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Early symbolic numeracy and gross, fine, and perceptual-motor skills in Mexican preschool children
Habilidades numéricas simbólicas y motricidad gruesa, fina y perceptivo-motoras en niños preescolares mexicanos

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Abstract. The relation between early numeracy and motor skills has previously been examined, however, different results have been obtained depending on whether gross, fine, or perceptual-motor skills were considered in the study and the numeracy outcomes that were analyzed. The goal of the present research was to examine the relation between preschool children's performance on two assessments of symbolic numeracy and gross, fine, and perceptual-motor skills. A total of one-hundred-and-twenty-three Mexican preschool children were assessed on their gross, fine, and perceptual-motor skills, their numeracy skills (i.e., applied problem-solving and symbolic number comparison) their numeracy precursor skills (i.e., number identification, cardinality and verbal counting), inhibitory control and visual-spatial working memory. Results from hierarchical linear regressions showed that applied problem-solving was predicted only by children's numeracy precursor skills while the ability to compare two symbolic numbers was significantly predicted only by perceptual-motor skills. The study highlights the importance of perceptual-motor skills to children's early numeracy learning.
Keywords: Early numeracy skills; motor skills; perceptual-motor skills; preschool children.

Resumen. La relación entre las habilidades numéricas tempranas y las habilidades motoras se ha examinado previamente, sin embargo, se han obtenido diferentes resultados dependiendo de si se consideraron las habilidades motoras gruesas, finas o perceptivo-motoras en el estudio, y de las variables dependientes (habilidades numéricas) que se analizaron. El objetivo de la presente investigación fue examinar la relación entre el desempeño de niños en edad preescolar en dos evaluaciones de habilidad numérica simbólica y la motricidad gruesa, fina y perceptivo-motriz. Un total de ciento veintitrés niños mexicanos en edad preescolar fueron evaluados en sus habilidades motoras gruesas, finas y perceptivo-motoras, sus habilidades numéricas (es decir, resolución de problemas aplicados y comparación numérica simbólica) y sus habilidades precursoras de matemáticas (es decir, identificación de números, cardinalidad y conteo verbal), control inhibitorio y memoria de trabajo visoespacial. Los resultados de las regresiones lineales jerárquicas mostraron que la resolución de problemas aplicados fue predicha solo por las habilidades precursoras de matemáticas, mientras que la capacidad de comparar dos números simbólicos fue predicha significativamente solo por las habilidades perceptivo-motoras. El estudio destaca la importancia de las habilidades perceptivo-motoras para el aprendizaje temprano de las matemáticas en los niños.
Palabras clave: Habilidades numéricas tempranas; habilidades motrices; habilidades perceptivo-motoras; niños de preescolar.

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Introduction

Early numeracy

Early numeracy skills have been the focus of much research over the past decades (e.g., Batchelor et al., 2015; Bialystok, 1992; Carey, 2004; Fuson, 1988; LeFevre et al., 2010; Purpura et al., 2013; VonAster & Shalev, 2007; Wiese, 2003; Wynn, 1990; 1992). In order to understand more complex arithmetic, children must master and be able to use the symbolic number system (Scalise & Ramani, 2021). The development of early symbolic numeracy begins during the preschool years. In her study, Wynn (1990) found that children begin to mentally represent the count list around their second year of life; subsequently, preschoolers acquire the cardinality principle and are able to associate number words with their cardinal meaning one by one and in order, becoming one-, two-, three-, and four-knowers at six-month intervals finalizing the process by around age four (LeCorre & Carey, 2007; Wynn, 1990).

Models of the development of early symbolic numeracy skills have been proposed (e.g., Bialystok, 1992; Krajewski & Schneider, 2009; LeFevre et al., 2010; Von Aster & Shalev, 2007; Author et al., 2017) and generally agree that children build their knowledge of more complex numeracy skills (e.g., number comparison and simple arithmetic) upon early symbolic skills such as learning to recite the number sequence in order, identifying the written numbers, mastering cardinality, associating the number words to the written digits, as well as each number word and digit to the corresponding quantity (Bialystok, 1992; Author et al., 2017; Krajewski & Schneider, 2009; LeFevre et al., 2010; Von Aster & Shalev, 2007). The development of these skills gradually allows preschoolers to perform more complex tasks such as symbolic number comparison and to solve math problems with an increased degree of difficulty (e.g., Batchelor et al., 2015; Durand et al., 2005; Holloway & Ansari, 2009; Lyons et al., 2014; Mundy & Gilmore, 2009; Purpura et al., 2013; Vanbinst & DeSmedt, 2016).

