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REVIEW AND SYNTHESIS

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Individual characteristics associated with elementary school children's mathematical word problem-solving skills: A systematic review and meta-analysis

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Abstract
The aim of this systematic review and meta-analysis was to identify and evaluate the effects of individual characteristics associated with mathematical word problem-solving skills among elementary school-aged children and to unpack the quality of studies investigating these associations. The systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), and records were obtained through five electronic databases and citation searching. Study quality was assessed by using the National Heart, Lung, and Blood Institute (NIH) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. The meta-analysis (139 reports and 1480 effect sizes) showed that students' overall mathematics achievement ($r = 0.56$), specific components of mathematics (e.g., calculation; r's $= 0.41$ to 0.52), basic mathematical processes (e.g., number naming; r's $= 0.42$ to 0.54), general cognitive skills (e.g., listening comprehension; r's $= 0.30$ to 0.58), and maths-related affective factors (e.g., motivation; r's $= 0.22$ to 0.33) were associated with mathematical word problem-solving. By and large, these associations did not depend on study quality (e.g., concerning aims, participants, predictors and outcomes). However,

to ensure generalisable, replicable and reliable results in future studies, promoting the study quality related to participants, predictors and outcomes is warranted. These findings provide a comprehensive understanding of various individual characteristics related to mathematical word problem-solving and the quality of studies investigating such associations.

KEYWORDS

elementary school, mathematics, meta-analysis, word problem-solving

Context and implications

Rationale for this study: This study investigated the associations between individual characteristics and mathematical word problem-solving skills among elementary schoolers and the quality of studies investigating these associations.

Why the new findings matter: Mathematical word problem-solving is an important yet demanding skill for students in elementary school, highlighting the need to understand which individual characteristics relate to such skills.

Implications for research and practice: These findings provide a comprehensive understanding of various individual characteristics related to mathematical word problem-solving skills. Therefore, the findings inform future research investigating the mechanisms and unique relationships between important individual characteristics and mathematical word problem-solving skills. The findings also indicate largely overlooked individual characteristics that should be investigated. By indicating the study quality areas where improvements are warranted, the findings inform future research efforts in producing more generalisable, replicable and reliable results. Also, through the results, elementary school teachers may prominently recognise children who are likely to experience challenges in word problem-solving skills.

INTRODUCTION

Modern society increasingly demands that individuals have the ability to apply, combine and understand mathematical knowledge in many areas of life, making word problem-solving an important aspect of mathematical learning (Fuchs et al., 2015; Gravemeijer et al., 2017; Verschaffel et al., 2020). Mathematical word problems can be defined as verbal descriptions of problem situations, from which one or more questions are raised and to which answers can be found by applying mathematical operations to either numerical data presented or derived from the problem statement (e.g., 'Tina has seven toy cars and five toy buses. How many toy vehicles does Tina have altogether?'; Verschaffel et al., 2000, 2020). Thus, such problems differ from arithmetic tasks presented in simple numerical (e.g., 2 + 5 = ?) or verbal form (e.g., How much is two plus five?; Verschaffel et al., 2020).

To better understand and support the development of students' word problem-solving skills, we need to understand how students' individual characteristics (e.g., reading comprehension, calculation) relate to such skills (De Smedt, 2022; Gilmore, 2023; Lin, 2021). This is particularly important across the elementary school years when students are formally introduced to word problem-solving, and when individual differences in mathematics tend to widen considerably (Zhang et al., 2020). Systematic reviews and meta-analyses that summarise research on a given topic while also critically evaluating the quality of such studies provide valuable and necessary information for gaining credible knowledge on these associations (Cooper et al., 2019).

Prior meta-analyses have found multiple individual characteristics (e.g., reading comprehension, calculation) to be associated with mathematical word problem-solving skills (Lin, 2021; Lin, Peng, Zeng, et al., 2021; Peng et al., 2016, 2019, 2020; Spiegel et al., 2021; Ünal et al., 2023; Xie et al., 2020; Yang et al., 2022). However, various individual characteristics such as student motivation (e.g., expectancies) or basic numerical processes (e.g., number naming) have been largely overlooked. Also, an updated meta-analysis is warranted, considering the substantial increase in research in this area during the last few years and some methodological limitations that should be addressed to ensure reliable results (e.g., dependency of effect sizes; Lin, 2021; Park et al., 2023). Moreover, the robustness of systematic reviews and meta-analyses depends on the quality of the included primary studies (Valentine, 2019). Yet, study quality evaluation has been largely neglected or only narrowly investigated in previous meta-analyses (see Table S1). Therefore, this systematic review and meta-analysis aimed to identify and evaluate the effects of individual characteristics associated with mathematical word problem-solving skills among elementary school-aged children and to unpack the quality of studies investigating such associations.

Theoretical background: Mathematical cognition as a multi-level construct

Mathematics is not a unitary construct but rather comprises multiple levels such as mathematical word problem-solving, calculation and magnitude comparison skills that are associated with one another (De Smedt, 2022; Gilmore, 2023). In addition, domain-general individual characteristics (e.g., working memory, language skills) and affective factors are related to learning mathematics (Camacho-Morles et al., 2021; Costa & Fleith, 2019; Peng et al., 2016). Moreover, associations between these individual characteristics and mathematics may depend on the investigated mathematical knowledge (Peng et al., 2019; Sowinski et al., 2015; Xie et al., 2020).

For untangling the relationships between mathematical cognition and specific individual characteristics (e.g., spatial ability or executive functions), various frameworks have been outlined (e.g., Cragg et al., 2017; Geary, 2004; Hawes & Ansari, 2020; LeFevre et al., 2010; Wong, 2021). Recently, Gilmore (2023) suggested a multi-level framework of mathematical cognition to understand the range of mechanisms and processes involved in learning mathematics in a broad sense. The framework distinguishes between three levels of mathematical cognition: overall mathematics achievement, proficiency in specific components of mathematics and basic mathematical processes. Overall mathematical achievement rises from proficiency in specific components of mathematics, which in turn utilise basic mathematical processes (Gilmore, 2023). Additionally, general cognitive skills are linked with each level of mathematical cognition independently (Gilmore, 2023). In this study, we focus on the specific component of mathematical word problem-solving skills and the links between such skills and other specific components of mathematics, overall achievement, basic mathematical processes and general cognitive skills. As mathematics-related affective factors (i.e., motivation and emotions) are known to play an important role in learning (Camacho-Morles et al., 2021; Costa & Fleith, 2019), such factors were also included in the investigation.

Overall mathematics achievement and mathematical word problem-solving

Overall mathematics achievement can be considered as individuals' overall attainments in the domain of mathematics (Gilmore, 2023). Such is typically assessed with measures combining a variety of mathematical areas and notations (Gilmore, 2023). Given that broad measures of mathematics comprise separable sub-components of mathematics (specific components of mathematics, e.g., calculation, word problem solving), such components are likely associated with the overall mathematics achievement. Furthermore, proficiency in mathematical word problem-solving requires proficiency in applying and combining a variety of mathematical knowledge and skills (Daroczy et al., 2015). Therefore, it is rational to expect a strong link between mathematical word problem-solving and broad mathematics achievement.

Proficiency in mathematical word problem-solving and other specific components of mathematics

Solving mathematical word problems usually requires an understanding of, for instance, arithmetic operations, geometry or algebra, depending on the content of different word problems (Dowker, 2014; Kintsch & Greeno, 1985). Consequently, previous meta-analyses have demonstrated a moderate to strong relationship between calculation and arithmetic fact retrieval and mathematical word problem-solving (see Table S1; Lin, 2021). However, other specific components of mathematics have been overlooked in prior meta-analyses.

