Applications of Language Studies

Hazrat-e Masoumeh University

jals.hmu.ac.ir

Linguistics Society of Iran

Exploring the Impact of Phonological Awareness on Elementary School Students' Mathematics Achievement

Elham Ziyayi

PhD in Linguistics, Department of Linguistics, Faculty of Letters and Humanities, Ferdowsi University, Mashhad, Iran

elhamziyayi@yahoo.com

Abstract

Phonological awareness is the recognition of the sound structure of words, and it is an important and reliable predictor of reading ability. Furthermore, it has been identified as a skill related to the development of mathematics skills for children. The present study aimed to explore the effect of phonological awareness on the mathematical performance of Persian female students. This research employed a quasi-experimental study, which included a pre- and post-test design with the control group. The population included 140 female second-grade students divided into a control and an experimental group. The experimental group underwent phonological awareness training for ten weeks, each session lasting 30-35 minutes, whereas the control group did not receive any intervention. The findings revealed that instructing phonemic awareness techniques in mathematics had a considerable effect on the operation area of the second-grade female students in elementary school. Phonological processing acts as a prerequisite for retrieving mathematical data and a facilitator for mathematical operations, and people with good phonological skills perform better in mathematics.

Keywords: phonological awareness, phoneme, reading, mathematics, operation area

Citation: Ziyayi, E. (2025). Exploring the impact of phonological awareness on elementary school students' mathematics achievement. *Applications of Language Studies*, *3*(1), 49–73.

Received: 2024-11-12
Revised: 2025-03-24
Accepted: 2025-03-27
Article type: Research paper

P-ISSN: 2588-6975
E-ISSN: 2588-6983
Publisher: Hazrat-e Masoumeh University Press
DOI: 10.22034/jals.2025.2045607.1049

1. Introduction

Human beings are inherently social creatures, needing to express feelings and emotions, exchange thoughts and opinions as well as communicate with others. Reading acts as an efficient means of communication and exchanging thoughts. In order to develop reading skills, a set of fundamental aptitudes must be acquired including grapheme-phoneme correspondence, phonetic representation, decoding, phonemic labeling, identifying the directional nature of written symbols, and knowledge of spelling rules (Thomson, 1991). Reading and writing lead to the development of phonological awareness, which brings about improvement in other capacities.

Today, the vast majority of school proficiencies, like reading, writing, and comprehension, are prerequisites for both academic and work situations (Kaltner & Jansen, 2014). Reading skills are of utmost importance as a person with satisfactory reading proficiency is more likely to succeed in mathematics, social studies as well as other scientific domains (Melekoglu, 2011).

A multitude of studies have also reported evidence of overlapping brain activation for math and phonology in this region (De Smedt & Boets, 2010; Pollack & Ashby, 2018; Simon et al., 2002). A number of mathematical problems, especially those solved by retrieval, are linked to phonological processing capability and necessitate activity in the left-brain areas responsible for phonological processing (Pollack & Ashby, 2018). Long-term studies have established that phonological skills can be used as a predictor of future math aptitude; accordingly, phonological awareness assessed in 4-5-year-old is significantly associated with mathematic skills (Koponen et al., 2007; Simmons et al., 2008). Examining all these cases together demonstrates that there exists a linguistic basis for certain mathematical dimensions.

There is an inseparable association between language proficiency and math performance, with language capabilities being a part of math knowledge. Accomplishing elementary mathematical tasks entails the retrieval of phonological codes as well as the encoding and preservation of phonological representations in instantaneous awareness (Simmons et al., 2008). Insufficiency in phonological processing postpones the employment and storage of verbal codes such as counting and solving simple math problems. Studies of various languages have evidenced a mutual connection between phonological awareness and learning (Plaza & Cohen, 2004; Soleimani et al., 2008). It follows that if children have issues with phonological awareness skills, they will encounter difficulties in mastering other skills such as reading and writing, and, consequently, in acquiring other sciences and knowledge. Meanwhile, the association between phonological awareness skills and mathematics may appear attenuated and unrelated while the results of many studies, including Hecht et al. (2001), Alloway et al. (2005), De Smedt and Boets (2010), Jordan et al. (2015), Kuzmina et al. (2019) and Kourti and Warmington (2021), have shown a strong association between phonological awareness skills and mathematic performance particularly among young children and in the first years of school going. Jobstl et al. (2023) believed that rapid automatic naming and number system knowledge explain variance in shared skills between reading and math. Reading and math involved domain-specific cognitive components, and both required visual and verbal networks and semantic information that was explained by rapid automatic naming. Guez et al (2022) showed that language skills in children aged five years and five months predicted multiplication but did not predict addition and subtraction scores at the age of 11.5 years. In contrast, early visuospatial skills predicted addition and subtraction but not multiplication scores. These results provided strong support for the existence of dissociation in mathematical mental operations and explained the existence of long-term associations between language and visual-spatial skills and computational abilities. While addition and subtraction may rely more on visual-spatial reasoning, multiplication relies on verbal abilities. Kourti and Warmington (2021) demonstrated that phonological awareness correlated with simple math skills such as math skills in preschool children and first-grade students. Mathematical skills were correlated with reading abilities and the age of the subjects. Amland et al. (2021) displayed that phonological awareness can predict math progress from preschool to first grade when elementary reading, elementary math, general language skills, and nonverbal abilities are controlled. In their opinions, the relationship between phonological awareness and math was limited to verbal math, that is, simple math problems presented orally and calculated mentally. Vanbinst et al. (2020) suggested that phonological awareness predicted not only beginner reading but also beginning mathematics.

