



UNIQUE CONTRIBUTIONS OF SUBITIZING AND SEQUENTIAL COUNTING TO ARITHMETIC COMPETENCE IN PRIMARY SCHOOL CHILDREN

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Abstract

Early numerical skills are considered critical foundations for the development of later mathematical competence. However, relatively few studies have examined the unique contributions of different foundational numerical processes within the same analytical framework. The present study investigated the relative roles of subitizing and sequential counting in explaining variability in early arithmetic competence among primary school children. A sample of 133 first-grade students completed computerized tasks assessing subitizing accuracy, forward counting, backward counting, and arithmetic competence. Correlation and hierarchical regression analyses were conducted to examine the relationships among these variables. Results indicated that both subitizing and sequential counting were significantly associated with arithmetic competence. However, when the shared variance among numerical skills was considered, backward counting emerged as the strongest independent predictor of arithmetic competence, accounting for the largest proportion of unique variance. Additional analyses examining reaction time and inverse efficiency scores further revealed that greater efficiency in numerical processing, particularly in backward counting, was associated with higher arithmetic performance. These findings suggest that early arithmetic competence may depend less on the recognition of small quantities and more on the ability to flexibly manipulate symbolic number sequences. From both developmental and educational perspectives, the results highlight the importance of symbolic sequence manipulation as a key mechanism linking early numerical representations to emerging arithmetic skills.

Keywords: subitizing, sequential counting, backward counting, arithmetic competence, numerical cognition

INTRODUCTION

Mathematical competence acquired in early childhood is a strong predictor of later academic and life outcomes, including employability, financial literacy, and health management (Geary, 2011; Dowker, 2023). Despite its critical importance, a substantial proportion of children experience persistent difficulties in acquiring foundational numerical skills. These challenges highlight the importance of understanding the cognitive mechanisms underlying early mathematical development and the factors that contribute to variability in children's arithmetic performance (Bruine de Bruin & Slovic, 2021; Kucian & von Aster, 2015).

Two foundational cognitive skills, subitizing and sequential counting, are widely recognized as key components of early numerical development and have been consistently associated with children's



emerging arithmetic competence. Subitizing refers to the rapid and accurate identification of small quantities, typically up to four items, without deliberate counting (Butterworth, 2010; Trick & Pylyshyn, 1994). This ability is supported by the Object Tracking System (OTS), a cognitive mechanism that enables the parallel individuation of a limited number of visual objects (Feigenson et al., 2004; vanMarle et al., 2016). Early numerical cognition has also been linked to approximate quantity processing mechanisms such as the Approximate Number System (ANS), which supports the estimation of larger quantities (Dolfi et al., 2024; Wilkey et al., 2020).

Subitizing can be broadly distinguished into perceptual and conceptual forms. Perceptual subitizing involves the rapid recognition of small quantities without sequential counting, whereas conceptual subitizing relies on grouping strategies that allow individuals to identify somewhat larger quantities through structured patterns (Clements & Sarama, 2014). Performance in subitizing tasks may vary depending on stimulus arrangement and visual complexity (Ashkenazi et al., 2013; Schindler et al., 2022). By enabling rapid identification of exact quantities, subitizing supports the mapping between perceptual quantities and verbal number labels.

Complementing subitizing, sequential counting represents a symbolic process involving the ordered recitation and application of number words according to principles such as stable order and one-to-one correspondence (Dowker, 2023). Through repeated engagement with number sequences, children learn to coordinate symbolic number words with quantities, enabling counting to function as an important developmental bridge toward arithmetic skills (Clements & Sarama, 2014; Estevez-Perez et al., 2019). While forward counting primarily involves retrieving a memorized sequence, backward counting requires the flexible manipulation of that sequence in reverse order. This process places greater demands on working memory and cognitive control and may therefore reflect a more advanced level of symbolic number processing that is closely related to arithmetic problem solving.