In search for the predictors of the development of these early numeracy skills researchers have analyzed them in relation to factors such as motor skills (see Cameron et al., 2016 for a review). This line of research builds upon the premise that movement forms the basis for the acquisition of knowledge by providing children with the ability to explore the environment and interact with others (Adolph & Franchak, 2017). However, motor skills can be categorized into three types: gross, fine and perceptual-motor skills and most studies do not assess the relation between early math skills and all three types of motor skills simultaneously; in addition, they do not focus exclusively on symbolic number skills (c.f. Pienaar et al., 2012). Furthermore, very little research on the relation between numeracy and motor skills has been conducted in Mexico, with three-to-five-year-old children (but see Huizar-Carrillo, 2014 for an intervention study employing qualitative methodology). Thus, the present study aims to fill these gaps in the literature with preschool-aged children.

Motor skills

Gross motor movements involve large muscle systems used in locomotion (e.g., walking, running, jumping) and coordinated actions such as throwing (Newborg et al., 2005). Fine motor skills are defined as the coordination and control of small muscles, in arms and hands that allow the child to, for example, pick up small objects or tie his or her shoelaces (Newborg et al., 2005; González et al., 2019).

Perceptual motor skills involve the integration of a child's fine- and perceptual-motor skills which are used in tasks such as piling blocks, copying designs, letters and numbers (Newborg et al., 2005). During the first years of life, as children acquire physical, linguistic, and cognitive skills, their perceptual capacities change with maturation and the acquisition and improvement of their motor skills. In early childhood, visual perception and movement often seem to function independently. Over the first year of life, the eyes can search and scan in ways that appear to be independent of the patterns of action in which the baby engages, however, by eighteen months, the baby begins integrating visual input and movement abilities (Adolph & Hoch, 2019). Finally, during the second year and later, children gradually develop skills (e.g., using their finger to point at specific visual targets upon request) that will contribute to their ability to perform complex visual-motor-perceptual tasks in later childhood (Cratty, 1986; United Nations International Children's Emergency Fund UNICEF, 2022). For the purpose of this paper and to be consistent with the measurement instrument used, we will refer to this ability as perceptual-motor.

The role of motor skills in the development of early numeracy skills

The development of motor skills is key to the development of cognitive skills (Cameron et al., 2016), for example when, through movement, children learn to calculate and estimate distances, depths, etc. (Adolph & Hoch, 2019). Lopes et al. (2013) found that gross motor skills allow children to learn concepts through exploration of their environment; these skills have also been associated with social development (Cameron et al., 2016) which has been suggested, favours learning by social interaction (Adolph & Franchak, 2017). Gross motor skills have been found to be related to academic achievement in primary school children. For example, Magistro et al. (2015) found that gross motor skills were correlated with teacher ratings of overall academic performance and math performance in a sample of Italian eight-year-olds. de Waal (2019) found that distinct aspects of gross motor coordination (e.g., one-and-two-legged jumps, skipping, catching, throwing) were significantly correlated with five-to-six-year-old children's performance on a math assessment that included measurement, patterns, space and shapes. More recently, Fernández-Sánchez et al. (2022) assessed 451 eight-to-ten-year-old children on their gross motor competence, executive functions (i.e., inhibitory control, cognitive flexibility, and working memory) and academic achievement (i.e. final school grades in language and math), and found a significant association between gross motor competence and the latent variable for academic achievement (which included both language and math) although the association was partially mediated by executive function for boys but not for girls. However, given the latent variable that included both language and math, it is unclear which specific aspect is related to children's gross motor skills.

Fine and perceptual-motor skills have been linked to cognitive development, visuo-spatial skills (Schwarzer et al., 2013) and academic outcomes, namely literacy (Suggate et al., 2019), language (see González et al., 2019 for a systematic review) and numeracy (see Barrocas et al., 2020 for a review). For example, a study by Pitchford et al. (2016) with five-to-six-year-olds used the Bruininks Ozeretsky Test to assess fine motor precision and fine motor integration. The authors also assessed children's word reading and mathematical reasoning skills (i.e., problem solving and interpreting graphs) and found that fine motor precision skills were related to their math abilities even after controlling for word reading, another measure of academic achievement.