Theories have demonstrated that verbal codes are employed in mathematics tasks, indicating that phonological processing abilities can influence math accomplishment (Simmons et al., 2008). Younger children utilize counting strategies to figure out math problems, and this requires them to retrieve the phonetic codes of number words (Logie & Baddeley, 1987). Geary (1993) believes that when children employ counting techniques to solve mathematical problems, they retrieve phonological representations of numerical words and keep the problem in their working memory (Geary, 1993). Hecht et al. (2001) indicated that if phonological codes are maintained with greater strength, their retrieval will be more rapid and precise. Generally, when children are confronted with a math problem (e.g., 2+2=x), they apply their phonological awareness and memory to identify the symbols, and they draw on counting techniques to solve the problem and finally, through continual engagement with the problem, the solution will gradually come to mind (Espinas & Fuchs, 2022).

Mathematical knowledge is an indispensable part of education, and any lack of understanding of math can have a detrimental effect on a person's performance in school and in real life. Recent research has shown that 7% of school-aged kids possess cognitive or neuropsychological deficiencies, which can be improved through the development of mathematical skills (Geary, 1993). Poor phonological ability is believed to have a direct effect on math achievement as math involves the retrieval and retention of verbal numerical codes (Robinson et al., 2002). For solving single-digit math problems, children either retrieve the phoneme-based numerical code directly from long-term memory or reconstruct the answer by counting the phonetic codes of the numbers (Hecht et al., 2001). Of the three aspects of phonological proficiency including syllable awareness, inter-syllabic awareness, and phonological awareness, phonological awareness has a greater impact on predicting math performance (Hecht et al., 2001). Some researchers have reported an association relationship between phonological and mathematical skills, especially phonological awareness, with the development of arithmetic and mathematical skills (Alloway et al., 2005; Koponen et al., 2007). A child would utilize a counting strategy to solve a math problem that involves a phonological system (Buchner et al., 1998). Counting necessitates the child to retrieve the phonetic representation of numerical words, which can be achieved through phonemic working memory (Logie & Baddeley, 1987). Difficulties in retrieving information make it hard for children with poor phonological skills to count, so they must resort to counting to solve math problems in their early years. Bearing in mind that children with poor phonology exhibit weaker counting skills and are less efficient, which in turn leaves them with fewer chances to get the right answer, for arithmetic calculations, the more effective the storage and manipulation of numerical representations in the phonological memory is, the greater the ability of working memory for arithmetic procedures (Bull & Johnston, 1997). Due to the fact that the math and reading processing center is located in the left hemisphere of the brain, and reading in turn reading is associated with a person's phonological knowledge, it appears that there is a substantial association between phonemic knowledge and mathematical aptitude, thereby requiring a person to decode and retain the exact depiction of the phonemes of the word in memory. The same procedure is also applied to mathematical problems, and the problem is finally processed using specific strategies.

Phonological awareness enhances basic math skills such that phonological working memory represents the extent to which phonological codes are accessed (De Smedt & Boets, 2010). The connection between phonological processing and math is a strong point of reference in phonological representations as well as phonological codes (Simmons et al., 2008). Poor phonological representation hinders the ability to manipulate, retrieve, and retain phonological codes. Similarly, poor phonological representation of mathematical data hinders their effective retrieval (Boada & Pennington, 2006).

To sum up, it is obvious that some students have phonological problems in some manner, so the problem in phonological awareness skills affects many aspects of a person's life, the least of which is problems in reading skills and consequently writing skills, which in turn affects other aspects of a person's life, including math, science and other areas of learning. Taking into account the great influence of phonological awareness on all aspects of education, therefore, by educating phonological awareness skills, difficulties can be circumvented and reading capabilities as well as other areas of knowledge are advanced. Finally, the outcomes of the present research are quite applicable and beneficial for students, educators, and practitioners in the area of education.

2. Literature Review

Studies have shown that phonological awareness is a substantial contributor to early reading acquisition (Vloedgraven & Verhoeven, 2009). Phonological awareness is an independent language function that forms the basis for the abilities of listening, speaking, and writing. A robust phonological awareness is an essential component of literacy, which is profoundly imperative in guessing the acquisition of reading and writing skills. It should be emphasized that having a satisfactory degree of mathematical knowledge is required for academic success. In this regard, obtaining mathematical knowledge in elementary school is fundamental (Clements & Sarama, 2016). Struggling with mathematics in elementary school is a stumbling block in reading or problem-solving (Geary et al., 1991). Neurocognitive studies have demonstrated that mathematics and phonology are involved in separate parts of the left frontal gyrus (Booth et al., 2002; Dehaene et al., 2005; Prado et al., 2011; Simon et al., 2002).

In a study, Yang and McBride (2020) examined phonological processing skills (phonological memory, phonological awareness, and rapid automatized naming, RAN) in relation to early Chinese reading and early Chinese mathematics for young children. Early Chinese reading was assessed with single-character reading and multi-character word reading, and early mathematics was assessed with procedural arithmetic and arithmetic story problems. Among 86 Chinese kindergarteners, phonological processing skills explained 20% of the variance in character reading and 28% of the variance in word reading; they accounted for 8% of the variance in arithmetic and 11% of the variance in story problem performance. Specifically, findings further highlighted the general importance of phonological awareness in early Chinese single-character reading, word reading, simple arithmetic, and story problems, and the specific role of RAN in single-character reading and simple arithmetic.