Basic mathematical processes and mathematical word problem-solving

Basic mathematical processes such as the ability to recognise and name numbers (number naming), compare numerical magnitudes (magnitude comparison and number line estimation) or understand numerical values depending on their place (place-value) are considered as foundational for learning and performing mathematical word problem-solving (De Smedt, 2022; Gilmore, 2023; Ünal et al., 2024). Consequently, one dimension of basic mathematical processes, number line estimation, has been shown to have a moderate relationship with mathematical word problem-solving across age groups (Ünal et al., 2024). Such understanding of numerical magnitudes may contribute to solving a word problem by, for instance, prompting a more efficient solving strategy by starting necessary calculations from the large number (i.e., $7+2$ instead of $2+7$). Also, difficulties in number naming have been found to predict difficulties in calculation abilities, highlighting the underlying role of number-naming skills on more advanced mathematical performance (Moeller et al., 2011). Moreover, considering the emphasis that number naming and mathematical word problem-solving place on language skills, these skills may be highly related to one another (Imbo et al., 2014). Still, none of the previous meta-analyses have investigated the relationship between basic mathematical processes (despite number line estimation; Ünal et al., 2024) with mathematical word problem-solving.

General cognitive skills and mathematical word problem-solving

Considering the nature of solving a mathematical word problem, a variety of domain-general cognitive skills are likely related to one's ability to solve a word problem. Given that word problems are presented within a text or stated verbally, several reading- and language-related skills play a vital role in understanding the problem (Boonen et al., 2016; Kintsch & Greeno, 1985). Especially, understanding the text (reading comprehension) or verbal language (language comprehension) is suggested to be strongly related to performance in mathematical word problems (Kintsch & Greeno, 1985). However, as being fluent in skills that underlie reading and language comprehension (i.e., reading accuracy and fluency, vocabulary, phonological processing) form the basis for understanding language-based information, such skills are also likely related to word problem-solving performance (Boonen et al., 2016; Fuchs & Fuchs, 2005; Ünal et al., 2023).

Functions of memory (i.e., short-term memory and working memory), the speed of processing and aspects of self-regulation (i.e., executive functions and attention) are also important areas for solving a mathematical word problem (Barnes & Raghubar, 2014; McClelland & Cameron, 2011). For example, when devising a plan for solving a problem or while carrying out mathematical operations, short-term memory allows one to store information and working memory provides a sketchpad for outlining the solution or performing mathematical operations (Coolen & Castronovo, 2023). Additionally, attention allows direction of the information processing towards the most relevant parts of the task, while executive functioning assists in the solving process by allowing to inhibit the distraction of irrelevant information sometimes included in a word problem or switching between operations and multiple solution steps (Awh et al., 2006; Barnes & Raghubar, 2014; Bull & Lee, 2014). Also, considering the demands that solving mathematical word problems places on cognitive capacity, the process is likely to benefit from the ability to retrieve and process information quickly (processing speed) by releasing cognitive capacity for other functions (Fuchs, Fuchs et al., 2008).

Successful solving of a mathematical word problem requires building a model of the problem situation (Boonen et al., 2016; Kintsch & Greeno, 1985). In building this model, the solver infers information needed for solving the problem that is not included in the text, making reasoning and spatial ability an integral part of the process (Boonen et al., 2016; Kintsch & Greeno, 1985). While building such a model, reasoning abilities assist in deducing relationships inside the presented problem whereas spatial abilities support the processing of visual information such as visualising numbers, solutions processes or problem situations (Hawes & Ansari, 2020; Hegarty & Kozhevnikov, 1999; Peng et al., 2019).

In line with the theoretical underpinnings, several general cognitive skills have been shown to be related to mathematical word problem-solving among children and adults (see Table S1; Lin, Peng, Zeng, et al., 2021; Peng et al., 2016, 2019, 2020, Spiegel et al., 2020; Ünal et al., 2023; Xie et al., 2020; Yang et al., 2022). Despite these efforts, the relations with some general cognitive skills (e.g., short-term memory and general vocabulary) with mathematical word problem-solving skills remain uninvestigated in a meta-analytical context.

Maths-related affective factors and mathematical word problem-solving

Affective factors such as student motivation (i.e., expectancies and values) and emotions (e.g., maths anxiety) play an important role in learning (Camacho-Morles et al., 2021; Costa & Fleith, 2019). According to prominent theories of motivation (e.g., situated expectancy-value-theory), students' performance is affected by both their expectancies of success and by the values they hold related to the specific task (Eccles & Wigfield, 2020, 2023; Wigfield & Cambria, 2010). Thus, problem solvers who believe in their competence to complete the task (e.g., high expectancy beliefs, self-concept or self-efficacy), enjoy solving mathematical tasks (e.g., high intrinsic value or interest) or place high importance on performing well in the task (high attainment value; Eccles & Wigfield, 2020, 2023). Though both expectancies and values are important aspects of learning-related activities, expectancies have been displayed to play a more central role in achievement while values are more central for students' persistence, choice and effort in doing a task (Guo et al., 2015; Trautwein et al., 2012).

During the past decade, more interest has been raised in how emotions relate to mathematical learning (Hanin & Van Nieuwenhoven, 2019). More specifically, according to the control-value theory of achievement emotions, experiencing emotions related to an activity or the outcomes of an activity affects students' motivation, concentration and the learning strategies they select (Pekrun et al., 2007; Pekrun & Stephens, 2010). Therefore, emotions may either hinder or promote learning (Pekrun et al., 2007; Pekrun & Stephens, 2010). Previous work on mathematics-related emotions has mainly focused on maths-related anxiety. Though the mechanisms between maths anxiety and mathematics performance are still under debate, higher maths anxiety is related to poorer performance in mathematics (Namkung et al., 2019). This relationship is thought to result from the hampering role that experiencing feelings of tension, fear and negative affect towards mathematics may have on a student's concentration, perseverance and functions of memory while solving mathematical tasks (Passolunghi et al., 2019; Wigfield & Meece, 1988).

Mathematical word problem-solving is viewed as a more complex process requiring more cognitive effort and persistence than, for example, calculations. Therefore, affective factors are considered to play a particularly important role in sustaining attention and completing such tasks (Muis et al., 2015; Zhang et al., 2019). However, affective characteristics (despite maths anxiety) have been overlooked in previous meta-analyses investigating mathematical word problem-solving as the outcome.

Present study

Considering that mathematics is not a unitary construct and that mathematical word problem-solving skills are crucial in today's world, understanding the broad set of individual characteristics related to such skills contributes to understanding the development and supporting of such skills (De Smedt, 2022; Gilmore, 2023; Gravemeijer et al., 2017). Individual differences in mathematics are known to only widen during elementary school and the associations between individual characteristics and mathematical word problem-solving may differ depending on children's age (Spiegel et al., 2021; Zhang et al., 2019; Zhang et al., 2020). Therefore, understanding individual characteristics associated with mathematical word problem-solving among elementary schoolers is of special importance, as students are generally formally introduced to and practise such skills in this educational period. To gain this understanding, systematic reviews and meta-analyses that also critically evaluate the quality of studies provide valuable information on such associations (Cooper et al., 2019).

Though previous meta-analyses have revealed that several individual characteristics are related to mathematical word problem-solving (e.g., Lin, 2021; Peng et al., 2016; Yang et al., 2021), we aim to address three research gaps. First, we investigate a comprehensive set of individual characteristics, as various characteristics (e.g., motivation and basic mathematical processes) have been largely overlooked in prior meta-analyses (see Table S1). Second, we provide an updated meta-analysis with robust variance estimation (RVE) methods (e.g., accounting for the dependency of effect sizes), given the substantial increase in research in this area during the last few years and some methodological limitations in previous meta-analyses (Lin, 2021; Park et al., 2023). The robustness of systematic reviews and meta-analyses is always dependent on the included primary studies (Valentine, 2019). Therefore, it is crucial to evaluate the impact and promote the quality of primary studies. Still, study quality evaluation has been largely neglected or narrowly investigated in previous meta-analyses (see Table S1). Therefore, we evaluate each included study's quality and the impact of such aspects on the association. Thus, the aim of this systematic review and meta-analysis was to identify and evaluate the effects of individual characteristics associated with mathematical word problem-solving skills among elementary school-aged children and to unpack the quality of studies investigating such associations. We focused on the following research questions:

1. What are the effects of individual characteristics on elementary school children's mathematical word problem-solving skills?
2. To what extent do the effects of individual characteristics on mathematical word problem-solving skills differ in terms of study quality?

