23 (.42)	4468	44	.76	41	.17*	17
Bahrain	BHR	2.39 (.38)	4985	21	.78	28	.11*	41
Belgium	BFL	2.23 (.39)	4311	45	.77	35	.13*	29
Bosnia and Herzegovina	BIH	2.43 (.35)	5218	16	.76	41	.12*	35
Bulgaria	BGR	2.25 (.49)	4059	40	.84	5	.41*	1
Canada	CAN	2.47 (.38)	9240	10	.82	11	.11*	41
Chile	CHL	2.28 (.42)	3698	37	.80	18	.20*	7
Chinese Taipei	CHN	2.19 (.43)	3584	47	.86	4	.20*	7
Croatia	CRO	2.48 (.35)	3649	7	.78	28	.16*	22
Cyprus	CYP	2.40 (.41)	3744	20	.82	11	.18*	14
Czech Republic	CZE	2.43 (.33)	3901	16	.75	46	.07*	49
Denmark	DNK	2.30 (.35)	1886	34	.75	46	.11*	41
Finland	FIN	2.25 (.35)	4105	40	.76	41	.11*	41
France	FRA	2.39 (.38)	3656	21	.76	41	.19*	10
Georgia	GEO	2.30 (.38)	3295	35	.74	51	.02	54
Germany	GRM	2.36 (.36)	2187	28	.75	46	.10*	47
Hong Kong	HKG	2.18 (.41)	2663	49	.84	5	.17*	17
Hungary	HUN	2.51 (.34)	4147	3	.75	46	.13*	29
Iran	IRN	2.16 (.43)	5475	50	.80	18	.17*	17
Ireland	IRL	2.48 (.39)	4228	7	.82	11	.19*	10
Italy	ITA	2.37 (.37)	3501	27	.74	51	.12*	35
Japan	JPN	2.12 (.42)	3840	51	.81	14	.16*	22

(Continues)

TABLE 2 (Continued)

Country	Country ID	HME *M* (*SD*)	*N* observations	HME rank	Cronbach's alpha	Alpha rank	HME-math achievement correlation	Correlation rank
Kazakhstan	KAZ	2.47 (.35)	4346	10	.78	28	.12*	35
Korea	KOR	2.39 (.42)	3798	21	.86	3	.21*	6
Kosovo	KSV	2.41 (.35)	3932	19	.74	51	.13*	29
Kuwait	KWT	2.33 (.41)	3263	31	.79	24	.11*	41
Latvia	LVA	2.39 (.36)	4212	21	.78	28	.10*	47
Lithuania	LTU	2.38 (.35)	3008	25	.78	28	.07*	49
Malta	MLT	2.50 (.37)	2573	6	.80	18	.18*	14
Montenegro	MNE	2.44 (.37)	4629	15	.78	28	.15*	25
Morocco	MRC	1.86 (.55)	6511	54	.84	5	.22*	4
New Zealand	NZL	2.51 (.39)	2018	3	.84	5	.12*	35
North Macedonia	NMC	2.46 (.38)	2733	13	.81	14	.20*	7
Northern Ireland	NIR	2.54 (.37)	1821	1	.83	10	.14*	27
Norway	NOR	2.30 (.36)	2291	35	.77	35	.12*	35
Oman	OMN	2.25 (.38)	6094	40	.74	51	.19*	10
Pakistan	PAK	2.00 (.45)	2963	53	.77	35	.17*	17
Philippines	PHL	2.25 (.39)	4788	40	.81	14	.18*	14
Poland	POL	2.51 (.32)	4543	3	.77	35	.05*	53
Portugal	PRT	2.35 (.37)	3986	29	.78	28	.16*	22
Qatar	QAT	2.31 (.41)	3785	33	.80	18	.17*	17
Russian Federation	RUS	2.52 (.35)	3912	2	.81	14	.07*	49
Saudi Arabia	SAU	2.27 (.42)	3333	39	.79	24	.13*	29
Serbia	SRB	2.48 (.35)	4127	7	.77	35	.24*	3
Singapore	SGP	2.28 (.45)	5737	37	.87	2	.14*	27
Slovak Republic	SVK	2.47 (.37)	3970	10	.80	18	.13*	29