Muitana and Amato (2022) studied the influence of phonological awareness on academic performance in Brazilian studies and presented the main standardized instruments used in the assessment of this skill. Articles from the last five years were searched in LILACS and SciELO databases using descriptors in English: "phonological awareness" and "reading" or "writing" or "mathematics" or "academic performance" or "academic ability", as well as descriptors in Portuguese using the same expressions. Open access studies carried out in Brazil, published in Portuguese, English, or Spanish, which used a standardized instrument and presented the descriptors mentioned in the title or abstract, were selected. The results revealed that out of the 18 articles analyzed, 17 concluded that phonological awareness was important for reading, writing, and mathematics, with reading and writing being the most investigated skills. The instruments used assessed the main components of phonological awareness and were developed by Brazilian authors. The findings showed that phonological awareness is a very important skill for academic performance in different grades. It reinforces the need for monitoring, assessment, and early intervention with skills in typical and atypical children.

In a study in 2023 by Li et al., 251 primary school children (mean age: 8.31 ± 0.89 years old), including 87 first graders, 83 second graders, and 81 third graders, participated. Children's rapid automatized naming was measured using a rapid digit naming task, and phonological awareness was measured with a character rhyming task. Additionally, children's visual perception was measured with a figure matching task, and mental rotation was measured with a 2D/3D mental rotation task. Children's mathematical abilities were measured with three mathematics tests: calculation task, mathematical problem-solving task, and mathematical reasoning task. Regression analyses and Bayesian hypothesis testing showed that phonological awareness uniquely contributed to children's mathematical abilities, especially mathematical problem-solving. The results suggested that phonological awareness serves as a key precursor of mathematical abilities during the primary education phase.

3. Method

This research employed a quasi-experimental method, which included a pre- and post-test design with the control group. This cross-sectional study was conducted between September 2022 and June 2023 on 140 female second-grade students of Quchan (one of the cities of Khorasan Razavi) with an average age of 7.6 who were randomly selected. The second-grade students were chosen because they have acquired basic knowledge of letters, sounds, and phonemes in the previous formal educational level (first grade) but their mastery is still limited. On the other hand, they have become familiar with basic mathematical concepts such as counting numbers, basic addition and subtraction of the first type, as well as the concept of a combination of numbers.

Analysis of the students' academic portfolios revealed that all of them had natural intelligence and had never been unsuccessful at the prior educational level (first grade). According to the study by Dastjerdi and Soleimani (2006), and considering the ages of subjects, five sub-tests of phonological awareness were used in the sub-section of phonemic awareness including the sub-test of naming and removing the initial phoneme, the sub-test of naming and removing the final phoneme, the sub-test of identifying words with the same final phoneme, the sub-test of removing the middle phoneme and finally the sub-test of phoneme segmentation. The math test was considered a dependent variable and based on the Iran Key Math Test of Mathematics which includes three areas of concepts, application, and operation. In this study, the researcher focused on the operation area; so teacher-made math test questions were designed in the operation area. The content of the test was approved by technical professors and experts in relation to the subject of the research and had the necessary validity. The reliability of the test was also calculated using Cronbach's alpha. It was 0.84, which indicates good reliability.

3.1. Data Collection

Phonological awareness and math tests were performed as a pre-test. Data was gathered through the utilization of the phonological awareness test of Dastjerdi and Soleimani (2006) and a teacher-made math test. The students were randomly divided into two control and experimental groups. After administering the diagnostic tests (phonemic awareness & math tests), 70 individuals were chosen as the experimental group (exposed to phonological awareness) and 70 as the control group (not exposed to phonological awareness and followed the natural process of education).

The experimental group underwent phonological awareness training for ten weeks, each session lasting 30-35 minutes, whereas the control group did not receive any intervention. The experimental group was trained in groups of five subjects. Grouping the trainees in groups of five helped the examiner to observe better and improve the students' learning experience through their discussions. Individual training proved to be quite lengthy with each subject having to spend 30-35 minutes per session. The primary phonological awareness aptitudes of the subjects included phoneme recognition as well as phoneme segmentation. The training was structured in such a way that the easier skills were taught first, followed by the more difficult ones once the participants mastered them. Initially, instruction focused on word and syllable recognition, culminating in teaching of recognizing the initial and final syllables of two-, three-, and four-syllable words. At the phoneme-related training sessions, the participants were presented with phoneme recognition techniques, followed by exploring phoneme segmentation. Phonological awareness training was presented in a systematic and organized fashion, which lent itself to plentiful practice and repetition, with various examples provided to encourage and improve the chances of success for the students. Each exercise included between 8 and 10 words with the training session lasting 30-35 minutes. Given that the training mainly focused on phonology, phoneme recognition, and segmentation, each session was tailored to its specific purposes.

During the phoneme recognition sessions, the examiner made the subject find the first, the middle, and the last phonemes in a word, identify words with the same final sound, or remove a phoneme from the word. During phoneme segmentation training, the subject was instructed to articulate each phoneme of the word consecutively, with a pause of two seconds between each phoneme. For example, to separate the phonemes of the word "hand" as "/h/, /æ/, /n/, /d/". To begin with, the examiner demonstrated this action to the subjects and then requested them to perform it. Through phoneme segmentation activities, the subjects realized that words consist of separate phonemes. During phoneme segmentation training, the subjects had difficulties with articulating the sound of the word accurately, inserting incorrect pauses between phonemes, and, for example, dividing the word into syllables rather than phonemes. In the case of these mistakes, the examiner would demonstrate the correct answer, direct the examinee to the right response, and finally, evaluate the subject to ensure proper word segmentation is being acquired. This is vital for students to have a successful learning experience and to maximize their progress. The examiner gave encouragement and praise when the subjects correctly answered during the procedure. Examples of phonemic awareness training are outlined below.

