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Investigation of Preschoolers' Mathematical Skills: A Systematic Literature Review

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Research Article

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Abstract

Background/purpose. Awareness of the mathematical skills and knowledge children possess in their early years is widely accepted. This includes various common positive aspects, not only for educators but also for researchers and policymakers. This study presents a systematic review conducted to meticulously identify empirical studies published in the Scopus-Index Journal database about the mathematical skills children aged 3 to 8 years old have mastered.

Materials/methods. This review followed the PRISMA guidelines and the research database comprised of Scopus-indexed journals. The technique followed used "keywords" and Boolean operators. The screening processes included reviewing abstracts, scanning complete texts of published articles, and rejecting those not meeting preset inclusion criteria. Moreover, systematic reviews, meta-analyses, and papers not written in English were also excluded. Of the 801 studies initially identified, a total of 15 empirical studies were included in the systematic review.

Results. Children master various math skills from a very young age, mainly in "numbers and operations", but face difficulties in skills related to "algebra" as well as "geometry and measurement". Additionally, several preschoolers' characteristics help to explain the acquisition of these skills, with "age" being the primary factor. Researchers use various research instruments and mainly conduct individual semi-structured interviews. Children's geometry skills and knowledge appear to have been studied to a small extent. The areas of "measurement" and "data analysis and probability" were found to be under active investigation.

Conclusion. It is worth noting that not only does a noticeable research gap exist for the math domains of "measurement," "geometry," and "data analysis and probability". Factors that seem to affect young children's math skills, such as "gender", "parents' educational level", and "attendance to a preparatory preschool" need further investigation. The implications of the current study's results extend beyond academia, providing valuable insights that educators and policymakers can leverage to enhance the quality of mathematics education during the early years period.

1. Introduction

In recent decades, preschoolers' mathematical achievements is a field that has attracted increasing research interest (Clements et al., 2008; Eleftheriadi et al., 2021; Lavidas et al., 2022; Wijns et al., 2019). Early mathematical abilities are considered indicators of forecasting not only children's future academic accomplishments (Aunola et al., 2004; Litkowski et al., 2020; Tsigilis et al., 2023; Zhang et al., 2017), but also their professional achievements (Nguyen et al., 2016; Seitz & Weinert, 2022; Vasilyeva et al., 2016). The key that makes mathematics so significant is that it is present in many domains of people's daily lives (National Council of Teachers of Mathematics [NCTM], 2000). Young children acquire math skills even from infancy (Eleftheriadi et al., 2021; MacDonald & Carmichael, 2018; Misirli et al., 2019; Reikeras et al., 2012), for instance, by distinguishing their mother from other strangers (Reikeras et al., 2012) or later by developing several basic mathematical ideas, including concepts that describe size (e.g., big, small) (Aunola et al., 2004). As a result, many toddlers have already developed informal math concepts even before they receive any formal education (Clarke et al., 2006).

Several children's demographic characteristics can explain early years acquisition of mathematical skills. Studies have mainly supported that the age of children (Dowker, 2008; Scalise et al., 2021; Vasilyeva et al., 2016), their gender (Nazaruk, 2020; Tsigilis et al., 2023; Wijns et al., 2019), their parents' educational level (Maricic & Stamatovic, 2018), their attendance to a preparatory school (Maricic & Stamatovic, 2018), and the country of their provenance (Kavkler et al., 2000; Seitz & Weinert, 2022; Vasilyeva et al., 2016; Xu & LeFevre, 2018) may influence the level of mathematical skills of preschoolers.

Although there are plenty of positive aspects of the awareness of mathematical skills children may possess in the early years, we did not find any systematic review in the current literature that presents the mathematical skills that preschoolers acquire in the various mathematical areas as well how various children's characteristics explain their acquisition of these mathematical skills. Instead, we found systematic reviews and meta-analyses on the association between executive functions (cognitive functions responsible for the regulation of human cognition and behavior) and the mathematical competences of young children (Emslander & Scherer, 2022; Zhong et al., 2022), the role of language on children's mathematical abilities (Turan & De Smedt, 2022), the correlation between number, line estimation, and the broader mathematical competence of children aged 4-14 years old, as well as a systematic review in early childhood education on the association of care quality with young children's outcomes (Von Suchodoletz et al., 2023). Additionally, we found a systematic review in which MacDonald and Murphy (2021) presented empirical studies about the mathematical education of children under 4 years of age.

The current study aims to address this gap in the literature though the systematic analysis of published empirical studies (ES) and presenting a picture of preschoolers' mathematical skills, corresponding factors that explain their skills, and the research instruments researchers employed in these ES. Through this systematic review, we aim to answer the following research questions:

(RQ1) What mathematical skills do children master in their early years?

(RQ2) What factors may explain the extent to which children master these mathematical skills?

(RQ3) What research instruments have been used to determine the mathematical skills of young children?

A systematic presentation of research into the mathematical knowledge and skills mastered by children between the ages of 3 and 8 years old, as well as the research instruments used in the literature is significant for various reasons. First, during their early years, children worldwide mostly attend preschool. The results of the current study aim to provide insight to academic researchers for future experimental and psychological studies, and to help in their selection of appropriate

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instruments to measure preschoolers' mathematics abilities (Litkowski et al., 2020). As a result, practices concerning mathematics education and knowledge will be promoted at the preschool level, as well as to national consultative councils and to other organizations (Nguyen et al., 2016). Additionally, teachers will be provided with multiple mathematical models that will not only support them to instruct more effectively in their classrooms, but also help them to create activities that promote the mathematical growth of their students (Eleftheriadi et al., 2021; Litkowski et al., 2020; Shiakalli et al., 2017).