MATERIALS AND METHODS

Literature search

The protocol of the current systematic review was pre-registered in the Open Science Framework (OSF) registry (https://osf.io/2wvfa).

The systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Page et al., 2021). Figure 1 summarises the flow of the literature search. The initial literature search was conducted in October 2022. In addition, an updated search was conducted in October 2023. Both searches followed the same protocol. Five electronic databases—Scopus, Web of Science, ERIC, PsycINFO and Academic Search Complete—were searched using the same search string (Table 1). For forming the search string, the Population, Exposure and Outcome (PEO) framework was employed (Moola et al., 2015). As the intention was to search for all studies investigating individual characteristics related to mathematical word problem-solving, exposures were not limited in the search terms. Electronic database searches were directed to abstracts and titles (in Scopus and Web of Science) or to abstracts only (in ERIC, PsycINFO and Academic

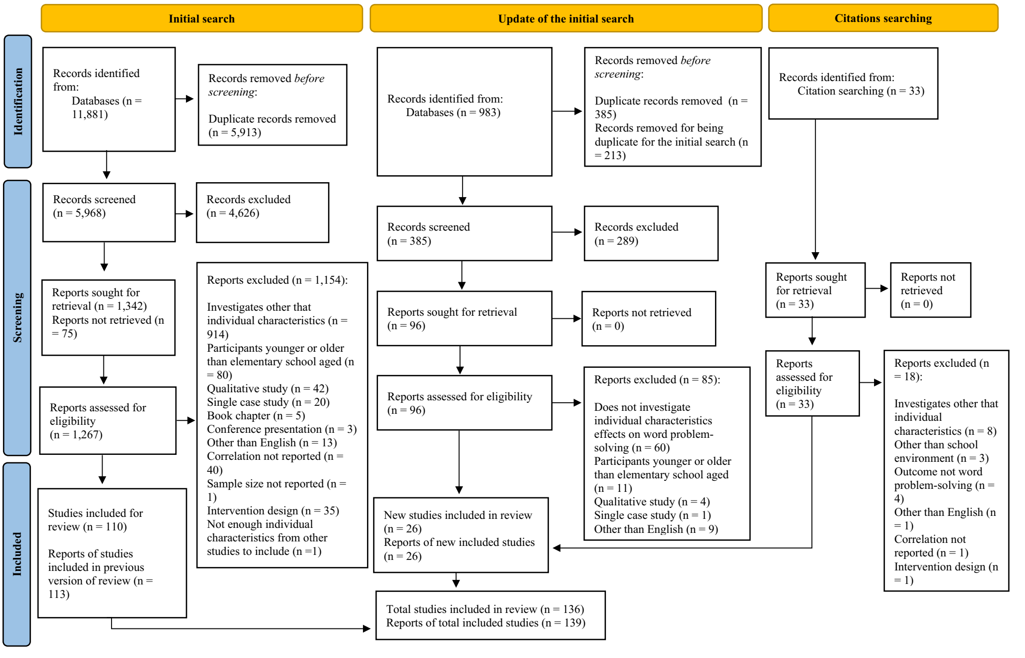

FIGURE 1 PRISMA flow chart for the systematic review.

TABLE 1 Search string used in all databases.

Population, exposure, outcome (PEO)	Search string
Population	"elementary school*" OR "elementary education" OR "elementary student*" OR "primary school*" OR "primary education" OR "primary student*" OR "middle school*" OR "junior school*" OR "junior high" OR "intermediate grade*" OR "intermediate school*" OR "grade 1" OR "grade 2" OR "grade 3" OR "grade 4" OR "grade 5" OR "grade 6" OR "grade one" OR "grade two" OR "grade three" OR "grade four" OR "grade five" OR "grade six" OR "1st grade*" OR "2nd grade*" OR "3rd grade*" OR "4th grade*" OR "5th grade*" OR "6th grade*" OR "first grade*" OR "second grade*" OR "third grade*" OR "fourth grade*" OR "fifth grade*" OR "sixth grade*" OR "year 1" OR "year 2" OR "year 3" OR "year 4" OR "year 5" OR "year 6" OR "year one" OR "year two" OR "year three" OR "year four" OR "year five" OR "year six" OR "primary 1" OR "primary 2" OR "primary 3" OR "primary 4" OR "primary 5" OR "primary 6" OR "primary one" OR "primary two" OR "primary three" OR "primary four" OR "primary five" OR "primary six"
Exposure	-
Outcome	"word problem*" OR "story problem*" OR "problem-solving"

Search Complete) depending on the features of the database. The searches were limited to peer-reviewed journal articles published in English. The year of publication was not limited. In addition, hand searching was conducted for the reference lists of the included studies and previously published meta-analyses in Table S1.

After attaining the records from the database searches, duplicates were removed. All records underwent screening in two phases, abstract and full-text phase. In both phases, two independent reviewers evaluated 50% of the records against the eligibility criteria after which inter-rater agreement was calculated. The eligibility criteria for the current systematic review consisted of six criteria. The included studies had to (1) investigate the effects of one or more individual (or contextual characteristics, Vessonen et al., 2024) on (2) mathematical word problem-solving (e.g., self-perception of problem-solving abilities or problem-solving strategies excluded) in a school environment, (3) among elementary school-aged (i.e., in first to sixth grades) children (other grade levels excluded if data not reported separately). In addition, the studies had to be (4) empirical quantitative studies (e.g., qualitative and single-case studies excluded), and (5) published in peer-reviewed journals in English (unpublished and non-peer-reviewed studies and studies reported in other than English language excluded). Additionally, for the current meta-analysis, we decided on the sixth eligibility criteria to summarise the individual characteristics associated with mathematical word problem-solving skills. Thus, studies (6) had to report at least one bivariate correlation (r) between an individual characteristic and mathematical word problem-solving and study sample size. Reports that were focused on intervention outcomes but reported correlations between individual characteristics and word problem-solving were excluded. This was done as evaluating the study quality of included reports was a major aspect of the present study and as including intervention reports would have resulted in using different design quality assessment tools. As quality assessment tools for different designs vary quite extensively, applying various tools would have compromised the interpretability of the findings. However, observational studies employing a sample consisting of intervention and control group participants were included (e.g., Fitzpatrick et al., 2020; Fuchs, Fuchs, et al., 2008; Jitendra et al., 2014). As indicated by the pre-registration, preliminarily we intended to include only studies with participants within the age range of 7 to 12, which is equal to the Finnish elementary school age range. However, many researchers had only reported the participants' grade level, making it difficult to deduce the age of these children. Thus, we included participants reported as being in first to sixth grades.

In the abstract phase, records were screened based on titles and abstracts and rated in terms of inclusion as 'yes', 'maybe' or 'no'. Inter-rater agreement between the reviewers after reviewing 50% of the abstracts (initial search: $n=2984$; update: $n=179$) was considered good (initial search $\kappa=0.85$; update: $\kappa=0.71$) and thus the first author completed the abstract screening. In the full-text screening phase, all studies rated as 'yes' or 'maybe' in the abstract screening underwent full-text screening. If full-texts could not be accessed through the universities of the authors, the authors of the article were contacted through ResearchGate or email (if an email address could be found). Both reviewers rated half of the full-texts against the eligibility criteria in terms of inclusion as 'include', 'maybe' or 'exclude', after which inter-rated agreement was calculated. After reviewing 50% of the full-texts (initial search: $n=634$; update: $n=48$), inter-rater agreement was considered good (initial search: $\kappa=0.86$; update: $\kappa=0.74$). Consequently, the first author completed the full-text screening. In both screening phases, all discrepancies between the reviewers and ambiguities were solved in a consensus meeting including all authors.