Arithmetic competence is typically conceptualized as a multidimensional construct involving numerical magnitude understanding, symbolic number knowledge, procedural skills, and arithmetic fact retrieval. Early numerical skills, such as subitizing and sequential counting, play a central role in this developmental progression by supporting children's ability to represent quantities, access number sequences, and coordinate numerical relationships during problem solving. Disruptions or delays in these foundational processes may therefore contribute to persistent variability in arithmetic performance. Empirical evidence supports this framework. Longitudinal research has shown that early subitizing and counting abilities are associated with later mathematics achievement (Gray & Reeve, 2014; Hannula-Sormunen et al., 2015; Lemaire & Callies, 2009). Furthermore, symbolic number processing, particularly symbolic number comparison and enumeration, has been identified as an important predictor of arithmetic development (Aragon et al., 2023). These findings highlight the role of early numerical representations and symbolic access processes in supporting children's emerging arithmetic competence (De Smedt et al., 2013; Mussolin et al., 2010; Rousselle & Noël, 2007). From this perspective, arithmetic competence can be understood as the outcome of an integrative process in which early quantitative representations become coordinated with symbolic numerical knowledge. Within this framework, subitizing supports the rapid identification of exact quantities, whereas sequential counting provides access to ordered symbolic number representations that enable children to represent numerical relationships and develop procedural strategies for solving arithmetic problems.

The relationship between foundational numerical skills and arithmetic performance may also be influenced by domain-general cognitive mechanisms such as executive functioning, working memory, and processing speed (Ashkenazi et al., 2009; Geary et al., 2007; Mazzocco & Grimm, 2013). For example, Cui et al. (2024) demonstrated that visual form perception fully mediated the relationship between subitizing and arithmetic ability, highlighting the role of perceptual and attentional processes in numerical development. However, relatively few studies have examined the unique and combined contributions of these foundational numerical skills within the same analytical framework.



Despite the substantial body of research on early numerical cognition, important gaps remain regarding how foundational numerical skills jointly contribute to children's developing arithmetic competence. Much of the existing evidence has been generated in Western European and North American contexts, leaving other educational settings comparatively underrepresented. Investigating these relationships in different linguistic and educational contexts provides an opportunity to examine the generalizability of existing theoretical models. In Türkiye, research examining the combined roles of subitizing and sequential counting in early arithmetic development remains limited. Examining these foundational processes within the same analytical framework may therefore contribute to a clearer understanding of how early numerical representations support the emergence of arithmetic competence. Previous research with Turkish children has highlighted the developmental importance of number concepts, counting principles, and the use of counting strategies in mathematical problem solving (Olkun et al., 2013; Olkun et al., 2014). Building on this evidence, examining subitizing and sequential counting together may provide a more differentiated understanding of the numerical processes associated with arithmetic competence among Turkish-speaking children. Such evidence may also contribute to the international literature by extending research on foundational numerical development to a comparatively underrepresented educational and linguistic context.

The present study examines the unique contributions of two foundational numerical skills (subitizing and sequential counting) to arithmetic competence in primary school children. Drawing on developmental models of numerical cognition, the study conceptualizes early arithmetic competence as emerging from the integration of non-symbolic quantity processing and symbolic number knowledge. Within this framework, subitizing reflects children's ability to rapidly recognize exact quantities, whereas sequential counting reflects their ability to access and flexibly manipulate ordered number sequences. Although previous research has established that both skills are associated with later mathematical achievement, relatively few studies have examined their relative contributions within the same analytical framework. It is therefore expected that both subitizing and sequential counting will be positively associated with children's arithmetic competence; however, because manipulating number sequences places greater demands on working memory and cognitive control, sequential counting, particularly backward counting, may account for additional variance in arithmetic performance beyond that explained by subitizing alone.

Based on these theoretical considerations, the present study addresses the following research questions:

RQ1. To what extent are subitizing and sequential counting associated with children's arithmetic competence?

RQ2. Do subitizing and sequential counting make unique contributions to explaining variability in arithmetic performance when examined within the same analytical model?