Researchers have proposed that the association between fine motor skills and numeracy may derive from children's ability to manipulate sets of objects with their hands and associate the set to a number representation (Cameron et al., 2016) and from the ability to use the pencil to write numbers and letters which may support the mapping between written digits, number words and quantities (Pitchford et al., 2016). Specifically, it has been suggested that fine motor skills allow the child to efficiently manipulate objects, which allows him or her to understand spatial concepts, shapes, quantities, which are basic for understanding magnitudes and mathematical reasoning (Cameron et al., 2016) and may also be indirectly related to math performance through perceptual-motor skills (Kim et al., 2018). A study by Fischer et al. (2020) showed that finger dexterity (assessed by the time children took to thread beads and place coins) was indirectly linked to numerical skills through children's ordinal and cardinal finger representations of number (ordinal representation was assessed by asking the child to count on their fingers and cardinal representation by asking the child to show a certain number of fingers). This relation has been explained because children initially use their fingers to count and representations are built upon this embodiment (Fischer et al., 2022).

While the above research points to a significant relation between early numeracy and fine motor skills (e.g., Barrocas et al., 2020), a recent longitudinal study by Malone et al. (2022) which included children aged five to six, found that after controlling for children's executive functions and the more proximal, domain specific predictors of math performance (i.e., counting, numerosity judgement, and addition), fine motor skills were no longer associated with their measure of arithmetic. Similarly, Gashaj et al. (2019) found in a sample of six-year-old kindergarten children that symbolic number tasks (i.e., number line and number comparison) were predicted by measures of executive function but not by either gross or fine motor skills; whereas gross motor skills predicted non-symbolic numeracy performance (i.e., number line and magnitude comparison). Thus, the findings have been mixed and do not allow for clear conclusions to be drawn about the relation between gross, fine, and perceptual-motor skills and numeracy performance. It is possible that the distinct results arise from the different methodologies used, for example, the study by Malone et al. (2022) controlled for domain specific skills, while the other studies did not, and while it is important that studies include domain specific skills, it is also important to include the three motor components (i.e., gross, fine and perceptual-motor skills); leaving out any of these factors does not allow for a clear picture of the relations among motor and numeracy skills.

With regards to perceptual-motor skills, research suggests that the acquisition of number concepts require the ability to recognize and visually reproduce representations of sets of objects, highlighting importance of these skills in the development of numerical concepts, (Cameron et al., 2016). Perceptual-motor skills have been previously found to be related to children's math performance, albeit in older children. For example, Pieters et al. (2012), conducted a study with a sample of seven-to-nine-year-old children including measures of manual dexterity, aiming and catching, balance, visual perception, motor coordination, and a test of visual-motor integration similar to the one used in the present study (children were asked to copy geometric figures) in relation to: a) procedural calculation (on which children were asked to solve arithmetic number fact problems) and b) number fact retrieval (which included mental computation and number system knowledge, such as being able to order numbers from largest to smallest). Their findings showed that visual-motor integration significantly predicted both outcomes. Pienaar et al. (2013) examined a sample of 812 South African six-year-old children who were assessed on their visual-motor skills (which included visual-motor integration, visual perception and motor coordination), motor proficiency and their academic performance (using a questionnaire completed by the children's teachers about their numeracy and literacy skills). Their findings showed that children with higher scores on visual-motor integration were rated as having higher performance on math, reading and writing by their teachers as compared to children with lower visual-motor integration skills.

Oberer et al. (2018) found that visual-motor skills, measured using tests in which children had to complete a simple maze, insert beads, and post coins in a box using both hands, are directly related to an academic achievement latent factor (which included completing sequences, addition and subtraction, reading comprehension and reading speed) in five-to-six-year-old children. Kim et al. (2018) conducted a longitudinal study in which they assessed five-and-six-year-old children on their visual-motor (assessed by asking children to copy increasingly complex figures using paper and pencil), fine motor coordination, attention and math skills (as measured by the KeyMath Numeration, Geometry and Measurement subtests); their findings showed that fine motor coordination skills were related to math through children's visual-motor skills; furthermore, visual-motor skills were longitudinally related to children's math performance, this association was observed to be reciprocal (i.e., visual-motor skills predicting math and math predicting visual-motor skills over three time points).

Nesbitt et al. (2019) found longitudinal associations between mathematics achievement and, executive function and visual motor-integration skills (measured using a copy design task) in kindergarten children. More recently, Escolano-Pérez et al. (2020) measured gross and fine motor skills in a sample of five-to-six-year-old-children to examine the longitudinal effect of these motor skills on academic competencies (i.e., literacy, mathematics and overall academic competency). Interestingly, their measure of fine motor skills included a subcomponent of fine motor integration which was assessed by asking the children to copy shapes, letters, words, and numbers (tasks similar to the ones used in the present study to assess perceptual-motor skills). Their findings show that only the fine motor integration component was related to children's mathematics performance.