2. Methodology

This review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2020). The research catalogue selected to find the published ES was the database of Scopus-indexed journals. We chose to conduct our research using only this database for various reasons. First, the Scopus database includes a wide range of literature from all over the world. Second, it comprises an extensive coverage of subject areas when compared to other databases (Vieira & Gomes, 2009). Third, not only are research papers subjected to a rigorous screening and evaluation process prior to publication, they are also constantly reassessed in order to ensure the quality of the data they present over time.

The procedure of searching for the ES was conducted during May 2023. To capture all research in this area, year of publication was decided not to be used in the search criteria. Following Cronin et al. (2008), the most common technique used to identify ES on academic databases is the use of "keywords," and thus should be chosen prudently. They also claimed that keywords should be chosen that specify terms that will produce the information sought, and alternative terms should also be used in order to provide a rich set of data. Therefore, it is suggested that a combination of keywords should be used along with Boolean operators ('AND', 'OR', and 'NOT'). In the current study, published articles were searched for on the Scopus-indexed database by using the string: *((math* OR numer* OR number*) AND (skill* OR Knowel* OR compet*) AND (early* OR kinder* OR prescho* OR toddler*) AND NOT (parent* OR disabil* OR second* OR risk*)).* As a result, a total of 801 research papers published between 1992 and 2023 were returned.

2.1. Screening Process

The screening process began with reviewing each paper's abstract in order to identify studies that appeared to meet the inclusion criteria and to reject those that met with the exclusion criteria (see Table 1).

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Empirical studies (ES)	Not ES (e.g., systematic reviews or meta-analyses)
ES mainly focused on math skills/abilities, as recommended by the National Teaching Council of Mathematics (2000)	ES that primarily investigated children's mathematical skills other than identified by NTCM (2000) or other skills in general.
ES with a sample of children aged 3 to 8 years old	ES with a sample of children outside of the age range 3 to 8 years old
ES with a sample of children with typical development	ES with a sample of children at risk or special needs
ES written in the English language	ES written in languages other than English

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Specifically, following the inclusion/exclusion criteria detailed in Table 1, we examined the collected papers to understand which mathematical skills, as guided by the NCTM (2000), young children have been shown to acquire with proficiency. Moreover, which factors were stated as likely to influence this developmental process, and which research instruments were employed to examine children's mathematical skills and knowledge was also checked. In the analysis of this data, we applied the process of "thematic analysis." In detail, we developed a coding scheme that included the dataset's primary ideas and themes under investigation. After applying the coding scheme to the collected data, we identified the relevant themes within each dataset entry. From this analysis, the identified themes were scrutinized, enabling interpretation of the diverse patterns and connections between the ES (Bryman, 2016).

From the 801 articles returned from the Scopus database, we excluded systematic reviews, meta-analyses, as well as papers not written in the English language. The search was also limited to subject areas such as social sciences, psychology, mathematics, computer science, the arts, humanities, and multidisciplinary research. From other subject areas were excluded 356 ES. Then, the abstract of each ES was screened so as to identify research that referred to mathematical skills or competencies specifically in children between the ages of 3 and 8 years old. This procedure resulted in 136 papers as potential candidates for inclusion in the systematic review (see Figure 1).

Next, guided by the first research question, we scanned the full text of these ES in order to examine whether or not their results revealed mathematical skills or competencies young children have mastered, based on the NCTM (2000) standards. As suggested by the NCTM, the largest international union for mathematical education and knowledge consists of various elements (standards), including *"numbers and operations," "algebra," "geometry," "measurement,"* and *"data analysis and probability*." Regarding young children's education, the thematic unit of "number and operations" concerns their ability to count correctly, knowledge of numbers and arithmetic, and understanding number systems and their structures (NCTM, 2000). Numeracy skills at very young ages involve, among other components, a growing awareness of the words used for numbers in civilization and the various ways in which they can be used in diverse situations (Eleftheriadi et al., 2023). Also included were knowledge of the cardinality principle (i.e., last number of a set points to the whole number of that set), ordinal place (i.e., one set is more significant than another) (Darnon & Fayol, 2022; Khan et al., 2021; Lavidas et al., 2022), as connections between a number and the quantity that it represents (NCTM, 2000). For "algebra," pertinent concepts refer to children's ability to create, recognize, and describe patterns as an understanding of relations (sorting, classification, and ordering of objects by size, number, or other properties) (NCTM, 2000). Pattern ability is one of the most common skills in the range of math concepts, while by the time youngsters learn to recognize and extend a pattern, they start to acquire problem-solving abilities (Leyva et al., 2021). "Geometry" refers to the ability to recognize and represent two- and three-dimensional shapes, plus the skill to decompose shapes to create new ones (Lavidas et al., 2022).

Other components concern knowledge of position and direction (NCTM, 2000). One widespread application of mathematics appears to be "measurement," which combines two mathematical areas: geometry and numerals. "Measurement" in prekindergarten through Grade 2 refers to a child's ability to understand the measurable features of objects, the methods used to take a measurement, and the application of suitable techniques and tools to determine measurements (NCTM, 2000). The area of "data analysis and probability" consists of posing questions that can be addressed by gathering, organizing, and collecting data (NCTM, 2000).

Concerning the current study's second research question, and taking into consideration that factors such as culture and family can play a fundamental role in the shaping and forming of children's growth, based on Vygotsky's (1962) ideas about "genetic development," specifically looked for

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possible preschoolers' characteristics that may explain the mathematical skills of children (Eleftheriadi et al., 2023; Graham et al., 1997).

Lastly, based on the third research question of this systematic review, we tried to identify which methodological instruments researchers had been employed to measure children's mathematical skills, as various researchers (Clements et al., 2008; Tsigilis et al., 2023) had mentioned there being limited instruments designed to measure the mathematical skills and competencies of young children. After completion of this procedure, a total of 15 eligible studies were selected for inclusion in the current review.