METHOD

Participants

The study sample consisted of 133 first-grade students enrolled in public primary schools in Ankara, Türkiye. Participants were selected according to several inclusion criteria. First, all children were native Turkish speakers to ensure linguistic consistency in the administration of numerical tasks. Second, students with any documented sensory, intellectual, or developmental disabilities (e.g., hearing, visual, or intellectual impairments) were excluded from the study based on school records and consultations with school counselors.

Teachers provided information about students' general mathematics performance and categorized them as average or low performers based on classroom assessments. This classification was used only to ensure variability in arithmetic performance and did not represent a formal diagnostic categorization.



To document the demographic characteristics of the sample, a background information form was completed for each participant. This form included information on students' gender as well as family socioeconomic indicators such as parental education levels and household income. The final sample was balanced in terms of gender and represented a range of socioeconomic backgrounds.

Stimuli and Tasks

The study employed three computerized paradigms designed to assess subitizing, sequential counting, and arithmetic competence. The computerized paradigms were developed as part of a larger research project supported by TÜBİTAK. All tasks were administered using specialized experimental software that presented stimuli on a computer screen and automatically recorded response accuracy and reaction times (in milliseconds). Instructions were pre-recorded and delivered audibly to ensure consistency in task administration.

Subitizing Task

Subitizing ability was assessed using a computerized adaptation of the task developed by Ashkenazi et al. (2013). In this task, participants were required to rapidly and accurately report the number of dots presented on the screen. Dot arrays ranged from 1 to 5 items and were displayed in both regular (structured) and scattered (random) spatial arrangements to capture variability in enumeration strategies.

Each trial began with a blank screen presented for 250 ms, followed by a fixation cross (+) displayed for 300 ms to orient participants' attention. After an additional 500 ms blank interval, the dot array appeared on the screen for 200 ms. Participants were instructed to report the number of dots as quickly and accurately as possible. Two practice trials were administered prior to the main task to ensure that participants understood the instructions.

The task consisted of 14 experimental trials presented in randomized order. Stimuli were generated using the NASCO program developed by Guillaume et al. (2020). All dots were displayed in black against a white background. Reaction time was calculated as the interval between stimulus onset and the participant's response. Accuracy scores were computed by assigning one point for each correct response and zero points for incorrect responses.

Sequential Counting Task

Sequential counting skills were assessed using computerized forward and backward counting tasks adapted from a commonly used counting sequence paradigm available through the Mathsframe educational resource. Participants were required to identify missing numbers within numerical sequences ranging from 1 to 99. The sequences progressed in rhythmic intervals of 1, 2, 3, 4, 5, or 10, thereby assessing children's ability to process and manipulate ordered number sequences.

Sequences were presented randomly and included items from both single-digit (1–9) and two-digit (10–99) number ranges. Each trial followed a standardized presentation sequence consisting of a 250 ms blank screen, a 300 ms fixation cross, and a 500 ms blank interval prior to stimulus presentation. The sequence remained visible on the screen until the participant responded.

Stimuli consisted of black numerical symbols displayed in Arial Black, 32-point font, against a white background within a black circular frame. Performance was measured using response accuracy, with one point assigned for each correct response and zero points for incorrect responses.

Arithmetic Competence Task

Arithmetic competence was assessed using two tasks: Operation Accuracy and Missing Operation. The Operation Accuracy task, adapted from Bellon et al. (2016), required participants to judge the correctness of basic arithmetic operations involving addition and subtraction. Each operation type included both correct and incorrect equations, with incorrect items generated by modifying the correct result by ± 1 . Participants indicated whether the presented operation was correct or incorrect.



The Missing Operation task was developed for the present study to assess children's ability to identify missing components within simple arithmetic expressions. Participants were required to determine the appropriate operation or value needed to complete the equation correctly.

Each trial followed a standardized presentation procedure consisting of a 250 ms blank screen, followed by a 300 ms fixation cross (+). The arithmetic problem was then displayed and remained visible until a response was made or a maximum response window of 20 seconds elapsed. If no response was provided within this time frame, the item was automatically coded as incorrect. Performance on the arithmetic task was evaluated using accuracy scores.