In the present study, we aim to examine the relations between gross, fine and perceptual- motor skills and two symbolic math outcomes (i.e., number comparison and a standardized measure of math problem solving) in three-to-five-year-old Mexican children. In order to better understand these relations, we include measures of symbolic precursor skills (Author et al., 2017) and control for executive function skills (Becker et al., 2014). Given the prior findings in the field, we expect that both symbolic precursor skills and fine and perceptual-motor skills to be predictive of children's symbolic numeracy skills.

Method

Participants

A total of 123 Mexican children (73 girls; mean age = 57.17 months, SD = 8.87 months, range: 38-71 months) recruited from 4 government funded preschools in three different communities of the state of Chihuahua, Mexico, participated in the present study. All participants were monolingual Spanish-speakers; as reported by the responding parent, 69.6% of the mothers and 78.8% of the fathers had completed high-school education or less.

Materials

Numeracy Precursors

Verbal count. The purpose of this test is to find out the highest number up to which children can count correctly. This assessment has been used in prior studies (e.g., Author et al., 2017; Dunbar et al., 2017). The test begins with a puppet asking the child to teach him how to count, because he only counts to 1. The child then counts as far as he knows and is stopped when he or she makes 1 mistake. If the child acknowledges his or her mistake and corrects it (without intervention), the child is allowed to continue. The score for this test is the highest number that the participant counted correctly.

Verbal give-n. This test is designed to find out if the child understands that numbers represent specific quantities (Wynn, 1992) and has been used as an assessment of cardinality knowledge (e.g., Litkowski et al., 2020). Children are presented with 20 cubes (approx. 3x3x3 cm) and a plate. The experimenter will then tell the child that a puppet wants him to give him 2 cubes, if he fails, he is asked for 1 cube, if he is correct, he is asked for two cubes again, if he is correct, he is asked for three but if he fails again, he is asked for one. Test continues in this way until children make two mistakes out of three on a given number for a maximum score of six points. It is considered an error if, when asked for a certain number of cubes, he provides an amount equal to one previously requested (for example, if he was asked for three cubes and answered correctly and when asked for four, he provides three, it is considered that the child does not know neither three nor four).

Written give-n. This test is intended to assess whether children know the meaning of written digits (Author, 2016). This test is carried out in the same way as the give-n task with the difference that instead of telling the child the number, the puppet shows the child the printed number (from one to six) and asks him or to provide the corresponding number of cubes (the experimenter never mentions the verbal number word).

Number recognition. This test aims to determine the number of digits that the child can recognize and name correctly (Purpura & Lonigan, 2015). The test consists of showing, in random order, cards with the numbers from one to 20 and asking the child to name them. This test is commonly used in research on the development of numerical skills in preschool. The maximum score corresponds to the number of numbers that the participant names correctly.

Symbolic Numeracy

Verbal number comparison. This test was adapted from Purpura et al. (2013) and has been used in prior research (e.g., Author et al., 2017). The child is verbally presented with two numbers and asked to identify the larger one. The test begins with the experimenter explaining that two puppets went shopping and that one bought a certain number of fruits and the other bought another quantity of fruits; after this explanation, the child is asked: "Who bought more?" The child is presented with the 20 items of the test, the child gets one point for each correct answer.

Written number comparison. In this test (adapted from Purpura et al., 2013), the child is visually presented with two numbers side by side and asked to identify the larger one. The test begins with the experimenter explaining that the puppets went shopping and that one bought "this amount" while the experimenter points to one of the digits, and the other puppet bought "this amount" while the experimenter just points to the other digit; the child is then asked: "Who bought more?" The child is presented with the 20 items of the test and is awarded one point for each correct answer.

Woodcock Johnson: Applied Problems subtest, (Muñoz-Sandoval et al., 2005). This subtest evaluates numerical skills, and the items consist of reasoned problems accompanied by images that involve addition, subtraction (e.g., ask the child to point to the flower that has three bees). One point was awarded for each correct response testing was stopped after six consecutive mistakes.

Motor skills

Gross and fine motor skills and perceptual-motor coordination were assessed with the motor subscales of the Battelle Development Inventory Second Edition BDI-2 (Newborg et al., 2005). The gross motor skill subscale included a total of 45 items which asked the child to, for example, walk up and down stairs, hop, and throw a ball. The fine motor subscale included a total of 30 items, some examples of the tasks children were asked to perform are tie a knot, cut paper in curve and straight lines, trace designs, and pick up small objects. Finally, the perceptual motor subscale is made up of 25 items on which children are asked to, for example, copy geometrical shapes, letters, and words, and make piles of cubes.