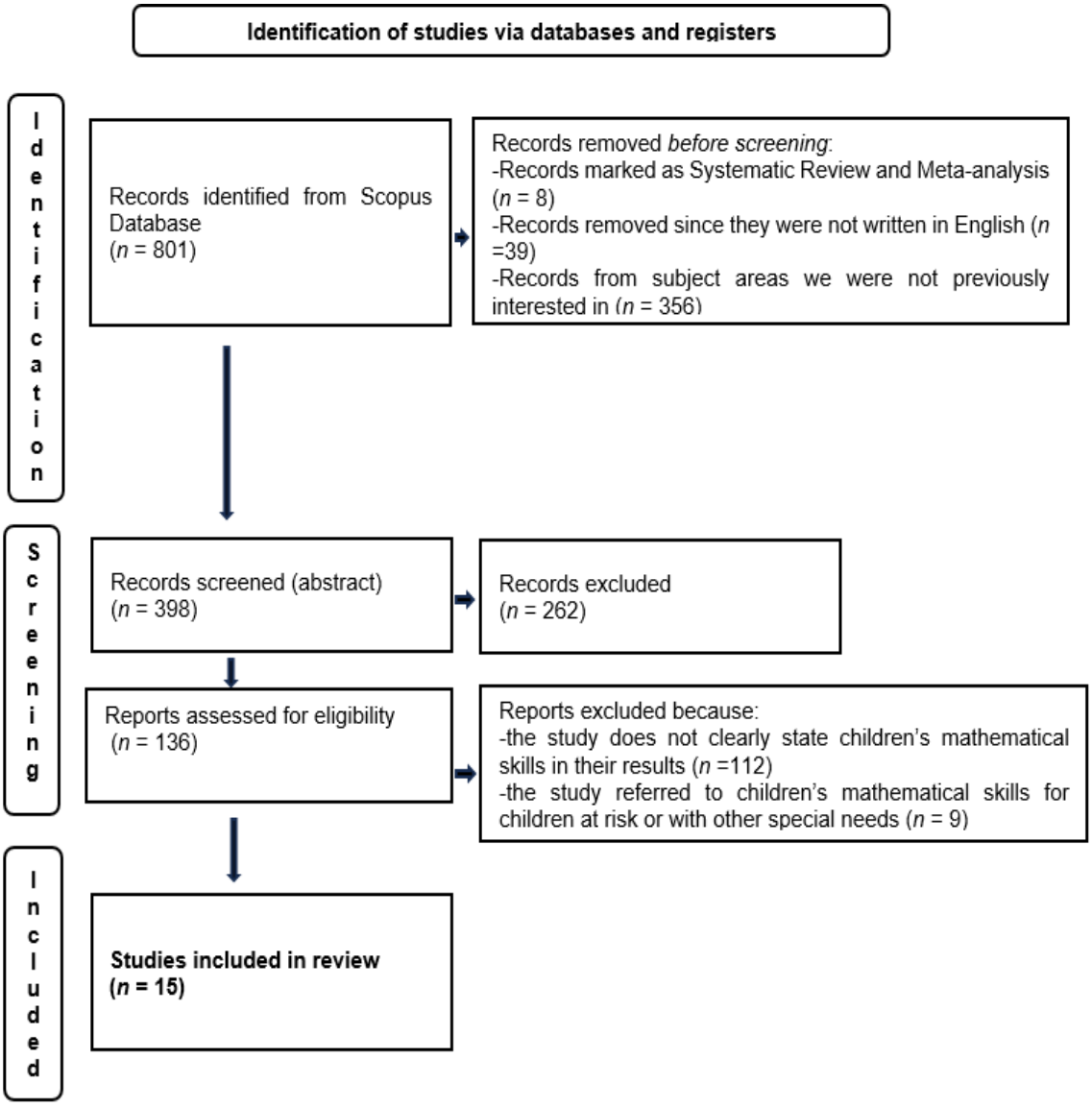

Figure 1. ES selection process according to PRISMA (Page et al., 2020)

3. Results

The selected 15 ES that met the inclusion criteria were published between 1993 and 2023 (see Appendix). Of these 15 studies, nine were conducted within the past 5 years, from 2018 to 2023, seven were conducted outside of Europe, with five conducted in the United States, one in Australia,

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and one in Russia. The remaining were conducted in Greece, Belgium, Slovenia, Serbia, the United Kingdom, and Poland.

3.1. Preschoolers' Mathematical Skills

Regarding our first research question, Table 2 presents the investigated preschoolers' mathematical skills in accordance with the NCTM (2000) proposed mathematics standards.

Table 2. Preschoolers' mathematical skills proposed by the NCTM (2000)