Validity and Reliability

Content validity of the paradigms was established through expert evaluation. A structured item specification table describing the objectives, instructions, and item construction procedures for each paradigm was submitted to three academics specializing in dyscalculia and learning disabilities. Experts evaluated each item with respect to theoretical relevance, clarity of instructions, alignment with the intended construct, and appropriateness of task difficulty on a five-point Likert scale (1 = not suitable to 5 = highly suitable).

Items were retained if they met the predefined criteria of a mean expert rating above 4.25, a standard deviation below 1.00, and a coefficient of variation under 25%. Items requiring revision were modified according to expert feedback prior to final task implementation.

Internal consistency reliability for each paradigm was calculated using the Kuder-Richardson Formula 20 (KR-20). The reliability coefficients indicated acceptable to high internal consistency across tasks: subitizing (.80), forward counting (.79), backward counting (.82), and arithmetic competence (.84). These values indicate that the paradigms provided reliable measurements of the targeted numerical constructs.

Procedure

Pilot Study

A pilot study was conducted with 15 first-grade students from two public primary schools in Ankara, Türkiye. Participants were identified by their classroom teachers as either average-performing ($n = 7$) or low-performing ($n = 8$) in mathematics. The sample included eight girls and seven boys, and none of the participants had any documented developmental or sensory disabilities.

Prior to participation, written informed consent was obtained from the students' parents. All pilot assessments were conducted individually using the computerized testing interface. Sessions took place in quiet rooms provided by the schools to ensure a distraction-free environment. During the administration, the participant and the researcher sat side by side, with students responding to the on-screen tasks while the researcher monitored the procedure.

The pilot study focused on evaluating the clarity of task instructions, the comprehensibility of the stimuli, and the overall administration time. Observations made during this phase informed minor adjustments to the paradigms and administration procedures prior to the main data collection.

Main Data Collection

The main data collection was conducted following ethical approval and official authorization from the Turkish Ministry of National Education. Individual assessment sessions were organized in designated quiet areas within the participating schools, such as empty classrooms, counseling rooms, or libraries.

Participation was voluntary, and all students were informed about the purpose and procedures of the study before the assessment began. Each session lasted approximately 20–25 minutes. A standardized administration protocol was followed for all participants. At the beginning of each session, the experimenter provided brief explanations and demonstrations of the tasks to ensure that participants understood the instructions. Participants were then asked to complete the tasks independently using the computerized interface.



The paradigms were administered in a fixed order: (1) subitizing, (2) sequential counting, and (3) arithmetic competence tasks. Upon completion of the assessment session, participants were thanked for their participation.

RESULTS

Descriptive statistics, correlation analyses, and hierarchical regression analyses were conducted to examine the relationships between subitizing, sequential counting, and arithmetic competence. Descriptive statistics for the primary study variables are presented in Table 1.

Table 1. Descriptive statistics for subitizing, sequential counting, and arithmetic measures

Variable	n	Mean	SD	Min	Max
Subitizing accuracy	133	10.13	2.95	0	14
Forward counting accuracy	133	5.35	2.52	0	10
Backward counting accuracy	133	4.95	2.80	0	10
Operation accuracy	133	6.83	1.27	3	8
Missing operation accuracy	132	8.05	3.11	0	14
Arithmetic competence	132	14.87	3.91	4	22
Subitizing RT (ms)	133	66,236.09	22,176.86	17,700	179,400
Forward counting RT (ms)	133	150,118.80	82,430.21	44,500	481,500
Backward counting RT (ms)	133	170,858.65	108,649.46	55,500	750,900
Operation RT (ms)	133	90,209.02	41,924.49	28,400	230,500
Missing operation RT (ms)	132	225,137.12	110,492.78	73,100	653,800

Note. RT = reaction time (milliseconds). RT values represent the total response time across trials. Arithmetic competence scores were calculated as the sum of operation accuracy and missing operation accuracy.