Education professionals in the education system can apply the results of this research in formulating lesson plans and giving practical skills training in primary schools, particularly in the first and second grades where students learn the fundamentals of reading, writing, and mathematics. The findings of this study can be highly pertinent to any future research in the domain of phonological awareness generally and phoneme awareness particularly, as well as factors influencing the learning and management of children experiencing learning disabilities. Finally, given the valuable results of this research for learning disability centers, phonemic awareness training can be applied to educate children with learning disabilities in these facilities as well as devise and implement suitable training and capability enhancement programs. It is noteworthy that some of the training sessions were derived from the phonological test of Dastjerdi and Soleimani (2006). Table 1 presents the course of training sessions.

Table 1

Phonological Awareness Training Sessions

Session	Training
1	Awareness and recognition of words, segmentation of sentence to words
2	Awareness of sounds, recognition of words with the same ending phoneme
3	Recognition of the initial sound of the word
4	Recognition of the initial sound of the word and removing it
5	Recognition of the final phoneme
6	Recognition of the ending sound of the word and removing it
7	Recognition of the middle sound of the word and removing it
8	Phoneme manipulation and Substitution
9	Phoneme segmentation
10	Phoneme segmentation and phoneme classification

In the following, to ascertain the effectiveness of phonological awareness training over a three-month interval (due to the lack of access of the researcher to the subjects because of the exam season and getting permission to attend classes again), both the control and experimental groups underwent a math test and a phonological awareness test as post-tests. Finally, descriptive and inferential statistics were then applied to analyze the obtained results.

3.2. Data Analysis

Considering that the phonological awareness test employed in the present study was a variant of the phonological awareness test by Dastjerdi and Soleimani (2009), its reliability was reassessed using Cronbach's alpha. The Cronbach's alpha coefficient for the entire phonological awareness test was 0.83, indicating good reliability.

For the components of the same final phoneme, phoneme segmentation, naming and removing the final ending phoneme, deleting the middle phoneme, and naming and deleting the initial phoneme, the numbers were obtained as 0.78, 0.80, 0.81, 0.77, and 0.79 respectively, which seemed appropriate. Besides, the reliability of the math test was calculated using Cronbach's alpha, yielding a score of 0.72 which is suitable reliability. For the purpose of data analysis, the Shapiro-Wilk test was applied to ascertain the normal distribution of the scores of the control and experimental groups. Levine's test was also applied to check the equality of variances and ultimately covariance analysis was performed.

4. Results

4.1. Descriptive Statistics

The research variables are elucidated. Tables 2 and 3 depict the skewness and kurtosis indices of the research variables to verify the normality. The normality of the data determines the optimal statistical method to answer the research questions (Dörnyei & Griffee, 2010). To measure the dispersion of the frequency of data and to verify the normality of the distribution, skewness and kurtosis statistical tests were used. According to the results for the control group, the mean operation score in the pre-test was 4.043, and in the post-test was 4.457.

Based on the results of the experimental group, the mean operation score in the pre-test was 4.1, and in the post-test was 5.44. Figure 1 shows the mean operation scores for both the control and experimental groups.

4.2. Inferential Statistics

In the present study, the Shapiro-Wilk test was utilized to evaluate the normality of the research variables. When checking the normality of the data, the null hypothesis of the normal distribution of the data is tested at a 5% margin of error. Therefore, if the test statistic is greater than 0.05, then there is no justification to reject the null hypothesis due to the normality of the data. That is to say, the data will conform to a normal distribution. Considering that the significance level of the pre- and post-test in the control group exceeds 0.05, it can be said that the investigated variables have a normal distribution.

Table 2

Results of Pre- and Post-Test Results in the Control Group

Variable	Pre-test				Post-test			
	Mean	SD	Skewness	Kurtosis	Mean	SD	Skewness	Kurtosis
Operation	4/043	0/842	-0/232	0/333	4/457	0/896	0/070	-0/696

Table 3

Results of Pre- and Post-Test in the Experimental Group

Variable	Pre-test				Post-test			
	Mean	SD	Skewness	Kurtosis	Mean	SD	Skewness	Kurtosis
Operation	4/100	0/745	-0/38	-0/420	5/44	0/795	0/644	-0/183

Figure 1

The Mean Operation Scores From Pre-Test and Post-Test in Two Control and Experimental Groups