Coding procedure

The first author extracted the following information from the included studies for each effect size on an Excel sheet: (1) study information including authors, year of publication and title; (2) participant group information including sample size, participant's grade level and age; (3) individual characteristic being measured; (4) outcome measure including the name of the measure; and finally (5) the reported bivariate correlation. Correlations that were reported as reverse (e.g., attention or executive functions) were multiplied by −1.

After coding the studies, individual characteristics were categorised based on the measurement information of each report (for a detailed description of the categories see Table S2). A cutoff of five studies per individual characteristic was used so that each category would have enough data independent from one another (Fisher & Tipton, 2015). This resulted in removing of effect sizes that did not fit into other individual characteristics categories and were from less than five studies (e.g., epistemic emotions [Di Leo et al., 2019]; computational estimation [Desli & Lioliou, 2020]; telling time [Andersson, 2008]; geometry [Tam & Chan, 2022]). As some studies contained measures combining a range of language-related items, these measures were categorised into a broad language and reading category. Our preliminary plan was to examine moderators (e.g., study design, children's age and difficulty status) for each individual characteristic. Due to the low number of studies in multiple individual characteristics categories and therefore the high potential of overfitting, such analyses are not reported (Fisher & Tipton, 2015; Geissbühler et al., 2021).

Study quality evaluation

Most observational study quality assessment tools are intended for health sciences, and thus involve questions that cannot be conclusively answered in educational sciences (e.g., 'Was a pre-specified or standard outcome definition used?'; Wolff et al., 2019). In the current investigation, study quality was assessed by using the National Heart, Lung, and Blood Institute (NIH) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Heart, Lung, and Blood Institute, 2013) which has been used in a previous meta-analysis with a similar aim (Spiegel et al., 2021). Such a tool also captures various dimensions of study quality (National Heart, Lung, and Blood Institute, 2013; Valentine, 2019).

The original tool has 14 items (Table 2). Each item is rated as 'Yes', 'No', 'Not applicable', or 'Not reported'. As the current meta-analysis is based on the descriptive information (i.e., correlations) derived from each study, item 14 addressing whether potential confounding variables were measured and adjusted in the analyses, was disregarded. Thus, each study was assessed with 13 items (Table 2). In addition to the detailed instructions for evaluating each question by the NIH (National Heart, Lung, and Blood Institute, 2013), we made further small clarifications (see Table 2). The first and second authors independently assessed the study quality of each report and discussed any discrepancies between ratings to reach a consensus.

Though the original tool does not categorise questions into sub-domains, for our results to be more informative and interpretable, we categorised questions into four domains based on another study quality assessment tool, Prediction Model Risk of Bias Assessment Tool (PROBAST; Wolff et al., 2019). Therefore, we fitted NIH quality assessment tool questions into the domains of participants, predictors, outcome and analysis, to gain a more detailed understanding of the study quality (Table 2). We also created an additional domain of aims, to capture the first question of the NIH tool.

After rating each study, ratings were coded numerically. 'Yes' was coded as 1, whereas 'no' and 'not reported' were coded as 0, as these answers may indicate a potential bias (Maass et al., 2015). 'Not applicable' was left blank in each item. Then, the mean quality rating of each sub-domain (i.e., aims, participants, predictors and outcome) was calculated by dividing each sum by the number of items that could be rated (Maass et al., 2015). In this regard, 'not applicable' ratings would not contribute negatively to study quality rating as instructed by NIH (e.g., in item 13, cross-sectional studies were rated as 'not applicable' as a follow-up rate would not be possible to rate).

Data analysis

Pearson correlation coefficients were used as the effect size of the current meta-analysis. Pearson correlation coefficients were transformed into Fisher's *z* scale and sample size into its variance as the variance of a correlation coefficient depends largely on the correlation itself (Borenstein et al., 2009). After conducting the meta-analyses with the transformed values, the effects and their confidence intervals were converted back to Pearson correlations for presentation. As the effects of individual characteristics are assumed to vary across studies due to other factors than only sampling error, a random-effects model was applied in all analyses (Borenstein et al., 2009).

Traditional meta-analysis assumes that effect sizes are independent of one another, which raises dependency issues if studies contribute multiple correlations for the same sample. If a study reported multiple correlations for the same sample, it was accounted for by using the RVE method in the 'robumeta' package in R (Fisher & Tipton, 2015). Employing this method, standard errors are adjusted to account for the correlations between different effect sizes. This method requires that the mean correlation (ρ) between all the effect sizes within a specific sample is estimated for calculating the between-study sampling variance estimate, τ^2. We estimated τ^2 with $\rho = 0.80$ in all analyses as this is the commonly accepted default value (Fisher & Tipton, 2015). A sensitivity analysis was conducted to ensure that the τ^2, average effects and their standard errors for each individual characteristic remain similar across different ρ values (Fisher & Tipton, 2015). Such sensitivity analysis revealed that the effects were robust over the range of different ρ estimates. Also, small sample correction was applied as many of the individual characteristics were measured in fewer than 30 studies (Park et al., 2023).

First, weighted summary effect size, confidence interval, and between-study sampling variance (τ^2) were calculated for each individual characteristic. As a rule of thumb,

TABLE 2 Study quality assessment domains, questions and elaborations by the authors.

Domain	Question by NIH	Clarification by authors
Aims	1. Was the research question or objective in this paper clearly stated?	If clear hypothesis but no research questions = Yes; if aim but no clear research questions = No
Participants	2. Was the study population clearly specified and defined?	
	3. Was the participation rate of eligible persons at least 50%?	Eligible persons are, for instance, children in the school where recruiting took place
	4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	
	5. Was a sample size justification, power description, or variance and effect estimates provided?	If sample size justification or power description = Yes
	13. Was loss to follow-up after baseline 20% or less?	If cross-sectional = NA
Predictors	6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	Cross-sectional studies = No (Instructed by NIH)
	7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	Cross-sectional studies = No (Instructed by NIH) Longitudinal studies sufficient time frame 6 months.
	8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	Continuous variables = NA
	9. Were the exposure measures (independent variables) clearly defined, valid, reliable and implemented consistently across all study participants?	All criteria (clearly defined, valid, reliable and implemented consistently) have to be met for 'Yes'.
	10. Was the exposure(s) assessed more than once over time?	
Outcome	11. Were the outcome measures (dependent variables) clearly defined, valid, reliable and implemented consistently across all study participants? 12. Were the outcome assessors blinded to the exposure status of participants?	All criteria (clearly defined, valid, reliable and implemented consistently) have to be met for 'Yes'. Validity may be reported elsewhere, reliability (e.g., Cronbach's alpha) has to be for the sample in question.

correlations can be interpreted as weak ($r = 0.10$), moderate ($r = 0.30$) and strong ($r = 0.50$; Cohen, 1977). Then, we performed Egger's test of publication bias for each individual characteristic to detect asymmetry in the funnel plot. A statistically significant p-value in Egger's test indicates that publication bias may exist in the data. Related to our second research question, we examined whether the associations between individual characteristics and mathematical word problem-solving are moderated by the study quality dimension ratings while accounting for variance within individual characteristics categories. Therefore, we performed a multiple meta-regression analysis including study quality dimensions and the individual characteristics category as predictors.

RESULTS

Our database searches (i.e., initial and update search) yielded a total of 12,864 records from which 6353 remained after removing duplicates. After excluding 4915 records based on abstract screening, 1396 full-texts were evaluated. After full-text screening and citation searching the final sample included 139 reports including 136 independent studies. For the current meta-analysis, these studies provided 1480 effect sizes between individual characteristics and word problem-solving involving 38,264 elementary school-aged students. The included studies, sample sizes, grade levels, and the included individual characteristics are presented in Table 3.