To address the first research question, Pearson correlation analyses were conducted to examine the associations between subitizing proficiency, sequential counting performance, and children's arithmetic competence. The correlation matrix for the main study variables is presented in Table 2.

Table 2. Pearson correlations among subitizing, sequential counting, and arithmetic competence

Variable	1	2	3	4
1. Subitizing accuracy	—			
2. Forward counting accuracy	.349***	—		
3. Backward counting accuracy	.431***	.787***	—	
4. Arithmetic competence	.412***	.629***	.708***	—

As shown in Table 2, arithmetic competence was positively associated with subitizing ($r = .412$), forward counting ($r = .629$), and backward counting ($r = .708$), with the strongest association observed for backward counting. In addition to these associations, significant relationships were observed among the predictor variables themselves. Subitizing accuracy was moderately correlated with both forward ($r = .349$) and backward counting ($r = .431$), while forward and backward counting showed a strong correlation ($r = .787$), suggesting that these skills represent closely related components of early numerical competence. Prior to conducting the regression analyses, potential multicollinearity among predictor variables was examined. Although forward and backward counting were strongly correlated, variance inflation factor (VIF) values ranged between 1.23 and 2.84, which are well below the commonly accepted threshold of 5. These values indicate that multicollinearity did not pose a threat to the stability of the regression estimates.

To examine the unique contributions of subitizing and sequential counting to arithmetic competence, a hierarchical multiple regression analysis was conducted. In the first model, subitizing accuracy was entered as the sole predictor to evaluate its independent contribution to arithmetic competence. In the second model, forward counting accuracy was added to examine whether sequential counting performance explained additional variance beyond subitizing proficiency. In the final model, backward counting accuracy was included to determine whether this more cognitively demanding



counting skill provided further explanatory power. The results of the hierarchical regression analysis are presented in Table 3.

Table 3. Hierarchical multiple regression predicting arithmetic competence

Model	Predictor	B	SE B	β	t	p	R ²	ΔR^2	VIF
1	Subitizing accuracy	.548	.106	.412	5.16	< .001	.170	—	1.00
2	Subitizing accuracy	.285	.094	.215	3.03	.003	.436	.266	1.15
	Forward counting accuracy	.856	.110	.553	7.81	< .001			1.15
3	Subitizing accuracy	.167	.090	.126	1.87	.064	.528	.091	1.23
	Forward counting accuracy	.284	.153	.183	1.85	.066			2.64
	Backward counting accuracy	.710	.143	.509	4.98	< .001			2.84

Note. Dependent variable = arithmetic competence. B = unstandardized regression coefficient; β = standardized regression coefficient; ΔR^2 = change in explained variance across hierarchical steps.

In the first model, subitizing accuracy was entered as the sole predictor. This model was statistically significant, $F_{(1,130)} = 26.62$, $p < .001$, explaining 17.0% of the variance in arithmetic competence ($R^2 = .170$). Subitizing accuracy was a significant predictor of arithmetic competence ($\beta = .412$, $p < .001$).

In the second model, forward counting accuracy was added to the regression equation. The inclusion of forward counting significantly improved the model, $\Delta R^2 = .266$, F change $_{(1,129)} = 60.99$, $p < .001$, increasing the total explained variance to 43.6% ($R^2 = .436$). Both subitizing accuracy ($\beta = .215$, $p = .003$) and forward counting accuracy ($\beta = .553$, $p < .001$) were significant predictors at this stage.