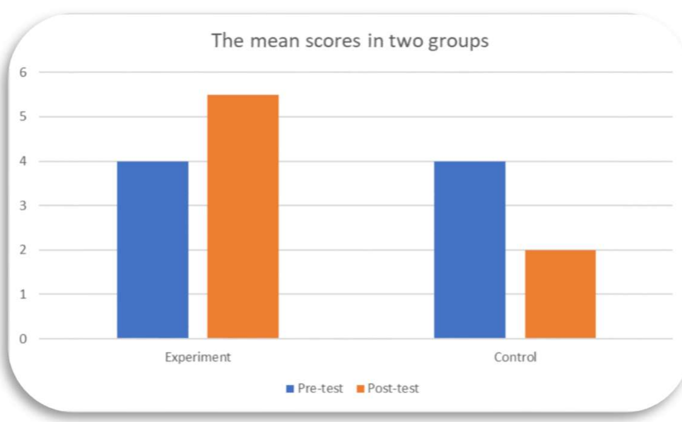

Table 4

Results of the Shapiro-Wilk Test in the Control Group

Variable	Pre-test			Post-test		
	Number	Test statistics	significance level	Number	Test statistics	significance level
Operation	70	0.874	0.071	70	0.879	0.083

Table 5

Results of the Shapiro-Wilk Test in the Experimental Group

Variable	Pre-test			Post-test		
	Number	Test statistics	significance level	Number	Test statistics	significance level
Operation	70	0.825	0.062	70	0.800	0.060

Since the significance level of the pre- and post-test in the experimental group is above 0.05, it is evident that the studied variables have a normal distribution. In addition, the analysis of covariance test was employed to assess the question: Does phonological awareness influence the operational area performance of second-grade female students? The tables below demonstrate the results. The mean and standard deviation of the two experimental and control groups in the post-test are presented in Table 6.

Table 6

Mean and Standard Deviation in Two Groups

Group	Mean	SD
Control	4.457	0.896
Experimental	5.443	0.792

Results from Table 6 demonstrate that in the post-test, the average score of the control group in mathematical operations was 4.457, whereas the average score of the experimental group was 5.443. Since Leven's test had a significance level greater than 0.05, the assumption of equality of variances is confirmed. Table 8 presents the results of covariance analysis.

Table 7

Results of Equality of Variances Test Pertaining to Operations

Leven statistic	Degree of freedom 1	Degree of freedom 2	level of significance
4.034	1	138	0.057

Table 8 reveals that the pre-test variable has an *F* statistic of 72.412 and a significance level of less than 0.05. In this way, the presupposition of a linear correlation between pre-test and post-test variables is verified.

Table 8

Results of Covariance Analysis Pertaining to Operations

Sources of variance	Sum of squares	Degrees of freedom	Mean squares	F statistic	Level of significance	Effect size
Modified model	68.117	2	34.058	72.303	<0.001	0.514
Width from the origin	29.271	1	29.271	62.141	<0.001	0.312
Pre-test	34.109	1	34.109	72.412	<0.001	0.346
Group	31.544	1	31.544	66.966	<0.001	0.328
Error	64.533	137	0.471			
Total	3563.000	140				
Modified Total	132.650	139				

In Table 8, the *F* statistic for the group variable was reported to be 66.966 and its significance level was lower than 0.001. In this way, it can be said with 99% certainty that there is a significant difference in the field of mathematical operations in both the control and experimental groups. In other words, the average operation score in the experimental group is greater than that of the control group. It is, therefore, evident that phonological awareness has a considerable effect on the operational test results of second-grade female students. Furthermore, the effect size of 0.328 was obtained which is a large effect size based on Cohen's criterion.

5. Discussion

The present study explored the effect of phonological awareness on the operation area of mathematical performance of monolingual Persian female students. Phonological awareness influenced the operation area of mathematics knowledge of second-grade female students. This means that phonological awareness training had a positive effect on the math operation area of second-grade female elementary school students. With a 99% certainty, it can be asserted that phonological awareness skill training has a positive effect on the performance of mathematical operations, including addition and subtraction.

After the concept area (there were three different fields in studying mathematics: concepts, application, and operation), phonological awareness skill training in the area of mathematical knowledge operations had the highest impact on the improvement and development of second-grade elementary school students.

The results of this study are in line with those of Hetch et al. (2001), Simmons et al. (2008), and Kuzmina et al. (2019). These researchers revealed that phonological awareness is a powerful indicator of math development. Evidently, these investigations have explored the association between phonemic awareness teaching methods and overall math performance. However, none have studied the efficacy of phonological awareness aptitude in a certain area of mathematics. Some researchers have confirmed the overlapping of phonological and mathematical processing networks. Some studies have not shown any correlation between phonemic and math skills. This can be attributed to various reasons in these studies. Factors such as not being limited to a specific age, the variety of tests used to measure phonetic skills, studying phonetic skills in general or as only a sub-component, using general tests to measure math skills in contrast to tests that give more accurate results of math, whether the initial level of math skills is controlled or not, the extent of controlling the general abilities of the cognitive domain and linguistic clarity, all affect the correlation between phonemic and math skills. Moreover, only the components of phonological awareness have been studied in the relevant literature, overlooking the age range and the corresponding training of phonemic awareness skills while these are especially taken into consideration in the current study.

Therefore, of the seven sub-components of phonological awareness, only five components of identifying words with the same final phoneme, phonetic crossing, naming and omitting the final phoneme, naming and omitting the initial phoneme, and omitting the middle phoneme were selected being suitable for the age group under study and the other two sub-components of phonological awareness, namely phonological composition and recognition of words with the same initial phoneme, were left out because they were not suitable for the age group under study.

Echoing the elucidation of the outcomes of this investigation, Hetch et al. (2001) believe that some phonological manipulations require mathematical processes. Tasks dealing with beginning and ending sounds necessitate subtraction processes, while phonological integration tasks require addition processes (Hecht et al., 2001). Subtraction is rarely memorized and relies mostly on numerical operations. In other words, subtraction involves numerical operation areas.