TABLE 2 (Continued)

Country	Country ID	HME *M* (*SD*)	*N* observations	HME rank	Cronbach's alpha	Alpha rank	HME-math achievement correlation	Correlation rank
South Africa	SAF	2.21 (.44)	9126	46	.80	18	.19*	10
Spain	SPA	2.33 (.37)	8326	31	.76	41	.15*	25
Sweden	SWE	2.19 (.40)	3176	47	.79	24	.07*	49
Turkey	TUR	2.10 (.56)	3663	52	.90	1	.41*	1
United Arab Emirates	UAE	2.43 (.41)	11,988	16	.84	5	.12*	35

*$p < .05$ after Bonferroni adjustment.

TABLE 3 Heatmap of HME item and mathematical achievement correlation coefficients by country.

Country ID	Count songs	Number toys	Count things	Games with shapes	Building blocks	Board and card games	Write numbers	Draw shapes	Weigh or measure things
ALB	.09*	.13*	.19*	.20*	.19*	.11*	.15*	.19*	.01
ARM	.04	.09*	.09*	.12*	.05	.06*	.04	.06*	.02
AUT	.08*	.02	.17*	.15*	.19*	.13*	−.02	.02	.04
AZE	.06*	.07*	.09*	.17*	.14*	.09*	.10*	.10*	.05
BHR	.07*	.06*	.10*	.11*	.10*	.05	.06*	.04	.00
BFL	.07*	.04	.12*	.19*	.18*	.14*	−.03	−.01	.04
BIH	.06*	.09*	.13*	.12*	.18*	.06*	−.03	.03	−.01
BGR	.22*	.31*	.35*	.39*	.34*	.28*	.29*	.22*	.13*
CAN	.02	.08*	.10*	.14*	.10*	.08*	.07*	.07*	.02
CHL	.11*	.17*	.15*	.21*	.19*	.12*	.08*	.10*	.02
CHN	.13*	.15*	.17*	.20*	.23*	.14*	.10*	.11*	.03
CRO	.07*	.12*	.13*	.15*	.13*	.11*	.09*	.05	.03
CYP	.10*	.15*	.14*	.16*	.17*	.13*	.08*	.05	.07*
CZE	.00	.00	.11*	.06	.07*	.06	.00	−.01	.07*
DNK	.05	.02	.14*	.07	.08	.10*	.05	.01	.07
FIN	.01	.00	.15*	.15*	.16*	.11*	.06	−.01	.05
FRA	.07*	.15*	.17*	.18*	.17*	.14*	.03	.06	.08*
GEO	−.08*	.02	.11*	.09*	.05	.02	−.06	−.04	−.02
GRM	.04	.00	.12*	.11*	.16*	.11*	−.04	.00	.09*
HKG	.11*	.13*	.15*	.17*	.16*	.10*	.08*	.03	.03
HUN	.01	.09*	.13*	.20*	.16*	.13*	−.04	.04	.07*
IRN	.11*	.09*	.14*	.18*	.18*	.12*	.04	.13*	−.05
IRL	.09*	.09*	.13*	.16*	.13*	.10*	.12*	.13*	.16*
ITA	.04	.07*	.11*	.15*	.16*	.08*	.01	.02	−.01
JPN	.03	.08*	.10*	.14*	.12*	.09*	.14*	.09*	.10*

Legend

.45
.40
.35
.30
.25
.20
.15
.10

TABLE 3 (Continued)