RQ1: What are the effects of individual characteristics on elementary school children's mathematical word problem-solving skills?

The overall weighted effects between individual characteristics and mathematical word problem-solving are presented in Table 4. All investigated individual characteristics were statistically significantly related to mathematical word problem-solving ($r=0.22$ to 0.58). Overall mathematics achievement (i.e., broad maths) was strongly related to mathematical word problem-solving ($r=0.56$). The effects of proficiency with specific components of mathematics (i.e., calculation and arithmetic fact retrieval; $r=0.47$ to 0.52) and of basic mathematical processes (e.g., magnitude comparison; $r=0.42$ to 0.54) were moderate to strong. The effects of general cognitive skills were mostly moderate ($r=0.26$ to 0.58), though broad language and reading displayed a strong effect and executive function a weak effect. Affective factors showed moderate to weak effects ($r=0.22$ to 0.33). Our analysis of publication bias showed that such bias is unlikely in the majority of the individual characteristics (excluding arithmetic fact retrieval, spatial ability and magnitude comparison). Such bias may result from including only peer-reviewed publications to ensure a transparent and reproducible search procedure. However, it may also be caused by between-study heterogeneity—which is expected, given that we assume the effect sizes vary based on other than sampling error (Harrer et al., 2021; Peters et al., 2007). As correction methods for publication bias are not recommended when such heterogeneity exists, we did not apply such methods (Harrer et al., 2021; Peters et al., 2007).

RQ2: To what extent do the effects of individual characteristics on mathematical word problem-solving skills differ in terms of study quality?

The rating for each study quality dimension per study is presented in Table S3 in the supplementary material. When evaluating the means for each study quality dimension across the included reports, the highest mean was for aims ($M=0.77$, $SD=0.42$) whereas the lowest was for participants ($M=0.20$, $SD=0.19$). These suggest that aims and research questions were fairly well communicated whereas the reporting of recruiting and characteristics of the participants were scarce. However, the means for the predictors ($M=0.34$, $SD=0.28$) and

TABLE 3 Study characteristics of the studies included in the meta-analysis and correlations that were extracted from them.

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Agostino et al. (2010)	155	3 to 6						x	x			x			x		x								
Aksu (1997)	155	6			x																x				
Al-Kiyumi and Albeloushi (2021)	183	4																							x
Andersson (2008)	182	3 to 4		x	x			x			x	x									x				
Andersson (2010)	249	3 to 4		x	x																x				
Arán Filipetti & Richaud (2016)	118	NR			x			x				x					x	x	x	x	x				
Basol et al. (2012)	126	3													x										
Bell et al. (1977)	80	4	x															x							
Björn et al. (2016)	224	4			x									x	x										
Boonen et al. (2016)	80	6													x										
Boonen et al. (2013)[a]	128	6											x		x										
Boonen et al. (2014)[a]	128	6											x		x										
Cai et al. (2016)	80	2		x				x			x						x		x						
Cai, Viljaranta, et al. (2018)	80	2		x		x																		x	x
Cai, Zhang, et al. (2018)	107	2		x	x			x				x					x			x		x			
Cai et al. (2022)	102	2		x	x			x			x	x					x								

(Continues)

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Campos et al. (2013)	103	3						x				x					x		x						
Can (2020)	158	4													x		x								
Canivez (2000)	863	6											x				x								
Cankoy and Tut (2005)	1006	4			x												x				x				
Cargnelutti et al. (2017)	198	2	x	x																			x		
Cartwright et al. (2022)	521	3 to 5					x	x										x	x						
Chan and Kwan (2021)	139	3														x		x	x						
Ching (2017)	246	3			x									x			x		x	x			x		
Cho et al. (2020)	368	1	x														x	x		x					
Cowan and Powell (2014)	258	2		x	x		x			x	x	x					x		x	x		x			
Day and Connor (2017)	282	3		x		x		x						x	x			x	x						
De Corte et al. (1990)	20	2			x									x											
Di Leo et al. (2019)	138	5 to 6						x																x	x
Di Lonardo Burr et al. (2022)	94	1		x																					
Doz et al. (2023)	107	5																					x		
Engelhart (1932)	568	5			x									x			x								
Filiz et al. (2018)	308	5						x																	

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Fitzpatrick et al. (2020)	83	6					x										x								
Fuchs et al. (2006)	312	3		x		x			x	x	x					x	x	x	x						
Fuchs, Compton, et al. (2008)	122	3		x		x			x								x	x							
Fuchs, Fuchs, et al. (2008)	924	3		x		x	x				x			x			x	x	x						
Fuchs et al. (2010)	312	1		x	x	x			x		x	x					x		x	x		x			
Fuchs et al. (2012)	279	2		x		x	x			x	x						x		x						
Fuchs et al. (2015)	206	2		x			x		x		x					x	x	x	x						
Fuchs et al. (2016)	962	2		x	x	x			x		x						x		x			x			
Fuchs et al. (2018)	325	2		x											x	x	x	x	x						
Fung et al. (2014)	179	2 to 4		x			x										x								x
Fung and Swanson (2017)	413	3 to 4										x					x		x						
Garofalo (1986)	95	5			x			x				x					x		x		x				
Gilbert and Fuchs (2017)	328	2							x					x			x		x						
Goodrich and Namkung (2019)	72	1 to 2												x	x			x							
Hanin and Van Nieuwenhoven (2019)	354	5 to 6				x																		x	

(Continues)

TABLE 3 (Continued)

Report	N	Grade	Overall mathematics achievement: Broad math	Proficiency with specific components of mathematics: Arithmetic fact retrieval	Proficiency with specific components of mathematics: Calculation	General cognitive skills: Attention	General cognitive skills: Broad language and reading	General cognitive skills: Executive functions	General cognitive skills: Listening comprehension	General cognitive skills: Phonological processing	General cognitive skills: Processing speed	General cognitive skills: Short-term memory	General cognitive skills: Spatial ability	General cognitive skills: Reading accuracy	General cognitive skills: Reading comprehension	General cognitive skills: Reading fluency	General cognitive skills: Reasoning	General cognitive skills: Vocabulary	General cognitive skills: Working memory	Basic mathematical processes: Magnitude comparison	Basic mathematical processes: Number naming	Affective characteristics: Number line estimation	Affective characteristics: Math anxiety	Affective characteristics: Motivation: Expectancies	Affective characteristics: Motivation: Values
Harris et al. (2021)	124	4 to 6											x												
Hecht et al. (2003)	105	5	x		x	x								x					x						
Hecht and Vagi (2010)[b]	181	4			x	x								x			x		x	x	x				
Hecht and Vagi (2012)[b]	181	4			x																x				
Hickendorff (2021)	444	3 to 6													x		x		x						
Houtz and Speedie (1978)	91	5															x	x	x						
Iglesias-Sarmiento et al. (2015)	49	5			x					x				x	x		x		x						
Jaakkola et al. (2021)	461	6	x																						
Jacobse and Harskamp (2012)	42	5						x																x	
Jenks et al. (2012)	73	1			x			x				x				x	x	x	x						
Jitendra et al. (2005)	77	2	x	x	x																				
Jitendra et al. (2013)	127	2				x	x																		
Jitendra et al. (2014)	136	2	x	x																					
Jõgi and Kikas (2016)	864	1			x	x		x	x								x								
Júlio-Costa et al. (2013)	61	1 to 6										x					x		x	x	x				
Kaskens et al. (2020)	610	4		x																			x	x	