Math skills	Mastered (Yes/No)*	ES
Number and Operations		
Counting 1-4 or small sets	YES (*n* = 3)	3/15
Counting 1-10	Yes (*n* = 3), No (*n* = 1)	4/15
Counting to 100	Yes (*n* = 1), No (*n* = 1)	2/15
Number Identification	Yes (*n* = 6: one-digit numbers), No (*n* = 1: two-digit numbers)	7/15
Ordinal numbers	Yes (*n* = 4)	4/15
Cardinality	Yes (*n* = 6), No (*n* = 1)	7/15
Reverse counting	Yes (*n* = 1: at 5 yrs), No (*n* = 1)	2/15
One-to-one correspondence	Yes (*n* = 2)	2/15
Part-part-whole	Yes (*n* = 2)	2/15
Addition	Yes (*n* = 3), No (*n* = 4)	7/15
Subtraction	Yes (*n* = 2), No (*n* = 4)	6/15
Multiplication	No (*n* = 2)	2/15
Division	Yes (*n* = 1), No (*n* = 1)	2/15
More-less	Yes (*n* = 2), No (*n* = 1)	3/15
Algebra		
Recognize and explain a pattern	Yes (*n* = 1)	1/15
Continue a pattern	Yes (*n* = 3), No (*n* = 1)	4/15
Create a pattern	No (*n* = 2)	2/15
Sorting (by color)	Yes (*n* = 1)	1/15
Geometry		
Recognize (cube, sphere)	Yes (*n* = 1)	1/15
Recognize (cylinder, rectangular prism)	No (*n* = 1)	1/15
Name two-dimensional shapes	Yes (*n* = 2)	2/15
Name three-dimensional shapes (cube, sphere)	Yes (*n* = 1)	1/15
Name three-dimensional shapes (cylinder, rectangular prism)	No (*n* = 1)	1/15
Location	Yes (*n* = 1)	1/15
Measurement		

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Math skills	Mastered (Yes/No)*	ES
Compare and order objects	Yes (*n* = 1)	1/15

**n: number of ES where researchers concluded whether preschoolers had mastered (Yes or No) the corresponding skills.*

As can be seen from Table 2, the vast majority of the ES on children's mathematical skills concerned "numbers and operations" (Aubrey, 1993; Clarke et al., 2006; Dowker, 2008; Eleftheriadi et al., 2023; Klein et al., 1999; Litkowski et al., 2020; Scalise et al., 2021; Zippert et al., 2020), with only a few studies on other math domains such as "geometry" (Clarke et al., 2006; Klein et al., 1999; Maricic & Stamatovic, 2018) and "measurement" (Clarke et al., 2006). It is worth noting that no ES investigated the math domain of "data analysis and probability."

To be more specific, in terms of "number and operation," most researchers studied the "cardinality principle" (Aubrey, 1993; Clarke et al., 2006; Dowker, 2008; Eleftheriadi et al., 2023; Litkowski et al., 2020; Scalise et al., 2021; Zippert et al., 2020), with their results indicating that the majority of children already master this skill by the age of 4 years old. "Number Identification" was another widely investigated competence (Aubrey, 1993; Clarke et al., 2006; Eleftheriadi et al., 2023; Litkowski et al., 2020; Scalise et al., 2021; Tsigilis et al., 2023; Vasilyeva et al., 2016). Six of the studies demonstrated that youngsters can correctly identify one-digit numbers by age 4, with one study (Vasilyeva et al., 2018) claiming that children can identify some two-digit numbers by age 5. Additionally, two ES (Clarke et al., 2006; Vasilyeva et al., 2016) investigated the math competence of "part-part-whole" and, as their results demonstrated, young children can master this skill by the age of 5 years old.

With regards "counting," four out of the 15 ES (Aubrey, 1993; Dowker, 2008; Eleftheriadi et al., 2023; Tsigilis et al., 2023) investigated the ability of young children to count from one to 10. Whilst one study (Aubrey, 1993) indicated that children do not possess the ability to count correctly up to 10 by the age of 4 years old, three (Dowker, 2008; Eleftheriadi et al., 2023; Tsigilis et al., 2023) ES showed that children can count to 10 correctly by age 4. Some studies (Clarke et al., 2006; Klein et al., 1999; Litkowski et al., 2020) attempted to investigate if young children can count small sets of numbers, and all proved that children master this skill by the age of 3 years old.

Additionally, two studies (Litkowski et al., 2020; Zippert et al., 2020) explored the skill of counting to 100 by 3 years old. Whilst Litkowski et al. (2020) revealed negative outcomes, Zippert et al. (2020), on the other hand, demonstrated that 4-year-old children can count up to 100 correctly. Moreover, two (Aubrey, 1993; Eleftheriadi et al., 2023) out of the 15 papers examined the ability of 4-5-year-old kindergarteners on "reverse counting" from 10 to one. The results pointed out that children do not possess this ability by age 5 (Aubrey, 1993), though they may be able to do so after age 5 (Eleftheriadi et al., 2023).

Four of the 15 papers investigated the ability to understand the relative position of numbers (Aubrey, 1993; Clarke et al., 2006; Dowker, 2008; Klein et al., 1999), with each proving that by the age 4, young children can recognize the ordinal position of numbers. Moreover, three (Clarke et al., 2006; Eleftheriadi et al., 2023; Scalise et al., 2021) of the 15 papers investigated the ability of young children to understand relationships between quantities ("more-less"), whilst two (Clarke et al., 2006; Eleftheriadi et al., 2023) demonstrated that youngsters seemed able to recognize which set had the most objects. The "one-to-one correspondence" skill was studied in three (Clarke et al., 2006; Eleftheriadi et al., 2023; Litkowski et al., 2020) of the 15 papers. The results indicated that by the age of 3, toddlers can relate each counted object to a numeric word. Lastly, two studies (Clarke et al., 2006; Vasilyeva et al., 2016) examined the "part-part-whole" skill which refers to understanding and

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representing the most commonly used fractions. The research outcomes demonstrated that by the age of 5, young children may engage in operations related to fractions.