Country ID	Count songs	Number toys	Count things	Games with shapes	Building blocks	Board and card games	Write numbers	Draw shapes	Weigh or measure things	
KAZ	.05	.11*	.09*	.13*	.12*	.11*	.04	.07*	−.05	.05
KOR	.15*	.15*	.16*	.20*	.18*	.15*	.12*	.12*	.10*	.00
KSV	.07*	.10*	.16*	.14*	.12*	.02	.05	.04	.00	−.05
KWT	.09*	.06	.12*	.08*	.07*	.02	.10*	.06	−.01	−.10
LVA	.01	.04	.08*	.14*	.12*	.15*	−.01	−.01	.04	−.15
LTU	−.01	.07	.06	.07	.14*	.12*	−.04	.01	.01	−.20
MLT	.16*	.13*	.17*	.14*	.15*	.09*	.05	.08*	.08*	−.25
MNE	.08*	.10*	.12*	.11*	.18*	.10*	.02	.08*	.04	−.30
MRC	.15*	.18*	.16*	.17*	.16*	.15*	.17*	.16*	.03	−.35
NZL	.05	.05	.14*	.13*	.14*	.07	.06	.05	.06	−.40
NMC	.16*	.13*	.15*	.22*	.21*	.07	.10*	.08*	.03	−.45
NIR	.06	.08	.12*	.13*	.12*	.09	.06	.07	.10*	
NOR	.06	.07	.11*	.11*	.09*	.08	.05	.03	.09*	
OMN	.09*	.12*	.14*	.16*	.13*	.11*	.13*	.09*	.02	
PAK	.13*	−.05	.12*	.13*	.16*	.04	.10*	.07	.11*	
PHL	.14*	.16*	.14*	.19*	.15*	.06*	.07*	.13*	−.04	
POL	.02	.05	.06*	.06*	.04	.07*	.00	−.02	.03	
PRT	.10*	.16*	.17*	.18*	.17*	.09*	.02	.03	.02	
QAT	.13*	.14*	.17*	.21*	.19*	.04	.09*	.03	−.02	
RUS	−.02	.07*	.08*	.09*	.07*	.10*	.01	.00	.01	
SAU	.11*	.07*	.11*	.11*	.11*	.07*	.11*	.10*	−.07*	
SRB	.10*	.14*	.17*	.30*	.25*	.10*	.07*	.10*	.04	
SGP	.07*	.11*	.11*	.15*	.19*	.10*	.09*	.04	.01	
SVK	.08*	.08*	.13*	.20*	.19*	.04	−.03	.01	.04	

(Continues)

TABLE 3 (Continued)

Country ID	Count songs	Number toys	Count things	Games with shapes	Building blocks	Board and card games	Write numbers	Draw shapes	Weigh or measure things
SAF	.15*	.15*	.15*	.19*	.17*	.12*	.03	.07*	−.02
SPA	.02	.16*	.12*	.18*	.18*	.06*	.06*	.03	.01
SWE	−.03	−.02	.15*	.10*	.12*	.08*	.03	−.02	.03
TUR	.27*	.30*	.34*	.38*	.31*	.30*	.27*	.31*	.21*
UAE	.10*	.12*	.11*	.14*	.16*	.05*	.03	.04*	−.03

*$p < .05$ after Bonferroni adjustment.

specific item. Further, parent engagement in items such as ‘count things’, ‘games with shapes’, ‘building blocks’, and ‘board and card games’ were positively related to children's mathematical achievement across all countries. Whereas parent engagement in items such as ‘counting songs’, ‘number toys’, ‘write numbers’, ‘draw shapes’, and ‘weigh or measure things’ showed very small positive to non-existent associations with children's mathematical achievement across countries. However, it is important to note that although some effects remained statistically significant, many of these relations are small, near zero, effect sizes.