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Kaskens et al. (2022)	458	4		x				x											x						
Kempert et al. (2011)	78	3			x										x		x	x							
Kikas et al. (2020)	231	6			x	x									x		x							x	
Korhonen et al. (2018)	624	3	x									x							x		x				
Lai et al. (2015)	217	4	x					x															x	x	
Lee et al. (2004)	151	5					x					x	x	x	x			x	x						
Lee et al. (2009)	255	5			x			x							x			x	x						
Lee et al. (2011)	151	4			x			x									x		x						
Leung and Wong (2023)	228	6			x								x				x		x			x			
Li, Zhang, et al. (2023)	251	1 to 3		x						x			x				x								
Li, Chen, et al. (2023)	798	5 to 6	x	x													x						x		
Limin et al. (2013)	69	5	x																						x
Lin, Peng, and Luo (2021)[c]	237	4		x	x		x				x						x	x	x						
Losenno et al. (2020)	134	3 to 6	x			x		x																	
Mackinson et al. (1997)	27	NR															x								
Meyer et al. (2010)	48	2										x							x						
Mielicki et al. (2021)	61	6	x					x									x			x		x			

(Continues)

TABLE 3 (Continued)

Report	N	Grade	Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes			Affective characteristics		
			Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Muis et al. (2015)	79	5	x					x																x	x
Munzar et al. (2021)	136 & 80	3 to 6 and 5 (separate samples)						x																x	x
Muth (1984)	200	6			x										x										
Mädamürk et al. (2016)	787	3			x												x	x							
Männamaa et al. (2012)	723	3	x		x			x		x							x	x	x		x				
Namkung and Fuchs (2012)	332	2		x	x															x		x			
Ng et al. (2021)	129	4							x					x	x		x								
Oostermeijer et al. (2014)	128	6											x												
Passolunghi et al. (2019)	145	4									x								x				x		
Passolunghi et al. (2022)	182	4						x							x		x								
Pavlin-Bernardić et al. (2008)	283	1 to 4																	x						
Peake et al. (2015)	449	2 to 5							x																
Peng and Lin (2019)[c]	237	4		x	x						x						x	x	x						
Pongsakdi et al. (2020)	891	4		x											x										
Samuelsson (2010)	105	5	x		x																			x	

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Schadl & Ufer (2023)	363	6	x		x																	x			
Schmerold et al. (2017)	74	1						x								x	x		x						
Seethaler et al. (2012)	184	1	x	x													x	x		x					
Seethaler et al. (2016)	292	1	x														x	x		x					
Singer et al. (2019)	200	3 to 6		x						x							x	x	x		x				
Sisco-Taylor et al. (2015)	142	3			x										x							x			
ŞiŞman and Aksu (2012)	445	6	x																						
Song et al. (2021)	147	2		x													x	x	x	x			x		
Spencer et al. (2020)	341	2		x					x							x	x	x	x						
Spencer et al. (2022)	370	1		x		x			x		x			x		x	x		x	x					
Swanson et al. (1993)	110	3			x	x						x							x						
Swanson and Sachse-Lee (2001)	73	2 to 6								x		x							x						
Swanson (2004)	69	2 to 6			x					x		x			x		x		x						
Swanson et al. (2008)	302	1		x			x	x		x								x	x						
Swanson & Fung (2016)	392	3					x	x		x		x					x		x	x		x			
Swanson et al. (2021)	343	1 to 3			x		x	x		x							x	x	x	x		x			
Tam et al. (2019)	92	2		x	x								x						x			x			

(Continues)

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Tam and Chan (2022)	324	1			x								x									x			
Tolar et al. (2012)	261	3		x		x											x	x							
Tong et al. (2023)	254	5											x				x		x						
Träff et al. (2018)	269	3		x	x		x			x	x		x				x		x	x					
Ulu (2016)	279	4												x	x	x									
Van der Ven et al. (2023)	2986	2 to 6																	x				x		x
van Garderen (2006)	66	6											x												
Vermeer et al. (2000)	158	6																						x	
Vilenius-Tuohimaa et al. (2008)	205	4												x	x										
Viterbori et al. (2015)	118	1		x	x																				
Vukovic et al. (2010)[d]	287	3		x	x									x	x										
Vukovic and Lesaux (2013)[d]	287	3			x					x			x				x		x						
Wang et al. (2016)	701	2		x			x				x						x		x						
Wang et al. (2020)	170	4		x	x			x		x	x						x	x							
Wang et al. (2022)	336	5						x					x		x		x								
Wong and Yip (2023)	273	4			x												x		x						
Xin and Zhang (2009)	119	4 to 6	x														x								

TABLE 3 (Continued)

			Overall mathematics achievement	Proficiency with specific components of mathematics		General cognitive skills														Basic mathematical processes		Affective characteristics			
Report	N	Grade	Broad math	Arithmetic fact retrieval	Calculation	Attention	Broad language and reading	Executive functions	Listening comprehension	Phonological processing	Processing speed	Short-term memory	Spatial ability	Reading accuracy	Reading comprehension	Reading fluency	Reasoning	Vocabulary	Working memory	Magnitude comparison	Number naming	Number line estimation	Math anxiety	Motivation: Expectancies	Motivation: Values
Xu et al. (2021)	147	2		x				x				x					x	x	x						
Yetim Karaca and Ceylan (2011)	206	6																						x	
Zhang et al. (2017)	378	1		x	x							x					x		x		x				
Zhang et al. (2018)	116	3		x		x									x		x						x		
Zheng et al. (2011)	310	2 to 4			x							x		x	x				x						
Zhang et al. (2023)	81	3						x		x		x	x				x								
Zhou et al. (2020)	1515	5																					x	x	
Zhu et al. (2017)	77	2		x				x									x					x			
Özcan & Dogan (2017)	185	1			x										x						x				

Note: Superscript letters mark studies that were regarded as using the same sample. Grade refers to participant's grade at the beginning of the study. NR, Participants' grade level not reported, inclusion based on age.

TABLE 4 Overall weighted effect sizes of individual characteristics.

Component	Individual characteristic	*K*	*k*	*r*	*r* interpretation	Df	95% CI Lower	95% CI Upper	τ^2	Egger's *p*
Overall mathematics achievement	Broad maths	21	36	0.56**	Strong	19.80	0.49	0.63	0.04	0.62
Proficiency with specific components of mathematics	Arithmetic fact retrieval	45	126	0.47**	Moderate	43.70	0.42	0.52	0.04	0.04
	Calculation	47	124	0.52**	Strong	45.50	0.48	0.56	0.05	0.36
General cognitive skills	Attention	19	55	0.41**	Moderate	17.80	0.33	0.48	0.03	0.06
	Broad reading and language	15	25	0.58**	Strong	14.00	0.46	0.67	0.07	0.76
	Executive functions	34	142	0.26**	Weak	32.20	0.22	0.31	0.02	0.14
	Listening comprehension	12	26	0.46**	Moderate	10.80	0.39	0.57	0.02	0.54
	Phonological processing	16	26	0.30**	Moderate	14.90	0.20	0.39	0.03	0.66
	Processing speed	16	28	0.34**	Moderate	14.70	0.26	0.40	0.01	0.42
	Short-term memory	23	91	0.33**	Moderate	21.70	0.27	0.39	0.03	0.09
	Spatial ability	15	30	0.42**	Moderate	13.90	0.33	0.50	0.03	0.01
	Reading accuracy	18	34	0.46**	Moderate	16.60	0.36	0.56	0.05	0.46
	Reading comprehension	28	82	0.49**	Moderate	26.30	0.44	0.54	0.02	0.12
	Reading fluency	9	19	0.45**	Moderate	7.84	0.34	0.55	0.02	0.25
	Reasoning	70	220	0.43**	Moderate	68.00	0.39	0.46	0.03	0.26
	Vocabulary	30	88	0.47**	Moderate	28.80	0.40	0.53	0.05	0.86
	Working memory	57	171	0.37**	Moderate	54.30	0.34	0.40	0.02	0.45
Basic mathematical processes	Magnitude comparison	17	34	0.44**	Moderate	15.90	0.33	0.54	0.06	0.03

TABLE 4 (Continued)

Component	Individual characteristic	*K*	*k*	*r*	*r* interpretation	Df	95% CI Lower	95% CI Upper	τ^2	Egger's *p*
	Number line estimation	14	22	0.42**	Moderate	12.80	0.33	0.51	0.03	0.52
	Number naming	13	40	0.54**	Strong	12.00	0.46	0.62	0.08	0.19
Affective factors	Maths anxiety	11	23	−0.25**	Weak	9.23	−0.32	−0.17	0.01	0.37
	Motivation: Expectancies	14	23	0.33**	Moderate	12.50	0.25	0.41	0.02	0.59
	Motivation: Values	9	15	0.22**	Weak	6.62	0.14	0.29	0.01	0.94

Note: Component refers to the component in the multi-level framework of mathematical cognition. Correlations are interpreted based on Cohen (1977) as weak ($r=0.10$), moderate ($r=0.30$) and strong ($r=0.50$).