As far as the domain of "operations" is concerned, researchers have studied "addition," "subtraction," "multiplication," and "division." Specifically, seven of the 15 studies (Aubrey, 1993; Dowker, 2008; Eleftheriadi et al., 2023; Kavkler et al., 2000; Klein et al., 1999; Litkowski et al., 2020; Tsigilis et al., 2023) investigated children's ability on "addition" tasks and three of them claimed (Eleftheriadi et al., 2023; Klein et al., 1999; Tsigilis et al., 2023) that young children by the age of 4 can solve simple addition tasks. However, the results appear less successful for "subtraction" tasks, while four (Aubrey, 1993; Dowker, 2008; Kavkler et al., 2000; Litkowski et al., 2020) out of the six studies (Aubrey, 1993; Dowker, 2008; Eleftheriadi et al., 2023; Kavkler et al., 2000; Litkowski et al., 2020; Tsigilis et al., 2023) which investigated this skill revealed that children face difficulties on solving related tasks. Two ES (Aubrey, 1993; Eleftheriadi et al., 2023) investigated the ability of children aged 4-5 on simple "multiplication" tasks, and clarified that youngsters do not master this math competence at 4 years old. The results seem to be controversial for "division," with one study (Aubrey, 1993) indicating that young children cannot solve simple division tasks successfully by 4 years of age, whereas another study (Eleftheriadi et al., 2023) demonstrated that they can.

Regarding the "algebra" domain, five of the 15 ES (Aubrey, 1993; Clarke et al., 2006; Klein et al., 1999; Wijns et al., 2019; Zippert et al., 2020) investigated pattern-related skills. More specifically, four of these five papers (Aubrey, 1993; Clarke et al., 2006; Klein et al., 1999; Zippert et al., 2020) referred to young children's ability to continue a pattern, whilst three (Clarke et al., 2006; Klein et al., 1999; Zippert et al., 2020) indicated that kindergarteners were shown to have mastered this skill. Two of the 15 studies (Aubrey, 1993; Wijns et al., 2019) referred to the ability to create a pattern, but demonstrated that children aged 4-5 do not master this competence. The results were more successful for "recognition and explaining a pattern," with one paper (Clarke et al., 2006) indicating that 5-year-old children possess this skill. Lastly, the same paper (Clarke et al., 2006) referred to the ability to sort items by color, and indicated that children aged 5 can successfully sort items by certain characteristics.

Less research was found to have been conducted on "geometry" with only two ES (Klein et al., 1999; Nazaruk, 2020) having investigated the ability of children aged 4-7 to name simple geometric shapes, and kindergarteners correctly having named the shape of a circle, square, triangle, and rectangle by the age of 4. Another paper (Maricic & Stamatovic, 2018) attempted to study the extent to which 5-6-year-old youngsters can name three-dimensional shapes. The outcomes revealed that children could not name shapes such as cylinders and rectangular prisms, but could name a cube and a sphere. One paper (Clarke et al., 2006) additionally investigated the ability of young children to understand words that refer to "location" (for example, "beside," "behind," or "in front of"). The study's results indicated that youngsters have mastered this skill by the age of 5.

Similarly, in terms of "measurement," only one ES (Clarke et al., 2006) had been conducted in this domain. Specifically, this ES demonstrated that children under 5 mastered the skill to order objects according to their length.

3.2. Demographic Characteristics Explaining Preschoolers' Mathematical Skills

Regarding our second research question, the table shown in the Appendix presents details of seven of the 15 ES examined which investigated "age" as a factor. More specifically, the various researchers had attempted to identify whether or not age has an influence over children's math skill achievement. Five of those seven papers proved that age is a crucial variable that affects the proficiency of math knowledge and, more specifically, that older children's skills on "numbers and operations" tasks are better than for younger children (Dowker, 2008; Scalise et al., 2021; Vasilyeva et al., 2016, 2018). Likewise, "gender" appears to be another quite significant factor, with three out

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of four papers that studied this factor suggesting that gender differences existed in the success rate of mathematical skills at young ages. In detail, one paper claimed that female children performed better on pattern tasks (Wijns et al., 2019), while another claimed that male children achieved higher scores on arithmetic operations (Tsigilis et al., 2023).

Another survey revealed that female children can more effectively find and point out a circle, whereas male children are better at finding and pointing out a triangle or a square (Nazaruk, 2020). Maricic and Stamatovic (2018) investigated two more factors; "parents' educational level" and "attendance to a preparatory preschool." In terms of the former, results revealed that preschoolers with a university-educated father performed better on geometry tasks than children whose fathers were primary or secondary school graduates. Regarding the latter, results showed that math skills were unrelated to "attendance to a preparatory preschool." The factor of "country/immigrant" was investigated by two studies (Kavkler et al., 2000; Vasilyeva et al., 2016), and their results showed that this factor did not seem to affect children's math skills on the ground, with no observed significant differences among the countries of their samples.

3.3. Research Instruments

Regarding the third research question of the current systematic review, our results revealed that researchers had used various instruments to measure children's mathematical skills. In detail, we identified the following research instruments:

- Child Math Assessment (CMA). Klein et al. (1999) used CMA to measure young children's numbers, arithmetic knowledge, and spatial and geometry skills (Misirli et al., 2019).
- Raven's Colored Matrices (non-verbal intelligence test). Kavkler et al. (2000) utilized this instrument to measure youngsters' intelligence levels in solving simple addition and subtraction problems.
- British Ability Scales (BAS). Kavkler et al. (2000) used BAS to measure the ability of young children to perform written calculations in all arithmetic operations.
- First Year of School Mathematics. Clarke et al. (2006) used this approach to measure the ability of young children in counting, one correspondence, more-less, patterning, ordinal numbers, part-part-whole reasoning, the language of location, number recognition, and ordering objects by their length.
- Wechsler Preschool and Primary Scale of Intelligence (WPPS-IIII) Arithmetic subtest – (Third ed., Wechsler, 1989). Dowker (2008) used this instrument to measure children's abilities in basic arithmetic operations such as addition and subtraction.
- Miura's (1987) experimental task (as cited in Vasilyeva et al., 2018) measured young children's math knowledge of two-digit numbers.
- Research-based Early Mathematics Assessment (REMA) Short Form. Zippert et al. (2020) used REMA to measure children's math knowledge in counting and cardinality principles.
- Teacher-based Repeating Patterning Assessment. Zippert et al. (2020) used this instrument to measure youngsters' pattern skills.
- PENS-B (Preschool Early Numeracy Screener). Litkowski et al. (2020) and Tsigilis et al. (2023) utilized the PENS-B to measure young children's math skills in one-to-one correspondence, cardinality principle, counting, number identification, addition, and subtraction.