Alternatively, the three-code model claims that there are different representational systems for the mental processing of numbers, each of which is related to different dimensions of calculation. As part of the language network, the verbal system is one of these systems; it is not just for numerical operations. This system is primarily tied to operations that require retrieving mathematical data from memory, such as multiplication and addition.

In this verbal system, numerical figures and mathematical information just like any other word are expressed lexically, phonetically, and syntactically. The system is linked to the language network of the left hemisphere (encompassing the middle and superior temporal gyrus) and most notably the left angular gyrus (Dehaene et al., 2005).

It seems that phonological awareness and phonological skill training affect mathematics because speech sounds play an important role in tasks such as math calculations and operations. Poor phonological ability may directly affect math achievement because math requires the retrieval and retention of verbal numerical codes.

There is a strong likelihood that different mathematical approaches will be utilized when operations affect brain activity. Temporoparietal brain activity is associated with math retrieval data (De Smedt, 2018).

Subtraction is a mathematical operation that necessitates temporal activity and can be solved using retrieval procedures and this is in line with the results of De Smedt and Boets (2010), who observed a notable association between phonological processing and problem retrieval and in fact, the quality of phonological representation explains the relationship between phonological processing and mathematical data retrieval. Simmons et al. (2008) were the pioneers of the exploration of the neural overlap between phonological and mathematical processing. They concentrated on the parietal cortex while observing brain activity during a phonological task and subtraction task. In the phonological task, subjects have to determine whether a specific phoneme is present in a visually presented word or not. This task requires a lot of activity in the inferior frontal gyrus and left angular gyrus compared to letter recognition control. In the subtraction task, a task involving the bilateral frontal parietal network, subjects have to subtract two numbers. By studying the overlap in brain activity between these two tasks, they found that a small area in the middle part of the posterior part of the intraparietal sulcus and the angular gyrus was activated during both tasks.

Andin et al. (2015) observed that the frontal regions of the left angular gyrus were more engaged in the phonemic task, while the posterior part of the left angular gyrus was more active in mathematics. Phonological memory, also known as the production or phonological loop, is the temporary encoding and storing of sound-based representations (Hecht et al., 2001). Decoding and storing phonological information in working memory should enable the child to pay close attention to solving continuous mathematical calculations (Bull & Johnston, 1997). For example, a child may decode "one plus two" as "1+2" when solving a simple math problem. Effective retrieval of simple math answers is possible when a strong link between the math problem and the representation of the answer is established in long-term memory (Siegler, 2015).

Neuro-imaging studies have confirmed the close relationship between phonological processing and mathematical data retrieval (Prado et al., 2011; Simon et al., 2002). These studies have shown that solving mathematical problems involves areas of the brain that are related to language processing (Pollack & Ashbay, 2018). Studies have also shown that children with math and reading problems are usually weak in phonological processing, while children who only have problems in math often do not have phonological problems (Geary, 1993; Moll et al., 2015). Studies have also proven that the co-occurrence of deficits in reading and math affects the quality of phonological representation, which is ultimately important for early reading and math (Amland et al., 2021).

Also, the evidence of cognitive neuroscience and neuro-imaging shows that there is an overlap between phonological awareness and mathematical performance; both are connected with the left temporal cortex areas of the brain, which leads to the activation of the left temporal cortex and the left gyrus. Meanwhile, activation of the left angular gyrus in phonological awareness tasks is related to individual differences (Mulhearn, 1999). Therefore, the left angular gyrus also plays a role in the use of mathematical numbers and figures in the sense that some mathematical dimensions have a linguistic basis (Vukovic & Lesaux, 2013). Since the same working memory that is used to solve mathematical problems is used to perform phonological tasks, both mathematical domains and phonological awareness require resources from phonological memory and central executive control. Repetition of mathematical data is based on phonological ability. When numerical data is repeated, phonological information must be generated and stored, and each repetition strengthens the association between the question and the answer (Jordan et al., 2015), which leads to learning. Therefore, the effect of phonological ability on math is more prominent in math functions that are based on data retrieval strategies (Polspoel et al., 2017).

To solve a simple problem, the general efficiency is the number naming codes that are available associated with the speed with which one can phonologically retrieve the answer code from long-term memory (Campbell, 1998). Successful retrieval of phonological naming codes requires the child's attention to use appropriate methods to solve the problem. On the other hand, phonological manipulation tasks such as subtracting or adding phonemes and syllables require mathematical processing (De Smedt, 2018). As a result, the phonological process can both facilitate and serve as a requirement for obtaining mathematical data. Put differently, phonologically proficient individuals outperform mathematicians. To be more precise, those with well-developed phonological skills tend to perform better in mathematics.

The quality of phonological representations can be important for solving mathematical problems in several ways. First, to solve a computational problem, the child must first convert the numbers and operations in the problem into speech-based codes (Dahaene et al., 1999; Hetch et al., 2001). It seems that children use this Arabic numerical to verbal translation in a routine and usual way not only to solve simple math problems but also for more general calculation problems such as divisions and long fractions. The second stage during which phonological representations may be important is after Arabic-to-verbal translation. The child must process phonological information using a task-solving strategy (=3+4); s/he must retrieve the answer directly from long-term memory, and thus the ability to solve such a problem depends on the storage of phonological information (Amland et al., 2021).

Conflict of interest

The author(s) certify/certifies that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in the present research paper.