In the final model, backward counting accuracy was included. This addition produced a further significant increase in explained variance, $\Delta R^2 = .091$, F change $_{(1,128)} = 24.75$, $p < .001$, with the full model explaining 52.8% of the variance in arithmetic competence ($R^2 = .528$). In the final model, backward counting accuracy emerged as the strongest predictor ($\beta = .509$, $p < .001$), whereas the effects of subitizing ($\beta = .126$, $p = .064$) and forward counting ($\beta = .183$, $p = .066$) were no longer statistically significant. Semi-partial correlations were examined to estimate the unique contribution of each predictor to arithmetic competence. Results indicated that backward counting accounted for the largest proportion of unique variance in arithmetic competence ($sr^2 = .091$). In contrast, the unique contributions of subitizing ($sr^2 = .013$) and forward counting ($sr^2 = .013$) were comparatively small. These findings suggest that although subitizing and forward counting are associated with arithmetic competence, backward counting provides the strongest independent contribution when all predictors are considered simultaneously.

Additional analyses examined RT measures to explore processing efficiency in early numerical tasks. Reaction time values represented the cumulative response time across trials. Pearson correlation analyses were conducted to examine whether processing speed in early numerical tasks was associated with arithmetic competence. The results are presented in Table 4.

Table 4. Pearson correlations between reaction time measures and arithmetic competence

Variable	1	2	3	4
1. Subitizing RT	—			
2. Forward counting RT	.318***	—		
3. Backward counting RT	.259**	.593***	—	
4. Arithmetic competence	-.362***	-.062	.039	—

Note. RT = reaction time (milliseconds). ** $p < .01$, *** $p < .001$.

As shown in Table 4, subitizing reaction time demonstrated a significant negative correlation with arithmetic competence ($r = -.362$, $p < .001$), indicating that slower subitizing responses were associated with lower arithmetic performance. In contrast, reaction times for forward counting



($r = .062, p = .482$) and backward counting ($r = .039, p = .657$) were not significantly associated with arithmetic competence.

Additionally, significant positive correlations were observed among the RT measures themselves. Subitizing RT was moderately correlated with forward counting RT ($r = .318, p < .001$) and backward counting RT ($r = .259, p = .003$), while forward and backward counting RT were strongly correlated ($r = .593, p < .001$), suggesting that processing speed across numerical tasks may reflect a partially shared cognitive component.

To provide a more integrated assessment of performance that accounts for both response accuracy and processing speed, inverse efficiency scores (IES) were calculated for the subitizing and sequential counting tasks (Bruyer & Brysbaert, 2011). IES values were computed by dividing reaction time by the proportion of correct responses. Pearson correlation analyses were then conducted to examine the relationships between efficiency scores and children's arithmetic competence. The results are presented in Table 5.

Table 5. Pearson correlations between inverse efficiency scores and arithmetic competence

Variable	1	2	3	4
1. Subitizing efficiency (IES)	—			
2. Forward counting efficiency (IES)	.264**	—		
3. Backward counting efficiency (IES)	.277**	.631***	—	
4. Arithmetic competence	-.395***	-.440***	-.505***	—

Note. IES = Inverse Efficiency Score (reaction time divided by accuracy). Higher IES values indicate lower processing efficiency. ** $p < .01$, *** $p < .001$.

DISCUSSION, CONCLUSION, and RECOMMENDATIONS

The present study examined how two foundational numerical skills (subitizing and sequential counting) contribute to variability in early arithmetic competence. Overall, the findings suggest that although both perceptual quantity recognition and symbolic number-sequence knowledge are associated with children's arithmetic performance, their contributions are not equivalent. Subitizing was significantly related to arithmetic competence, indicating that early quantity representations remain an important component of numerical development (De Smedt et al., 2013; Feigenson et al., 2004; Schneider et al., 2017). However, when the shared variance among numerical skills was considered, backward counting emerged as the strongest independent predictor of arithmetic competence. This pattern suggests that the ability to flexibly manipulate symbolic number sequences may play a particularly central role in the transition from early quantity representations to formal arithmetic processing (Dowker, 2023). In this sense, variability in early arithmetic competence appears to depend less on the mere recognition of quantities and more on children's capacity to operate on symbolic number sequences in a flexible and coordinated manner.