Through use of these instruments in their research, Dowker (2008), Litkowski et al. (2020), Tsigilis et al. (2023), Vasilyeva et al. (2018), and Zippert et al. (2020) conducted individual semi-structured interviews with children in their samples in order to measure youngsters' math skills (Katsidima et al., 2023; Pogiatzi et al., 2022). Clarke et al. (2006) also employed semi-structured interviews, and in contrast with the former researchers, the process was conducted by the children's teachers. Kavkler et al. (2000), Klein et al. (1999), Nazaruk (2020), and Vasilyeva et al. (2016) made use of the listed

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instruments, with children in their samples either completing math tasks individually (Vasilyeva et al., 2016) or in groups (Kavkler et al., 2000). In the remainder of the studies, the researchers used instruments that they specifically created based on the literature; for example, for math tasks or activities (Aubrey, 1993; Eleftheriadi et al., 2023; Maricic & Stamatovic, 2018; Scalise et al., 2021; Wijns et al., 2019), and/or on the national curriculum of their respective country (Aubrey, 1993; Eleftheriadi et al., 2023; Maricic & Stamatovic, 2018). Specifically, Aubrey (1993), Scalise et al. (2021), and Wijns et al. (2019) conducted individual semi-structured interviews with children in their sample, whilst Eleftheriadi et al. (2023) and Maricic and Stamatovic (2018) also conducted individual semi-structured interviews in which they examined children through verbal questioning.

4. Discussion and Conclusion

This systematic review involves 15 empirical studies that investigated the mathematical skills of children aged from 3 to 8 years old, published between 1993 and May 2023 in Scopus-Indexed journals. The findings demonstrate that preschoolers have a wide range of mathematical skills, which researchers investigated using multiple research instruments. The studies focused mainly on the domain of "numbers and operations," but less on "algebra," "geometry," and "measurement," and none were found that focused on "data analysis and probability."

The results for "numbers and operations" appear optimistic with children having mastered the related number and math skills by age 4. However, more research is needed on the capability of children to count larger sets (e.g., up to 100), as we only identified two ES. The "age" factor appears to be crucial and positively related to the acquisition of relative skills. For example, it was shown that as the age of students increase, so does their ability to count larger sets of items successfully. In the area of "operations," the results were less promising. More specifically, while preschoolers can perform successful operations related to addition, they experienced difficulties with both subtraction and multiplication skills. Regarding the ability of young children to successfully complete division tasks, the results were somewhat controversial, with the generalization of the results more difficult. The preceding results may be explained by the fact that some mathematical skills, such as verbal counting, are practiced more often in the preschool classroom than other math skills, such as number operations (Litkowski et al., 2020).

Regarding "algebra," the results indicate that young children face some difficulties in related math skills since they may or may not be able to continue patterns, and were shown to not be able to create patterns by themselves. More research should therefore be conducted on recognizing and explaining patterns and on young children's ability to sort items based on their characteristics, as only one ES was identified for each, hence we were unable to provide a conclusion. The math domains of "geometry" and "measurement" were found to be domains that also require further investigation. At the same time, we identified some ES about children's abilities to recognize and name shapes, with only one based on location abilities and measurement. This may be explained by preschool curricula for mathematics education being distributed differently for the development of geometry concepts (Maricic & Stamatovic, 2018). Although concepts about geometry are mainly abstract, the results of the current systematic review revealed that young children can recognize basic two-dimensional shapes (Klein et al., 1999; Nazaruk, 2020) and some three-dimensional shapes from the age of 5 years old (Maricic & Stamatovic, 2018).

With regards to the demographic characteristics that affect children's math performance, the results demonstrate that age is a primary factor in the extent to which a child will master a mathematical skill. This finding was clear from the results of this review, with most ES reporting that older children performed better than younger ones in most mathematical areas. At the preschool age, the development of inhibitory control and other cognitive skills (linked to memory and executive functions) proliferates (Anderson & Reidy, 2012; Vasilyeva et al., 2016). Moreover, this age-related

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enhancement can probably be explained by the different developmental characteristics and the level of "pre-operational thinking" of children in each age range (Nazaruk, 2020). However, we identified certain factors that seem to have been investigated less, such as "parents' educational level" and "attendance to a preparatory preschool" in only one ES (Maricic & Stamatovic, 2018). As their results showed, the former had an effect on the level of mathematical skills of youngsters, while the latter did not. It is therefore necessary that further investigation be conducted in order to draw generalizable conclusions. The gender of a child seems to be another significant but controversial factor, since the findings of the ES seem not to converge.

Lastly, regarding the current review's third research question, most investigators employed a variety of research instruments to measure children's mathematical skills from various domains of the NCTM (2000), with much fewer based on the existing literature and/or the respective national curricula.

Finally, although some studies about young children's mathematical education have been conducted, further systematic reviews of their mathematical skills and knowledge are still needed.

5. Implications and Limitations

First and foremost, the findings of the current systematic review centered on the mathematical skills and knowledge that children possess in their early years. Therefore, this review has the potential to contribute to the mathematics literature as well as being utilized as a guiding platform for researchers, policymakers, or even journal publishers in future investigations into young children's mathematical skills. Also, it may be used by teachers to design and conduct mathematical activities with specific targets adapted to the learning requirements and math skills of each age group.