Control variables

Inhibitory control. Black and White Stroop test was developed by Vendetti, et al. (2016). In this test, 21 cards (10 black, 11 white) of 3 x 5 inches are used. The experimenter shows the cards to the child and says "this card is black and this card is white, when I show you the black card I want you to say white and when I show you the white card I want you to say black." The cards are shown in a preset order: BWBWWBBWBWWBWBWBWWBWB. Each correct answer corresponds to one point. The child is given three practice trials with each color on which feedback is provided.

Visuospatial working memory. Adaptation for i-Pad of the Corsi Block Tapping Test. This test has been used in numerous investigations as a measure of visuospatial working memory, beginning with LeFevre et al. (2010) and subsequently used in later research (e.g., Dunbar et al., 2016). During testing, the child must observe how green buttons light up on the screen and must repeat the sequence by touching each button that has lit up. For the present study, the forward version was used with two trials per sequence; the length of the sequences increased until the child failed at both trials (available at https://hume.ca/ix/pathspan).

Procedure

All procedures in this study were approved by the Ethics in Research Committee (Name of of Faculty of Medicine and Biological Sciences of the Autonomous University of Chihuahua.).

Children were recruited through four local preschools in three communities of the state of Chihuahua. The directors of the preschools were contacted by a researcher to ask if they were interested in taking part in the study; once the director agreed, a letter was provided detailing the study goals and procedures and asking for permission to contact the parents, invite them to the study, and conduct testing within the preschool.

Once permission from the school director was obtained, a letter describing the study was sent home to all the parents along with the informed consent and an envelope in which they returned the informed consent to their children's teacher. Only the children whose parents returned the informed consent forms allowing their child to participate were invited to take part in the study; furthermore, only those who verbally agreed were assessed. Children were assessed individually by four trained experimenters; the tasks were administered in random order. Testing took place within the preschools during school hours; children were tested on either one or two separate days depending on the child as he or she was allowed to stop testing at any time and resume on another day; after completing the tasks, children were awarded a sticker and thanked for their participation. Data collection took a total of five months.

Analyses

The present study aimed to examine the relations between gross, fine and perceptual-motor skills and two symbolic math outcomes while controlling for measures of executive function (i.e., inhibitory control, visual-spatial working memory) and importantly, precursor symbolic numeracy skills. Our hypothesis was that, when included simultaneously in a model, fine and perceptual-motor skills would be predictive of children's number comparison and math problem solving skills as would the symbolic numeracy precursor skills.

As an initial step, we analyzed the descriptive statistics to assess the level of development of the precursor skills (i.e., verbal count, written number recognition, give n, and written give-n) and the symbolic numeracy measures (i.e., verbal and written number comparison and the applied problems subtest). Next, we created a composite precursor skill variable from children's scores on a) verbal counting, b) verbal give-n, c) written give-n, and d) written number recognition tasks.

The final step included performing two hierarchical linear regressions. Hierarchical regression analyses consist of a series of regression analyses in which the independent variables are entered in a predetermined order, at each step, one more variable or a set of variables is entered into de model; the resulting model is assessed using the R^2 and the partial and semipartial correlation coefficients. The analyses are planned in advance and according to theory, thus, the researcher is able to observe the effect of the variables of interest (which are entered in a final step) above and beyond the effect of the variables entered in the first steps (Cohen et al., 2002, p. 158). For the present study, two hierarchical regressions were planned: the first predicting symbolic number comparison and the second, predicting scores from the Woodcock Johnson Applied Problems subtest. Assumptions of regression were checked and met prior to conducting each of the analyses.

The choice of order of entry into the model was theoretically driven; first it was important to control for the effect of age, thus, this variable was included in Model 1; next, research has found that executive function skills are correlates of children's math skills (e.g., LeFevre et el., 2013), thus these variables were entered in Model 2; following Malone et al. (2022) we entered the precursor numeracy skills in Model 3 as these are closely related domain specific predictors of math outcomes and we desired to remove the variability associated with them prior to assessing variance explained by the motor skills; finally, the motor skills were entered one by one into separate models to assess the specific effect of each, gross motor was entered in Model 4 as research has found that when entered with fine motor skills (Model 5), the former are no longer predictive of math outcomes (see Escolano-Pérez et al., 2020), finally perceptual motor skills were entered in Model 6 following research by Suggate et al. (2019) and Escolano-Pérez et al. (2020); the analyses was set up this way as our goal was to assess whether motor skills account for variance over and above that accounted for by age, executive functions and precursor numeracy skills.