Exploratory grouping analyses

As part of our preregistration, we discussed grouping countries to explain differences in the HME. Each of the considered grouping variables can be seen on the project's OSF page (https://osf.io/c5h7x/). These included groups such as Gross Enrollment Ratio in Tertiary Education, Western, Human Development Index (HDI), TIMSS Math Achievement Groupings, and the Gini Index. There were multiple reservations about the grouping variables for reasons ranging from some countries missing data or information, which resulted in them being excluded from group analyses (i.e., Gini Index), to unequal groupings (i.e., HDI), to random cut-offs (i.e., 50% for Gross Enrollment Ratio in Tertiary Ed). For these reasons, the authors decided not to go forward with any exploratory grouping analyses in the final manuscript.

DISCUSSION

Utilizing data from a large, international data set, the present study examined the HME across a broader representation of countries. By including more countries in our analyses than any prior research, our study presents an essential first step in studying the HME from a broader international perspective and analysing the same measure across multiple countries in the same age group. Findings from our study showed that families in certain countries engaged in home mathematics activities (as measured by this scale) more frequently than families in other countries, and all countries demonstrated acceptable reliability across the nine home mathematical survey items. Further, our findings highlight that although the global average relation between the HME and children's mathematical achievement was like that of previous research (Daucourt et al., 2021), we observed substantial variation around this average relation across countries. These results demonstrate that international research is both beneficial and imperative for theoretical and practical implications to further our understanding of how the HME contributes to children's development of early mathematics skills in different contexts.

Importantly, our findings demonstrated a large amount of variability surrounding family reports of engaging in HME activities. Survey questions in the HME area have inherently been developed from a limited perspective (Anders et al., 2012; Melhuish et al., 2008; Sarama & Clements, 2009), which restricts our knowledge of the types of mathematics activities that may be present across homes globally. Therefore, reported differences in activity frequency may not solely reflect the wide range of the HME in different country contexts, but also emphasize that these measures do not adequately represent the full range of HME activities across different settings. It could be some items might be more prone to variations in interpretation between countries than other items. One future direction to better capture the international approach in the home environment could be to use participatory research methods to develop country-specific research tools. For example, Cahoon et al. (2021) took a similar approach to capture this diversity in Northern Ireland and found that other activities and topics emerged when parents were prompted to talk about their engagement with their children in mathematics. Thus, considerations for examining country and cultural factors in the measurement and contribution of the home environment on children's mathematical performance are important areas for future research.

Consistent with our hypotheses, the reliability across the subset of nine HME items was acceptable in all countries. Notably, the reliability of a measure tells us the degree to which the interrelation among the items on a scale is consistent with one another implying that the items are measuring the same construct. In the case of this study, acceptable reliability was observed across all countries suggesting that all items were related. However, what is unknown is whether a specific item from the survey consistently performs worse across all countries or differently between countries. Future research should examine whether there are specific items that might be better suited to measure the HME for everyone or whether these items are potentially invariant in other countries.

Finally, this study demonstrated positive although very weak (i.e., most lie between .10 and .20) significant associations between the frequency of home mathematics activities families reported and children's mathematical achievement. This finding aligns with earlier studies that have examined the HME (e.g., Daucourt et al., 2021; Mutaf-Yıldız et al., 2020). However, one important note from the current study was again the large level of variability in this association across the 54 countries. The small relation between the HME and children's mathematical achievement in countries such as Georgia compared to the moderate relation in Turkey and Bulgaria emphasizes that the role of the HME in children's mathematical development differs between these countries. The range of this relation across countries led us to examine the relation between individual HME items and children's mathematical achievement. These sensitivity analyses demonstrated parent engagement in some items, such as 'playing with blocks' and 'games with shapes', showed relatively stronger correlations with achievement, which would suggest these activities can be related back to the well-documented relation between spatial abilities and mathematics in the literature (Hawes et al., 2022; Wolfgang et al., 2001). However, the analyses also demonstrated that parent engagement in some items, such as 'counting songs', 'number toys', 'write numbers', 'draw shapes' and 'weigh or measure things' showed differential (very small positive to non-existent) relations to children's mathematical achievement across countries. Therefore, fostering parent engagement in home activities such as these might be more important for children's mathematical achievement in some countries compared to others. Furthermore, the variation in the association suggests that there are important cross-cultural differences in the HME and mathematical achievement. To create better recommendations tailored to a population of interest, future work should conduct deeper investigations of the HME within countries.