This review study's findings underscore the necessity for further research in this domain. To be more specific, we found no other systematic review of young children's mathematical skills. In addition, more studies need to be conducted in the areas of "geometry," "measurement," and specifically in "data analysis-probability," since none were identified in this review.

Moreover, teachers play a pivotal role in providing preschoolers with various math opportunities (Lavidas et al., 2023; MacDonald & Murphy, 2021; Ozdemir & Kinik Topalsan, 2022; Wilkinson, 2024), and can therefore leverage children's strengths in certain mathematical areas so as to bolster skills in areas where challenges are known to exist. For example, in the "algebra" unit, teachers can help children to understand that just as numbers follow rules, so does the creation of patterns (Zippert et al., 2020).

Considering the age-related differences in children's math skills, we suggest preschool educators adopt an approach conducive to mixed-age classes. Educators may take advantage of the positive role of play in childhood and organize separate games with educational math content in two age groups. Individualizing teaching approaches for students and utilizing age-appropriate math materials are considered suitable means to addressing challenges in math skills specific to preschoolers (Eleftheriadi et al., 2023).

Regarding factors that affect children's mathematical knowledge, investigators in the future should systematically explore gender-related differences in math performance since the current literature provides controversial results in this area (Tsigilis et al., 2023).

In terms of the research instruments used in the examined studies, further valid and reliable research instruments should be established to measure children's mathematical skills identically and to ensure that results are comparable. Lastly, taking into consideration that the research instruments identified in this systematic review mainly measured children's mathematical skills from the domain

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of "number and operations" and "algebra," we recommend that new research instruments be developed that explore other math domains such as "geometry" and "measurement."

This systematic review has certain limitations. First and foremost, we only used the Scopus-Index Journal database to identify published empirical studies on the mathematical skills possessed by preschool-aged children. Future reviews could consider studies from other databases such as Web of Science. Secondly, there are some limitations in terms of the exclusion criteria applied in this review since only studies written in the English language were included. As such, there may be ES and other systematic reviews about preschoolers' mathematical skills published in other languages that could be included in future reviews.

Moreover, the current systematic review included ES published as of March 2023, and newer relevant research may now be published. Thirdly, most of the studies included in this review used American samples, with fewer in Europe or elsewhere. In order to achieve generalized findings, a figurative range of countries is needed. Finally, it should be noted that in the included empirical research, authors used similar but not the same research instruments to measure preschoolers' math skills.

Declarations

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Appendix

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
Aubrey (1993)	United Kingdom	4-5	Mathematical skills: counting, number identification, ordinal numbers, addition, subtraction, cardinality, multiplication, division, reverse counting, pattern.	Empirical study, individual interview, by researcher/ *N* = 16	Count 1-10: *n* = 5 Number identification: *n* = 12 Ordinal numbers: *n* = 11 Addition: *n* = 5 Subtraction: *n* = 8 Cardinality: *n* = 14 Multiplication: n/a Division: n/a Reverse counting: n/a

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
					Copy and continue pattern: *n* = 7 Repeat and continue pattern: *n* = 6 Create a pattern: n/a
Klein et al. (1999)	United States	4-5	Mathematical skills: counting, ordinal number, addition, subtraction, geometry (naming simple geometric shapes), pattern	Experiment (pretest, posttest, Child Math Assessment (CMA), by researcher/ *N* = 83	Counting small sets, ordinal numbers (1st, 2nd), addition and subtraction with equal sets, geometry, pattern (continuation) acquisition. Less success counting large sets, understanding ordinal number terms (3rd, 4th), and solving two-set addition/subtraction problems with unequal sets. Extending pattern and ordering a series of six objects: n/a
Kavkler et al. (2000)	Slovenia	6-8	Mathematical skills: Addition/subtraction Demographic factor: Country	Comparative study, Raven's Colored Matrices (non-verbal intelligence test), British Ability Scales (BAS) (normative measure of arithmetic attainment), individual testing, by researcher/ *N* = 80	Addition (problem): Slovene students 6yrs unable, 7yrs able English students, 6-7 yrs. Subtraction: Slovene students 6-7 yrs unable; English students 6yrs unable, 7yrs able Demographic factor: Country (not significant)
Clarke et al. (2006)	Australia	5	Mathematical skills: Sorting (by color), counting to 4, more-	Individual interview, First year school mathematics, teacher	Sorting (by color): 100% Count to 4: 99%

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
			less, cardinality, location, pattern, ordinal numbers, number identification, part-part-whole, numbers before/after, one-to-one correspondence, measurement (smallest to largest)	tested/ *N1* = 1,438, *N2* = 1,450	More-less: 99% Cardinal number: 98% Language of Location: 97% Recognize a pattern: 99% Continue Pattern: 87% Explain Pattern: 87% Ordinal number (3rd, 5th): 85%, Cardinality: number up to 5; high %, up to 9, 44% (accomplished well, larger sets (5, 9) not surprisingly were more difficult). Number identification: In general, larger numbers were more complex tasks Part-part-whole (number 6): 99% Numbers before/after: high % One-to-one correspondence: 99% Measurement (ordering): 94%
Dowker (2008)	United Kingdom	4	Mathematical skills: cardinal, counting, ordinal, addition, subtraction Demographic factor: Age	Individual testing, WPPS-IIII Arithmetic subtest (Wechsler, 1989), testing by an adult/ *N* = 80	Count to 10: 62% Cardinal: 70% Ordinal numbers: 60% Addition: 45% Subtraction: 31% Demographic factor: Age (significant)
Vasilyeva et al. (2016)	United States, Russia, Taiwan,	5-8	Mathematical skills: number identification, part-part-whole	Comparative study, Miura's (1987) experimental task,	Number identification: first-graders 99%, kindergartners 94%