References

Alloway, T. P., Gathercole, S. E., Adams, A. M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, *23*(3), 417-426. https://doi.org/10.1348/026151005X26804

Amland, T., Lervåg, A., & Melby-Lervåg, M. (2021). Comorbidity between math and reading problems: Is phonological processing a mutual factor? *Human Neuroscience*, *14*. https://doi.org/10.3389/fnhum.2020.577304

Andin, J., Fransson, P., Rönnberg, J., & Rudner, M. (2015). Phonology and arithmetic in the language–calculation network. *Brain and Language*, *143*, 97-105. https://doi.org/10.1016/j.bandl.2015.02.004

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. Journal of Experimental *Child Psychology*, *95*(3), 153-193. https://doi.org/10.1016/j.jecp.2006.04.003

Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (2002). Functional anatomy of intra-and cross-modal lexical tasks. *Neuroimage*, *16*(1), 7-22. https://doi.org/10.1006/nimg.2002.1081

Buchner, A., Steffens, M. C., Irmen, L., & Wender, K. F. (1998). Irrelevant auditory material affects counting. *Journal of Experimental Psychology*: Learning, Memory, and Cognition, *24*(1), 48. https://psycnet.apa.org/doi/10.1037/0278-7393.24.1.48

Bull, R., & Johnston, R. S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology*, *65*(1), 1-24. https://doi.org/10.1006/jecp.1996.2358

Campbell, J. (1998). Linguistic influences in cognitive arithmetic: Comment on Noel, Fias and Brsybaert (1997). *Cognition*, *67*(3), 353-364. https://doi.org/10.1016/s0010-0277(98)00025-0

Clements, D. H., & Sarama, J. (2016). Math, science, and technology in the early grades. *The Future of Children*, *26*(2), 75-94. https://www.jstor.org/stable/43940582

Dastjerdi, M., & Soleimani, Z. (2006). What is phonological awareness? *Exceptional Children*, *6*(4), 931-954. http://joec.ir/article-1-396-en.html

De Smedt, B. (2018). Language and arithmetic: The potential role of phonological processing. In Heterogeneity of function in numerical cognition (pp. 51-74). Elsevier.

De Smedt, B., & Boets, B. (2010). Phonological processing and arithmetic fact retrieval: Evidence from developmental dyslexia. *Neuropsychologia*, *48*(14), 3973-3981. https://doi.org/10.1016/j.neuropsychologia.2010.10.018

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2005). Three parietal circuits for number processing. In The handbook of mathematical cognition (pp. 433-453). Psychology Press.

Dehaene, S., Spelke, E., Pinel, P., Stanescu, R., & Tsivkin, S. (1999). Sources of mathematical thinking: Behavioural and brain-imaging evidence. *Science*, *284*, 970–974. https://doi.org/10.1126/science.284.5416.970

Dörnyei, Z., & Griffee, D. T. (2010). Research methods in applied linguistics. Wiley Online Library.

Espinas, D. R., & Fuchs, L. S. (2022). The effects of language instruction on math development. *Child Development Perspectives*, *16*(2), 69-75. https://doi.org/10.1111/cdep.12444

Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological, and genetic components. *Psychological Bulletin*, *114*(2), 345. https://psycnet.apa.org/doi/10.1037/0033-2909.114.2.345

Geary, D. C., Brown, S. C., & Samaranayake, V. A. (1991). Cognitive addition: A short longitudinal study of strategy choice and speed-of-processing differences in normal and mathematically disabled children. *Developmental Psychology*, *27*(5), 787. https://psycnet.apa.org/doi/10.1037/0012-1649.27.5.787

Guez, A., Piazza, M., Pinheiro-Chagas, P., Peyre, H., Heude, B., & Ramus, F. (2022). Preschool language and visuospatial skills respectively predict multiplication and addition/subtraction skills in middle school children. *Developmental Science*, *26*(3). https://doi.org/10.1111/desc.13316

Hecht, S. A., Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (2001). The relations between phonological processing abilities and emerging individual differences in mathematical computation skills: A longitudinal study from second to fifth grades. *Journal of Experimental Child Psychology*, *79*(2), 192-227. https://doi.org/10.1006/jecp.2000.2586

Jobstl, V., Steiner, A. F., Deimann, P., Kastner-Koller, U., & Landerl, K. (2023). A-B-3—associations and dissociations of reading and arithmetic: Is domain-specific prediction outdated? *Plos ONE*, *18*(5). https://doi.org/10.1371/journal.pone.0285437

Jordan, J. A., Wylie, J., & Mulhern, G. (2015). Mathematics and reading difficulty subtypes: Minor phonological influences on mathematics for 5–7-years-old. *Linguistic Influences on Mathematics*, *6*, 89-107. https://doi.org/10.3389/fpsyg.2015.00221

Kaltner, S., & Jansen, P. (2014). Mental rotation and motor performance in children with developmental dyslexia. *Research in Developmental Disabilities*, *35*(3), 741-754. https://doi.org/10.1016/j.ridd.2013.10.003

Koponen, T., Aunola, K., Ahonen, T., & Nurmi, J. E. (2007). Cognitive predictors of single-digit and procedural calculation skills and their covariation with reading skill. *Journal of Experimental Child Psychology*, *97*(3), 220-241.