The observed association between subitizing and arithmetic competence is consistent with developmental models suggesting that early numerical understanding begins with the rapid recognition of small quantities (Butterworth, 2010; Trick & Pylyshyn, 1994). Children who more efficiently recognized small numerosities demonstrated stronger arithmetic performance, supporting the view that early quantity representations provide a cognitive foundation for later numerical learning (Gray & Reeve, 2014; Hannula-Sormunen et al., 2015). However, the relatively small unique contribution of subitizing when other numerical skills were considered suggests that perceptual quantity recognition alone may not be sufficient to explain variability in arithmetic competence.

Recent international research further supports the importance of foundational numerical processes in the development of arithmetic competence. For example, Leuenberger et al. (2024) demonstrated that instructional support targeting conceptual subitizing and non-counting strategies can enhance first-grade students' numerical and computation competencies, while recent research has continued to identify counting and subitizing as important components of early mathematical development (Cruz et al., 2024). At the same time, evidence suggests that arithmetic performance depends on a broader



combination of numerical abilities, including counting knowledge and number-line representations (Chan & Mazzocco, 2024). Viewed alongside these findings, the present results extend the international literature by showing that, although subitizing is associated with arithmetic competence, the ability to manipulate symbolic number sequences, particularly through backward counting, may provide additional explanatory value for individual differences in first-grade arithmetic performance.

Sequential counting represents a critical step in the transition from perceptual quantity recognition to symbolic numerical processing (vanMarle et al., 2016). Forward counting requires children to access and reproduce the ordered sequence of number words, thereby supporting the coordination of symbolic representations with quantity information. In the present study, forward counting was strongly correlated with arithmetic competence, indicating that children who demonstrated greater fluency in accessing number sequences also tended to perform better in arithmetic tasks. However, when considered alongside other numerical predictors, forward counting did not uniquely explain additional variance in arithmetic performance. This pattern suggests that while forward counting reflects an important stage in the acquisition of symbolic numerical knowledge, its role may primarily involve the retrieval of memorized number sequences rather than the flexible manipulation of those sequences during problem solving (Geary, 2011). In this sense, forward counting may reflect children's access to symbolic numerical knowledge, whereas successful arithmetic performance appears to require the ability to actively transform and reorganize those symbolic representations.

In contrast to forward counting, backward counting emerged as the strongest independent predictor of arithmetic competence. Backward counting requires children to actively manipulate the number sequence in reverse order, a process that places greater demands on working memory, cognitive control, and the internal representation of the mental number line (Lemaire & Callies, 2009). Backward counting may reflect children's ability to mentally traverse the mental number line, a process closely aligned with the cognitive mechanisms underlying subtraction and arithmetic transformation. The substantial unique contribution of backward counting observed in this study suggests that arithmetic competence may depend less on the ability to retrieve number sequences and more on the ability to flexibly manipulate them, a pattern consistent with evidence showing that numerical ordering abilities predict arithmetic competence (Dowker, 2023; Lyons & Beilock, 2011). From a developmental perspective, this finding supports the idea that early arithmetic skills are closely linked to children's capacity to operate on symbolic number representations rather than merely accessing them. The results therefore highlight backward counting as a particularly informative indicator of children's readiness to engage in more complex arithmetic reasoning. Taken together, these findings suggest a developmental progression in early numerical competence, in which perceptual quantity recognition provides the initial foundation for numerical understanding, forward counting supports the acquisition of symbolic number sequences, and backward counting reflects a more advanced stage involving the flexible manipulation of symbolic numerical representations that directly supports arithmetic reasoning. From this perspective, backward counting may function as a behavioral indicator of children's emerging capacity to manipulate symbolic number structures, a cognitive process that appears to be closely aligned with the demands of early arithmetic reasoning.