Results

Descriptive statistics

Descriptive statistics for the study variables are provided in Table 1; as can be observed, all the measures had good reliabilities for the present sample. One variable presented both skew and kurtosis z scores values above 4, (i.e., verbal count), the variable was examined for outliers and only one data point had a z value of 4.76, however, removing this data point did not significantly reduce the skew and kurtosis values, thus, the data point was kept. The variable written number recognition presented skew value above 4, but had a normal kurtosis z score and also has excellent reliability. Thus, as both these variables were chosen to be included in the Principal Components Analyses (to summarize the relations in the observed variables and create the precursor skills variable), this deviation from normality did not pose a serious problem (Tabachnick & Fidel, 2013, p. 618) and thus, no transformations were performed on the data. No data imputation was performed for missing data (the number of participants who completed each assessment is provided in Table 1); analyses were conducted by automatically omitting the missing data points.

Table 1.
Descriptive statistics for all participants

	N	Min	Max	Mean	SD	Skew	Kurtosis	Reliability
Age	123	38	71	57.17	8.87	-1.93	-1.97	-
Verbal count	118	0	59	11.46	9.99	9.28	11.75	-
Verbal Give N	123	0	6	4.22	1.84	-2.04	-2.60	.84
Written number recognition	118	0	19	5.67	4.91	4.34	0.59	.92
Written Give N	118	0	6	3.32	2.39	-.614	3.64	.92
Spoken number word comparison	118	0	20	11.71	5.63	-2.42	1.01	.89
Written number comparison	118	0	20	11.52	5.40	-1.66	-0.78	.88
Composite symbolic number comparison	118	0	40	23.23	10.32	-1.98	-0.67	.93
Applied problems	119	0	23	11.05	4.78	-.491	-0.80	.90
Inhibitory control	120	0	20	13.83	6.73	3.77	-1.98	.96
Visual-spatial WM	114	0	7	1.89	1.78	3.46	-0.25	
Gross Motor	119	57	88	77.55	6.85	-3.19	-0.33	.87
Fine Motor	105	14	59	44.10	8.23	-2.43	1.63	.87
Perceptual-motor	105	16	43	26.58	6.59	2.94	1.21	.88

Note. Reliabilities are Cronbach's Alpha calculated for the present sample.

Correlations

Table 2 shows the correlations among all the study variables for all participants. All precursor skills variables were moderately to highly intercorrelated; the symbolic comparison skills were also moderately intercorrelated.

Gross, fine and perceptual-motor skills were moderately correlated with the numeracy measures, being the highest correlations with performance on the perceptual-motor subtest.

Table 2.
Intercorrelations among the study variables

		Precursor skills				Symbolic number comparison		Executive functions				
	Age	Verbal count	Verbal Give N	Number recog.	Written Give N	Verbal	Written	Applied prob.	Inhib. Ctrl.	Path Span	Gross motor	Fine motor
Verbal count	.416**											
Give N	.570**	.540**										
Number recognition	.475**	.560**	.682**									
Written Give N	.523**	.566**	.833**	.770**								
Verbal comp.	.453**	.429**	.667**	.627**	.682**							
Digit comp.	.458**	.519**	.729**	.691**	.745**	.751**						
Applied problems	.617**	.514**	.764**	.603**	.671**	.682**	.706**					
Inhib. Ctrl.	.462**	.301**	.536**	.364**	.530**	.396**	.374**	.553**				
Visual-spatial WM	.490**	.362**	.536**	.464**	.539**	.517**	.490**	.550**	.401**			
Gross motor	.726**	.343**	.535**	.394**	.420**	.388**	.427**	.618**	.375**	.500**		
Fine motor	.667**	.436**	.542**	.451**	.579**	.489**	.543**	.624**	.406**	.442**	.658**	
Perceptual-motor	.641**	.531**	.721**	.623**	.675**	.587**	.692**	.663**	.500**	.540**	.568**	.561**

Note. **p<.01. Ns =99-119

We conducted a principal components analysis using the following variables: a) verbal count, b) verbal give-n, c) written give-n, and d) written number recognition; factor scores were saved to create a composite variable which we labeled "precursor skills." This analysis was viable given the moderate to high intercorrelations among the variables. The PCA resulted in a single factor that explained 76.16% of the variance; loadings for the variables were .786, .894, .925, and .879 for verbal count, verbal give-n, written give-n, written number recognition respectively; n = 118, KMO = .80.

The scores for the verbal and written comparison skills were highly intercorrelated, thus we added the scores for both tests to create a single "symbolic comparison" variable.

The intercorrelations among the composite variables, inhibitory control, visual-spatial working memory and motor skills are presented in Table 3As shown in Table 3, symbolic comparison skills and applied problem-solving skills were, as expected, significantly and positively correlated with the precursor skill variable and the gross, fine and perceptual-motor skills variables. Inhibitory control and the visual-spatial working memory were also correlated with all variables

.