Kourti, A., & Warmington, M. (2021). The relationship between mathematical abilities and phonological awareness skills in Greek students: A cross-sectional study in 1st graders. *Developmental & Adolescent Health*, *1*(3), 24-31. https://doi.org/10.54088/klgu85tis

Kuzmina, Y., Ivanova, A., & Kaiky, D. (2019). The effect of phonological processing on mathematics performance in elementary school varies for boys and girls: Fixed effects longitudinal analysis. *British Educational Research Journal* *45*(3), 640–661. https://doi.org/10.1002/berj.3518

Li, L., Zhang, H., Qi, Y., Lei, X., Yu, X., & Liu, H. (2023). More than visual-spatial skills: The important role of phonological awareness in mathematical abilities among Chinese primary school children. *Current Psychology*, *42*, 31810–31823 https://doi.org/10.1007/s12144-022-04151-2

Logie, R. H., & Baddeley, A. D. (1987). Cognitive processes in counting. Journal of Experimental Psychology: *Learning, Memory, and Cognition*, *13*(2), 310. https://psycnet.apa.org/doi/10.1037/0278-7393.13.2.310

Melekoglu, M. A. (2011). Impact of motivation to read on reading gains for struggling readers with and without learning disabilities. *Learning Disability Quarterly*, *34*(4), 248-261.

Moll, K., Göbel, S. M., & Snowling, M. J. (2015). Basic number processing in children with specific learning disorders: *Comorbidity of reading and mathematics disorders*. *Child Neuropsychology*, *21*(3), 399-417. https://doi.org/10.1080/09297049.2014.899570

Muitana, G. O. E., & Amato, C. A. de la H. (2022). The role of phonological awareness for reading, writing and mathematics in Brazilian studies and main assessment instruments: A narrative review. *Distúrb Comun, São Paulo*, *34*(2), e55697 https://doi.org/10.23925/2176-2724.2022v34i2e55697

Mulhearn S. G. K. (1999). Abdominal muscle endurance and its association with posture and low back pain: An initial investigation in male and female elite gymnastics. *Physiotherapy*, *85*(4), 210-6. https://doi.org/10.1152/japplphysiol.00572.2001

Plaza, M., & Cohen, H. (2004). Predictive influence of phonological processing, morphological/syntactic skill, and naming speed on spelling performance. *Brain and Cognition*, *55*(2), 368-373. https://doi.org/10.1016/j.bandc.2004.02.076

Pollack, C., & Ashby, N. C. (2018). Where arithmetic and phonology meet: The meta-analytic convergence of arithmetic and phonological processing in the brain. *Developmental Cognitive Neuroscience*, *30*, 251-264. https://doi.org/10.1016/j.dcn.2017.05.003

Polspoel, B., Peters, L., Vandermosten, M., & De Smedt, B. (2017). Strategy over operation: Neural activation in subtraction and multiplication during fact retrieval and procedural strategy use in children. *Human Brain Mapping*, *38*(9), 4657-4670. https://doi.org/10.1002/hbm.23691

Prado, J. M., Mutreja, R., Zhang, H., Mehta, R., Desroches, A. S., Minas, J. E., & Booth, J. R. (2011). Distinct representations of subtraction and multiplication in the neural systems for numerosity and language. *Human Brain Mapping*, *32*(11), 1932-1947. https://doi.org/10.1002/hbm.21159

Robinson, C. S., Menchetti, B. M., & Torgesen, J. K. (2002). Toward a two-factor theory of one type of mathematics disabilities. *Learning Disabilities Research & Practice*, *17*(2), 81-89. https://doi.org/10.1111/1540-5826.00035

Siegler, R. S. (2015). Variation, selection, and cognitive change. In Developing cognitive competence (pp. 31-76). Psychology Press.

Simmons, F., Singleton, C., & Horne, J. (2008). Brief report—Phonological awareness and visual-spatial sketchpad functioning predict early arithmetic attainment: Evidence from a longitudinal study. *European Journal of Cognitive Psychology*, *20*(4), 711-722. https://doi.org/10.1080/09541440701614922

Simon, O., Mangin, J. F., Cohen, L., Le Bihan, D., & Dehaene, S. (2002). Topographical layout of hand, eye, calculation, and language-related areas in the human parietal lobe. *Neuron*, *33*(3), 475-487.

Soleimani, Z., Arami, A., Mahmoudi Bakhtiari, B., & Jalai, S. (2008). The relationship between phonological awareness and dictation score of Persian second language students. *Cognitive Science Updates*, *37*(10), 21-28.

Thomson, M. E. (1991). Developmental dyslexia. Whurr publisher.

Vanbinst, K., Bergen, E., Ghesquière, P., & De Smedt, B. (2020). Cross-domain associations of key cognitive correlates of early reading and early arithmetic in 5-year-olds. *Early Childhood Research Quarterly*, *51*, 144–152. https://doi.org/10.1016/j.ecresq.2019.10.009

Vloedgraven, J., & Verhoeven, L. (2009). The nature of phonological awareness throughout the elementary grades: An item response theory perspective. *Learning and individual differences*, *19*(2), 161-169. https://doi.org/10.1016/j.lindif.2008.09.005

Vukovic, R. K., & Lesaux, N. K. (2013). The relationship between linguistic skills and arithmetic knowledge. *Learning and Individual Differences*, *23*, 87–91. http://dx.doi.org/10.1016/j.lindif.2012.10.007

Yang, X., & Mc Bride, C. (2020). How do phonological processing abilities contribute to early Chinese reading and mathematics? *Educational Psychology*, *40*(7), 893–911. https://doi.org/10.1080/01443410.2020.1771679