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
	South Korea		Demographic factors: country, age	individual test, by researcher/ *N* = 598	Part-part-whole: first-graders 98%, kindergartners 82% Demographic factors: age (significant), country (not significant)
Maricic & Stamatovic (2018)	Serbia	5-6	Mathematical skills: Geometry Demographic factors: Gender, parents' education level, preparatory program	Individual interview (oral examination), by researcher/ *N* = 290	Recognize and name cube and sphere, high % Cylinder, 52.4% Rectangular prism, 16% Demographic factors: Parents education level (significant); gender and preparatory program (not significant)
Vasilyeva et al. (2018)	Russia	5-6	Mathematical skills: Knowledge of multi-digit numbers Demographic factor: Age	Raven's Colored Progressive Matrices, individual interview, by researcher/ *N* = 173	Many preschoolers could read/write multi-digit numbers Demographic factor: Age (significant)
Zippert et al. (2020)	United States	4-6	Mathematical skills: Counting, cardinality, pattern (continue, extend pattern) Demographic factor: Age	Research-based Early Mathematics Assessment (REMA) Short Form, Teacher-based Repeating Patterning Assessment (Rittle-Johnson et al., 2019), Wechsler Intelligence Scale for Children (Wechsler, 2003) and Corsi Block task, individual assessment, by researcher, (PathSpan program)/ *N* = 65	Count to 100, 75% Cardinality, 59% Pattern skills, high % Demographic factor: Age (not significant)
Wijns et al. (2019)	Belgium	4-5 (avg. 4)	Mathematical skills: Pattern Demographic factors: gender, age	Individual test, by students, by researchers/ *N* = 400	Create a pattern: 37% Demographic factors: Gender (significant, females made more

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
					patterns); Age (not significant)
Nazaruk (2020)	Poland	5-7	Mathematical skills: Geometry Demographic factors: gender, age	Individual interview, by teacher/ *N* = 176	[Recognize a] circle 69.87%, triangle 59.66%, square 84.25%, rectangle 89.64% Demographic factors: Gender: Females scored higher on finding and pointing to a circle/rectangle. Males scored higher on finding and pointing to a triangle/square. Age (significant)
Litkowski et al. (2020)	United States	3-5	Mathematical skills: Cardinality (how many and give *n*), one-to-one correspondence, counting, numeral identification, addition, subtraction	PENS-B (Numeracy measures, Purpura & Lonigan 2015), tasks completed individually, by researcher/ *N* = 801	Cardinality-How many (3): 3yrs 50.0%; 4yrs 80.6%; 5yrs 95.9% Cardinality-Give *n*: 3yrs 37.0%; 4yrs 68.7%; 5 yrs 87.4% One-to-one correspondence: 3yrs 72.2%; 4yrs 86.3%; 5yrs 95.9% Verbal counting: 3yrs 64.8% counted to 5, 0.0% counted to 100; 4yrs 85.0% counted to 5, 0.7% to 100; 5yrs 95.6% counted to 5, 7.1% to 100. Number identification: 3yrs 55.8% identified 1, 3.8% identified 15; 4yrs 80.3% identified 1, 26.5% identified 15; 5yrs 95.7% identified 1, 40.9% identified 15. Addition: 3yrs 40.4% (0+2), 5.8% (2+2); 4yrs 47.0% (0+2), 19.1% (2+2); 5yrs

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
					64.7% (0+2), 33.7% (2+2). Subtraction: 3yrs 30.8% (2-1), 9.6% (4-1); 4yrs 43.6% (2-1), 20.4% (4-1); 5yrs 56.9% (2-1), 35.3% (4-1).
Scalise et al. (2021)	United States	3-5	Mathematical skills: More-Less (compare sets of dots), counting to 25, cardinality, number identification 1-10, symbolic magnitude (compare numeral pairs from 1 to 9) Demographic factor: Age	Individual tests, by researcher/ *N* = 115	a) poor math abilities on all numerical measures (*n* = 13) b) moderate math abilities on all numerical measures (*n* = 35) c) strong counting and numeral skills but poor magnitude skills (*n* = 26) d) strong math abilities on all numerical measures (*n* = 41) 23% strong counting numerical skills but poor magnitude skills Demographic factor: age (significant)
Tsigilis et al. (2023)	Greece	4-6	Mathematical skills: Number identification, counting, addition, subtraction Demographic factor: Gender	PENS-B (Purpura et al., 2015), individual interview, by researcher/ *N* = 906	Number identification 91.3% Counting to 11 90.1% Addition 95.7% Subtraction 69.9% Demographic factor: Gender (preschool, no difference in numeracy skills, males outperformed females on arithmetic operations)

Reference	Country	Ages (years)	Research objectives/ Skills assessed	Search assessment instrument/ Sample size	Results (presentation of success)
Eleftheriadi et al. (2023)	Greece	4-5, 5-6	Mathematical skills: Counting, cardinality, reverse counting, number identification, comparison of quantities, more-less, addition, subtraction, division, multiplication	Semi-structured interview, by researcher/ *N* = 15	Count to 10: 4yrs, 6/6; 5yrs, 9/9 Cardinality: 4yrs, 4/6; 5yrs, 7/9 Reverse counting: 4yrs, 2/6; 5yrs, 9/9 Number identification: 4yrs, 3/6; 5yrs, 9/9 Comparison of quantities: 4yrs, 6/6; 5yrs, 9/9 More-less: 4yrs, 4/6; 5yrs, all Addition: 4yrs, 6/6; 5yrs, 9/9 Subtraction: 4yrs, 6/6, 5yrs, 9/9 Division: 4yrs, 5/6; 5yrs, 8/9 Multiplication: 4yrs, 0/6; 5yrs, 9/9

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