Table 3.

Intercorrelations among the composite variables, applied problems and motor skill variables

	Age	Inhibitory control	Visual-spatial WM	Precursor	Symbolic comparison	Applied problems	Gross motor	Fine motor
Inhibitory ctrl.	.462***							
Path Span	.490***	.401***						
Precursor skills	.571***	.510***	.566***					
Symbolic Comparison	.487***	.411***	.541***	.793***				
Applied problems	.617***	.553***	.550***	.746***	.741***			
Gross motor	.726***	.375***	.500***	.502***	.435***	.618***		
Fine motor	.667***	.401***	.442***	.581***	.552***	.624***	.658***	
Perceptual-motor	.651***	.500***	.540***	.728***	.684***	.663***	.568***	.561***

Note. ***p<.001. Ns = 99-119

Table 4.
Hierarchical linear regressions explaining variance in symbolic number comparison skills and applied problems

	Symbolic Number Comparison				Applied Problems			
	B	sr	R^2	Change R^2	B	sr	R^2	Change R^2
Model 1			.301	.301***			.397	.397***
Age	.548***	.548			.630***	.630		
Model 2			.415	.114***			.506	.109***
Age	.303**	.243			.388***	.312		
Inhibitory ctrl.	.142	.125			.241**	.211		
Visual-spatial WM	.341***	.284			.251**	.209		
Model 3			.640	.225***			.612	.106***
Age	.100	.076			.249**	.189		
Inhibitory ctrl.	-.021	-.018			.129	.108		
Visual-spatial WM	.121	.094			.100	.078		
Precursor skills	.668***	.474			.458***	.325		
Model 4			.642	.002			.633	.020*
Age	.156	.087			.077	.043		
Inhibitory ctrl.	-.027	-.023			.147	.123		
Visual-spatial WM	.126	.098			.084	.065		
Precursor skills	.671***	.476			.450***	.319		
Gross Motor	-.073	-.046			.229*	.143		
Model 5			.648	.007			.639	.006
Age	.123	.067			.045	.025		
Inhibitory ctrl.	-.034	-.028			.141	.117		
Visual-spatial WM	.124	.096			.081	.063		
Precursor skills	.649***	.453			.429***	.299		
Gross Motor	-.115	-.069			.188	.112		
Fine Motor	.121	.082			.116	.079		
Model 6			.670	.022*			.646	.007
Age	.065	.035			.030	.016		
Inhibitory ctrl.	-.060	-.049			.134	.110		
Visual-spatial WM	.106	.081			.076	.059		
Precursor skills	.549***	.346			.403***	.254		
Gross Motor	-.139	-.082			.182	.108		
Fine Motor	.131	.088			.119	.080		
Perceptual-mot.	.231*	.147			.061	.039		

Note. *p<.05, **p<.01, ***p<.001. Model statistics for symbolic comparison: Model 1. F(1, 93) = 40.01, p<.001; Model 2. F(3, 91) = 21.48, p<.001; Model 3. F(4, 90) = 39.94, p<.001; Model 4. F(5, 89) = 31.89, p<.001; Model 5. F(6, 88) = 27.05, p<.001; Model 6. F(7, 87) = 25.24, p<.001. Model statistics for Applied Problems: Model 1. F(1, 93) = 61.31, p<.001; Model 2. F(3, 91) = 31.12, p<.001; Model 3. F(4, 90) = 35.52, p<.001; Model 4. F(5, 89) = 30.65, p<.001; Model 5. F(6, 88) = 25.93, p<.001; Model 6. F(7, 87) = 22.12, p<.001.

Hierarchical Regression Analyses

In order to assess whether children's motor skills would be predictive of number comparison and their math problem solving skills over and above the effect of age, executive functions, and the symbolic precursor skills, we conducted two hierarchical linear regressions; results are shown in Table 4.

Symbolic Number Comparison

As detailed in the analyses section, we began by including age in Model 1 to control for this variable, followed by both inhibitory and visual-spatial working memory (Model 2), at this stage, only visual-spatial WM was predictive of symbolic number comparison. Once the precursor skill composite was included (Model 3) neither inhibitory control nor visual-spatial WM were predictive of the outcome. The gross, fine, and perceptual-motor skills were included one by one in models 4 through 6; note that in these models the symbolic precursor skills remained a significant predictor.

Gross motor skills (model 4) were unrelated to children's symbolic comparison skills, fine motor skills (model 5) were not significantly related to the outcome, however, perceptual-motor skills (model 6) were predictive of symbolic number comparison over and above the effect of the symbolic precursor skills and gross and fine motor skills.