In addition to accuracy-based analyses, the present study also examined the role of processing efficiency in early numerical performance. Reaction time analyses indicated that slower responses in the subitizing task were associated with lower arithmetic competence, suggesting that efficiency in rapid quantity recognition may reflect broader cognitive processing efficiency in early numerical tasks. Furthermore, analyses based on inverse efficiency scores revealed consistent relationships between efficiency in numerical processing and arithmetic competence, particularly for backward counting. Children who processed backward counting sequences more efficiently demonstrated substantially stronger arithmetic performance. These findings support the view that early mathematical competence is influenced not only by the accuracy of numerical representations but also by the efficiency with which these representations can be accessed and manipulated during cognitive processing (Wilkey et al., 2020). From a cognitive perspective, this pattern aligns with process-oriented accounts of numerical development suggesting that arithmetic performance depends



not only on the availability of numerical representations but also on the efficiency with which these representations can be coordinated during real-time problem solving (De Smedt et al., 2013). These results suggest that the development of arithmetic competence may depend not only on what numerical representations children possess, but also on how efficiently those representations can be mobilized during cognitive processing.

The linguistic and educational context should also be considered when interpreting these findings. Previous research with Turkish children has highlighted the importance of counting processes in the development of number concepts and mathematical problem solving (Olkun et al., 2013). Research with Turkish first-grade students has also demonstrated the developmental importance of counting principles during the early stages of formal mathematics education (Olkun et al., 2014). Although the present study was not designed to directly examine linguistic or cross-cultural effects, the strong association between sequential counting, particularly backward counting, and arithmetic competence provides further evidence from Turkish-speaking first-grade children. From an international perspective, these findings contribute evidence from a comparatively underrepresented educational and linguistic context and suggest that the role of sequential counting in arithmetic development warrants further examination across languages and educational systems.

From an educational perspective, the findings suggest that early mathematics instruction should emphasize not only counting proficiency but also the flexible manipulation of number sequences (Clements & Sarama, 2014). Although early mathematics activities frequently focus on forward counting and number identification, instructional tasks that require children to manipulate numerical sequences, such as backward counting, may more effectively support the development of arithmetic reasoning. Engaging students in such sequence-manipulation activities may strengthen number-line representations and provide an important bridge between early counting skills and the emergence of flexible arithmetic strategies (Kucian & von Aster, 2015).

Despite its contributions, several limitations should be considered when interpreting the findings. First, the cross-sectional design limits the ability to draw conclusions about developmental trajectories or causal relationships among numerical skills and arithmetic competence. Longitudinal research would provide stronger evidence regarding how these relationships evolve over time. Second, arithmetic competence was assessed using experimental paradigms rather than standardized mathematics assessments, which may limit the direct comparability of the findings with classroom-based achievement measures. Future studies could integrate standardized mathematics assessments to further examine the generalizability of the results. Finally, the present study focused on a sample of first-grade students in a single educational context. Replication across different age groups and educational systems would help clarify the extent to which the observed relationships reflect broader developmental patterns in early numerical cognition. Future longitudinal studies across diverse educational contexts are needed to clarify how early numerical skills develop into formal arithmetic competence.

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Ethics and Conflict of Interest

This study was conducted in accordance with the principles of ethical research involving human participants. Ethical approval was obtained from the Ankara University Ethics Committee (Approval Date: July 17, 2023; Meeting No. 16; Decision No. 159). In addition, the necessary official permissions to conduct the study in schools were obtained from the relevant authorities affiliated with the Turkish Ministry of National Education. Written informed consent was obtained from the parents or legal guardians of all participating children, and participation was voluntary. Participants were informed about the study procedures and their right to withdraw from the study at any time. All data were treated confidentially and used solely for scientific research purposes. We have no conflict of



interest to disclose. The authors declare that there are no conflicts of interest regarding the research, authorship, and/or publication of this article.

Author Contribution

Prof. Guldenoglu conceptualized the study and wrote the manuscript. Dr. Arslan collected the data. Assoc. Prof. Ozkubat contributed to the study design and provided support for the literature review. All authors reviewed and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study were collected as part of a national project supported by the Scientific and Technological Research Institution of Turkey (Project number: 123K646). Due to the terms of the project agreement, the data are not publicly available but may be made available by the authors upon reasonable request.

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