The substantial variability across countries in both the frequency of engaging in HME activities and the HME-achievement relation presents the field with many questions for future work. These differences may be due to a plethora of potential factors. For example, differences in parent beliefs about mathematics may differ across cultural groups (del Río et al., 2017; LeFevre et al., 2010). Alternatively, resources in the home (Melhuish et al., 2008) or differences in caregiver-educator communications (Lin et al., 2019) may also substantially vary across countries. Finally, differences across the frequency of engagement could also be due to parents engaging in certain activities because they see the need for further development in that specific area for their child. Future research is needed to understand the ways in which specific countries rely on specific aspects of the home environment as an educational tool and how and why these variations take place.

Limitations

The current study makes a clear contribution to the literature in demonstrating international variability of the HME. However, by using retrospective reports from parents, the accuracy of reporting may have been affected by the time since the activities occurred. Interestingly, it should be noted that the average relation seen in the current study is similar to that reported by Daucourt et al. (2021), which included the use of different methods (both concurrent and retrospective survey responses). Thus, a more important limitation here is the use of surveys to assess the home environment. Parent reports can be biased towards higher amounts of activities than normal to show favourable engagement (Johnson & Christensen, 2019). Future research should, therefore, perhaps combine parent reports with naturalistic observations of the home environment across different countries to increase the accuracy of measurement.

Although the current study includes 54 countries across the globe, it is limited by those who participated in the larger TIMSS data collection. Many of the countries that participate in the TIMSS demonstrate lower economic inequality, and all are part of the OECD. In addition, out of the 64 countries that participated in the TIMSS, 10 countries did not participate in the home survey. Therefore, although this study is broader internationally than previous research, it does not capture the large variation in economic inequality present in our world. Future research should continue to diversify research to include the other 75% of countries in the world to better understand global perspectives on mathematics.

Conclusion

Prior research has highlighted the importance of emphasizing diversity in participants in our research samples (Henrich et al., 2010), particularly in the HME literature (e.g., Hornburg et al., 2021). Given the existing survey questions that assess the HME have been developed from limited perspectives (e.g., LeFevre et al., 2009; Melhuish et al., 2008; Sarama & Clements, 2009), our knowledge of specific activities and responses for different countries has been restricted. Thus, using a large, international data set that sampled families across 54 countries, this study increases diversity and representation in the literature that has not previously existed. Our findings showed substantial variability across countries in the frequency of families engaging in HME activities and the HME-mathematical achievement relation. Overall, this study highlights the importance of taking a broader, international approach to not just participant recruitment, but also the measurement of various constructs (e.g., children's home learning environments).

AUTHOR CONTRIBUTIONS

Alexa Ellis: Conceptualization; data curation; formal analysis; investigation; methodology; software; validation; visualization; writing – original draft; writing – review and editing. **Jimena Cosso:** Conceptualization; investigation; validation; writing – review and editing. **Robert J. Duncan:** Conceptualization; investigation; supervision; validation; writing – review and editing. **María Inés Susperreguy:** Conceptualization; investigation; supervision; writing – review and editing. **Victoria Simms:** Conceptualization; investigation; supervision; writing – review and editing. **David J. Purpura:** Conceptualization; funding acquisition; investigation; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest.

OPEN RESEARCH BADGES

This article has earned Open Data and Preregistered Research Designs badges. Data and the preregistered design and analysis plan are available at https://osf.io/c5h7x/.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available from IEA's Trends in International Mathematics and Science Study—TIMSS 2019 at https://timss2019.org/international-database/.

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