Applied Problems

We again began by including age in Model 1, followed by both inhibitory and visual-spatial working memory (Model 2), at this stage, both executive function measures were significantly predictive of applied problems. Once the precursor skill composite was included (Model 3) neither inhibitory control nor visual-spatial WM predicted applied problems scores. The gross, fine, and perceptual-motor skills were included one by one (models 4 through 6) again, in these three models, the symbolic precursor skills remained predictive of children's applied problems scores.

Gross motor skills were related to children's problem-solving skills when neither fine (Model 5) nor perceptual-motor skills (Model 6) were included. Both fine and perceptual-motor motor skills were unrelated to applied problems solving.

Discussion and Conclusions

The goal of the present study was to examine the relations between children's, gross, fine and perceptual-motor skills, symbolic numeracy precursor skills and two symbolic math outcomes (e.g., symbolic number comparison and applied math problem solving) controlling for children's inhibitory control and visual-spatial working memory in Mexican preschool children. Our hypothesis was that fine and perceptual-motor skills as well as symbolic numeracy precursor skills, would be predictive of children's symbolic number comparison and applied math problem solving skills.

Our findings provide partial evidence for our hypothesis, as only children's performance on symbolic number comparison was predicted by both perceptual-motor and precursor symbolic numeracy skills; applied problem solving was predicted by children's symbolic precursor skills; fine motor skills did not significantly predict either outcome.

Prior studies have assessed the relation between children's motor skills and their numeracy performance. These studies however, assessed numeracy skills in relation to: only gross motor skills (de Waal, 2019; Lopes et al., 2013; Vanhala, 2022); only fine motor skills (Barrocas et al., 2020); visual motor integration and executive functions (Nesbitt et al., 2019) or a combination of two motor skills (e.g., Escolano-Pérez et al., 2020). Furthermore, only one study included math precursor skills (Malone et al., 2022). Studies that included visual perception, visual-motor integration and motor coordination (e.g., Pienaar et al., 2012) did not control for executive function and their samples were older (7-to-9-year-olds).

Thus, it is difficult to understand the relations between children's early math skills and their precursor, gross, fine and perceptual-motor skills if they are not included in the same analyses in a sample of preschool children; the present study intended to fill this gap in the literature.

Consistent with prior research, we found significant moderate univariate correlations among our numeracy measures and gross (e.g., Lopes et al., 2013; Magistro et al., 2015; Waal, 2019), fine (Barrocas et al., 2020), and perceptual-motor skills (e.g., Oberer et al., 2018). As has been described, when assessed alone, all three motor skills are thus related to children's numeracy performance, however, our results provide additional information. By including measures of early symbolic numeracy precursor skills and gross, fine and perceptual-motor skills in two regression models we found that, for symbolic number comparison, both perceptual motor and precursor symbolic numeracy skills predicted performance while only the symbolic numeracy precursor skills predicted performance on the applied problems assessment while controlling for measures of inhibitory control and visual-spatial working memory. These findings are consistent with those of Nesbitt et al. (2019) who found a significant association between mathematics achievement, executive functions and visual motor-integration skills in kindergarten children. Similarly, Malone et al. (2022) found that only the domain-specific skills -but not fine motor skills- predicted arithmetic ability; in our study, the measure of applied problem solving involved very basic arithmetic problems and was only predicted by the precursor skills; while fine motor skills were not found to be a significant predictor of either applied problems or symbolic comparison skills.

It is interesting that perceptual-motor skills accounted for unique variance on symbolic number comparison over and above the symbolic precursor skills. It is possible that children's ability to visually identify and discriminate among the numbers is easier for those children who are more capable of copying them (Pieenar et al., 2013); children who can discriminate between written number symbols are also more likely to achieve the mappings among quantities, number-words and digits (Author et al., 2017). Thus, at this initial stage in their education, those children who are able to better copy the numbers may also benefit from more practice in associating the written number to the number word and the quantity therefore enhancing their ability to compare among two number words and among two digits. However, more research, specifically more comparative studies with samples of Latin American preschool aged children and intervention studies are necessary to better assess the effect of perceptual motor skills on early math.

There were two limitations to the present study. The first was that a cross sectional design was used. It is important to conduct longitudinal studies in order to better analyze the development of motor and math skills as they unfold together. Second, the sample size was relatively small and did not include a sample of children from private schools; thus, future studies should include samples from private and government funded schools as children from higher SES may be exposed to motor stimulation at home and thus may provide a broader picture of the relationship between motor and numeracy skills. However, despite the limitations, the study contributes novel evidence on the relation between Mexican preschool children's early math and motor skills.

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