Abbreviations: CI, confidence interval for *r*; df, degrees of freedom; Egger's *p*, Egger's test *p*-value; *k*, number of effect sizes; *K*, number of studies; *r*, weighted average Pearson correlation; τ^2, between-study sampling variance.

**$p < 0.01$.

outcomes ($M=0.36$, SD 0.23) were also quite low, indicating that measurement methods and reporting were generally poor in the studies.

A multiple meta-regression analysis including study quality dimensions and individual characteristics categories indicated that the aims dimension significantly predicted the associations between individual characteristics and mathematical word problem-solving skills ($\beta=-0.08$, df $=47.67$, 95% CI [−0.14, −0.01], $p=0.02$), suggesting that studies with clear research questions or hypotheses observed lower associations. However, this effect was quite small. As a sensitivity analysis, we report overall average effects for each individual characteristic with data including only studies that received the score 1 from the aims dimension (see Table S4 in the supplementary material). Study quality dimensions of participants ($\beta=-0.07$, $df=40.73$, 95% CI [−0.08, 0.21], $p>0.05$), predictors ($\beta=0.02$, df $=45.03$, 95% CI [−0.07, 0.13], $p>0.05$), or outcome ($\beta=-0.50$, $df=47.87$, 95% CI [−0.18, 0.08], $p>0.05$) did not moderate the observed associations.

DISCUSSION

This systematic review and meta-analysis aimed to identify and evaluate the effects of individual characteristics associated with mathematical word problem-solving skills among elementary school-aged children and to unpack the quality of studies investigating such associations. To extend previous research, we searched and estimated the effects of individual characteristics related to word problem-solving among elementary schoolers, statistically accounted for the non-independence of effect sizes and small sample sizes, and evaluated study quality.

In line with the multi-level framework of mathematical cognition (Gilmore, 2023), all investigated individual characteristics (i.e., overall mathematics achievement, specific components of mathematics, basic mathematical processes, general cognitive skills and maths-related affective factors) were associated with mathematical word problem-solving among elementary school-aged children. In addition, the associations varied from weak to strong (RQ 1). Therefore, we replicated some of the associations previously found among a wide age range (e.g., Lin, 2021; Peng et al., 2016; Yang et al., 2022). Furthermore, we extended previous investigations by showing a consistent association between multiple overlooked individual characteristics (e.g., motivation, number naming, magnitude comparison skills) with mathematical word problem-solving skills. By and large, these associations did not seem to depend on study quality (RQ 2; e.g., concerning aims, participants, predictors and outcomes). However, it seemed that the methods and reporting related to participants, predictors and outcomes were overall fairly weak.

Individual characteristics associated with mathematical word problem-solving (RQ 1)

Levels of mathematical cognition and mathematical word problem-solving

Related to our first research question concerning the relationships between individual characteristics and mathematical word problem-solving skills, the investigated individual characteristics in each level of mathematical cognition (i.e., overall mathematics achievement, specific components of mathematics and basic mathematical processes) were related to mathematical word problem-solving. Reflecting on the fact that solving mathematical word problems requires a variety of mathematical knowledge and skills (Daroczy et al., 2015), it is rational that such skills are strongly related to students' overall mathematics achievement.

Furthermore, the moderate to strong associations between basic mathematical processes (magnitude comparison, number naming and number line estimation) and word problem-solving are especially notable, given the scarcity of meta-analyses on these associations (see Table S1 in the supplementary material). These relationships may be explained by the foundational nature of basic mathematical processes for more advanced mathematical knowledge (Imbo et al., 2014; Schneider et al., 2017). As elementary school-aged children have only recently been formally introduced to mathematical word problem-solving, they may still rely heavily on such cornerstones of mathematical knowledge (Gilmore, 2023; Zhang et al., 2017). On one hand, the strong link between number naming and mathematical word problem solving may result from the link between basic mathematical processes and general cognitive skills (e.g., language skills, rapid automatised naming or working memory), as number naming requires children to be able to retrieve and process language-based information (i.e., linking number words to number symbols; Gilmore, 2023; Imbo et al., 2014; Zhang et al., 2017). Some studies have found that basic mathematical processes may uniquely contribute to mathematics when controlling for general cognitive skills (Ünal et al., 2024; Zhang et al., 2017). Therefore, our findings prompt future research to disentangle the mechanisms and uniqueness of basic mathematical processes associated with mathematical word problem-solving, as such investigations remain scarce (see Ünal et al., 2024; Zhang et al., 2017).

In terms of the moderate to strong associations between mathematical word problem-solving and other specific components of mathematics, our results validate the findings of previous meta-analyses while employing more rigorous methods (Lin, 2021). However, the strong association between calculation and mathematical word problem-solving was found to be smaller in our study than in the prior meta-analysis ($r=0.52$ compared to $r=0.62$; Lin, 2021). This discrepancy may be explained by the fact that the meta-analysis by Lin (2021) included both kindergarten-aged and elementary school-aged children and did not account for the dependency of effect sizes (Fisher & Tipton, 2015). Nonetheless, this strong relationship between calculation and mathematical word problem-solving supports the notion that calculation skills may play a role in mathematical word problem-solving skills in elementary school but that these skills are not entirely overlapping. Notably, our findings also highlight that less research exists on the association between many specific components of mathematics such as algebraic thinking and geometry knowledge with mathematical word problem-solving among elementary schoolers. Therefore, our findings prompt more research endeavours to understand these relationships.

General cognitive skills and mathematical word problem-solving

Concerning the mainly moderate association between general cognitive skills and mathematical word problem-solving, our findings replicate some of the associations found in previous meta-analyses across the age span (Lin, 2021; Lin, Peng, Zeng, et al., 2021; Peng et al., 2016; Peng et al., 2020; Peng & Lin, 2019; Spiegel et al., 2021; Ünal et al., 2023; Xie et al., 2020; Yang et al., 2022). It is quite reasonable that language- and reading-related general cognitive skills presented the strongest association with mathematical word problem solving, as students are required to process language-based information when solving mathematical word problems (Daroczy et al., 2015; Kintsch & Greeno, 1985). Nonetheless, complementing previous meta-analyses, our findings seem to advocate for the importance of language-based skills in a broad sense as the combination of language- and reading-related skills (e.g., vocabulary, listening and reading comprehension) showed the strongest association (from all individual characteristics) with mathematical word problem-solving. This would encourage future efforts to examine the mechanisms of this relationship and the possibility of supporting mathematical word problem-solving skills by supporting students' language and reading skills in a broad sense. After all, supporting students' language or reading skills has recently shown some promise for being effective in supporting elementary school-aged children's mathematical word problem-solving skills (e.g., Fuchs et al., 2021; Fuchs et al., 2024).

Interestingly, spatial ability was more strongly related to mathematical word problem-solving skills among this age group contrasted to individuals across the age span ($r=0.32$ and 0.46; Xie et al., 2020). This is especially notable as previous meta-analyses have not found the relationship between spatial skills and overall mathematics achievement to vary as a function of age (Atit et al., 2022; Xie et al., 2020). Our finding may imply that especially when solving a mathematical word problem, elementary school-aged children rely heavily on mapping the solution visually whereas previous research has suggested that older individuals might rely more on mere application of mathematical operations (Atit et al., 2022). Instead of a direct relation, spatial skills may also aid students in comparing magnitudes on a mental number line or building visual-schematic representations of the problem, pointing towards a more indirect relationship (Boonen et al., 2013; Tam et al., 2019). Thus, further research should examine the potential mechanism of this relationship to better understand the development and support of students' mathematical word problem-solving skills.

Maths-related affective factors and mathematical word problem-solving

Our results displayed a general association between affective factors (i.e., motivation and emotions) and mathematical word problem-solving. This finding extends both the multi-level framework of mathematical cognition (Gilmore, 2023) and the previous meta-analyses (Barroso et al., 2021; Zhang et al., 2019) as such aspects have been largely overlooked. Within the affective factors, our findings especially highlight the role of students' beliefs in their competence. Our findings reflect a similar pattern found in previous studies concerning the mathematical knowledge of middle and secondary school-aged students (Guo et al., 2015; Trautwein et al., 2012). That is, students' expectancies of how well they are going to do in the task or how competent they view themselves in a particular domain, are more strongly related to their mathematics performance than the value they place on doing well in a task (Guo et al., 2015; Trautwein et al., 2012). Considering these associations are weak to moderate, it seems that affective factors do not capture as much individual differences in mathematical word problem solving as, for instance, cognitive individual characteristics. However, this does not infer that affective factors would not be significant for solving word problems.

Importantly, compared to the large amount of evidence there is on the association between general cognitive skills and mathematical word problem-solving in this age group, significantly less research has been conducted on the role of affective factors—for instance, the role of other achievement emotions than maths anxiety could not be investigated in the current meta-analysis due to the small number of studies. Also, though overall the different components of situated expectancy-value-theory (Eccles & Wigfield, 2020) in relation to mathematical word problem-solving seem to be understudied, evidence concerning the cost-dimension seems to be especially lacking.

Given that we demonstrated a general association between affective factors and mathematical word problem-solving and that these associations seem to be less examined, our findings raise important questions concerning the mechanism of these associations—for instance, whether it would be possible to support students' mathematical word problem-solving through supporting also their motivation (especially their expectancy beliefs, self-concept or self-efficacy). Individuals' expectancy beliefs and self-concept are closely related to perceptions of task difficulty (Eccles & Wigfield, 2020, 2023). Considering that mathematical word problem-solving may seem even disproportionately difficult to students, supporting the beliefs students have about their competence could motivate them to engage more in mathematical word problem-solving activities. Of course, experimental studies are needed to gain knowledge of such possibilities.

Study quality associated with relationships between individual characteristics and mathematical word problem-solving (RQ 2)

Related to our second research question, our findings provided valuable new information regarding the role of study quality, as previous meta-analyses have rarely considered this aspect while studying associations between individual characteristics and mathematical word problem-solving (see Table S1 in the supplementary material; e.g., Barroso et al., 2021; Peng et al., 2020; Spiegel et al., 2021). However, in line with some studies (Spiegel et al., 2021), we found that study quality did not substantially moderate the strength of the associations between individual characteristics and mathematical word problem-solving skills (RQ 2).

While these findings are somewhat comforting, and we observed that studies included in this review were relatively clear in reporting their aims, we also found significant deficiencies in several quality aspects. Indeed, information concerning sample selection and the measurement of predictors and outcomes was inadequate. Adequate recruitment and reporting of participants ensure researchers and practitioners evaluate the population to which findings can be generalised (Hartling et al., 2009). It also ensures that researchers may replicate and compare the findings between studies (Hartling et al., 2009; Moola et al., 2015). For instance, if students in a given study represent only low socioeconomic status families, it should be clearly reported for the readers to determine that the results may not hold for other study populations and to compare findings across different studies (Codding et al., 2023; Valentine, 2019). Similarly, robustness concerning measuring the predictors and outcomes of a study ensures the reliability of the findings and potential inferences of causal relationships (Mokkink et al., 2010). Notably, the low ratings in the measurement of predictors are also likely to result from the large number of cross-sectional studies. That is, three of the five included study quality questions address this aspect, and naturally value longitudinal designs. Therefore, the findings seem to also represent the sparsity of longitudinal investigations concerning the associations between individual characteristics and mathematical word problem-solving. Overall, for future research, it seems important to pay specific attention to the aspects of sample selection and measurement to ensure the generalisability, replicability and reliability of the results (Hartling et al., 2009; Moola et al., 2015; Valentine, 2019).

Limitations and recommendations for research and practice

Like any study, the current study has limitations. First, we did not include grey literature such as unpublished articles or dissertations (Park et al., 2023). Though the majority of our investigations of publication bias indicated the low probability of such bias, results concerning magnitude comparison, spatial ability and arithmetic fact retrieval should be cautiously interpreted. That is, results concerning these individual characteristics may be inflated since studies including larger or statistically significant effect sizes tend to be more prominently published (Gage et al., 2017; Park et al., 2023). Second, we did not investigate the effects of every individual characteristic we found due to there being so few studies. For example, we combined mathematics-specific vocabulary with general vocabulary as mathematics vocabulary was investigated in such few studies. Furthermore, moderation effects beyond study quality were not assessed due to the high risk of overfitting

(Fisher & Tipton, 2015; Geissbühler et al., 2021). Fourth, our findings cannot advocate for the uniqueness of the individual characteristics effects as making such deductions would require the use of meta-analysis structural equation modelling techniques, which were beyond the scope of this investigation. Fifth, due to study quality assessment being a major part of the current study and as applying varying assessment tools may compromise the interpretability of the findings, intervention reports were excluded, though such could also provide valuable information.

Despite the limitations, our findings have implications for research and practice. First, by indicating the extent to which various individual characteristics are associated with mathematical word problem-solving skills, our study encourages future research to examine the mechanisms and uniqueness of the relationships between individual characteristics and mathematical word problem-solving. For instance, it remains unclear if some of the characteristics (e.g., number line estimation) relate to word problem-solving directly or through other important skills (e.g., spatial ability). In addition, future research should aim to unravel the role of more overlooked individual characteristics (e.g., geometry skills, place-value understanding, emotions). Second, given the strong associations between some individual characteristics and word problem-solving, practitioners may more prominently recognise those students who are likely to struggle with word problems. As an example, when educators recognise low performance in reading and language skills or number naming, they ought to pay increased attention to those students' word problem-solving skills. Third, to improve the generalisability, replicability and reliability of results in this field, our findings encourage researchers to improve especially the reporting of sample selection and measurement.

CONCLUSIONS

The results demonstrate that a broad range of individual characteristics (i.e., students' overall mathematics achievement, specific components of mathematics, basic mathematical processes, general cognitive skills, and maths-related affective factors) are associated with elementary school-aged children's mathematical word problem-solving skills and that the magnitude of these associations varies considerably (RQ 1). Also, the associations between individual characteristics and mathematical word problem-solving skills hold for different quality studies (RQ 2).

AUTHOR CONTRIBUTIONS

T. Vessonen: Conceptualization; investigation; funding acquisition; writing – original draft; methodology; validation; visualization; software; formal analysis; data curation; resources; project administration. **M. Dahlberg:** Investigation; writing – review and editing; formal analysis; methodology; data curation; conceptualization. **H. Hellstrand:** Conceptualization; funding acquisition; project administration; writing – review and editing; investigation. **A. Widlund:** Conceptualization; writing – review and editing; investigation. **P. Söderberg:** Conceptualization; writing – review and editing; investigation. **J. Korhonen:** Conceptualization; methodology; writing – review and editing; investigation. **P. Aunio:** Conceptualization; supervision; writing – review and editing; project administration; investigation; funding acquisition. **A. Laine:** Conceptualization; writing – review and editing; project administration; supervision; investigation; funding acquisition.

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CONFLICT OF INTEREST STATEMENT

We have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The present study was a secondary analysis of published literature and did not therefore require ethical approval.

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