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Review and Prospect of Research on the Ability to Estimate the Number of Primary School Children

Tianqin Liu

Liaocheng University, Liaocheng, Shandong, 252059, China

ABSTRACT
The ability to estimate quantities is the core foundation of children's mathematical cognitive development, which essentially involves the psychological transformation of non symbolic information into numerical symbols through spatial mapping and proportional reasoning. Research has shown that children's development follows a cross-cultural universal path from logarithmic compression to linear representation. Chinese children excel in symbol estimation and strategy transfer due to their visual advantage in Chinese characters and numbers and early systematic training. The analysis of influencing factors shows that the characteristics of symbol systems, spatial skills, language abilities, and task design affect the ability to estimate quantities through interactive effects. The current research has limitations such as insufficient analysis of dynamic development mechanisms, unclear neural basis of digital representation, and lack of personalized educational interventions. In the future, a multidisciplinary integration framework needs to be constructed, and cross-cultural research needs to reveal the mechanism by which language structure shapes quantitative representations. This article proposes a collaborative research paradigm of "neural behavior education culture" to promote the transformation of mathematics education towards precision and provide a scientific path for the development of children's mathematical literacy in the digital age.

KEYWORDS
Quantity estimation capability; Cognitive neural mechanisms; Cross cultural differences and educational interventions

In the context of the digital age, the importance of mathematics learning for individual daily life and academic development has become increasingly evident. With the deep penetration of technologies such as artificial intelligence and big data, mathematical literacy has evolved from traditional subject abilities to core survival skills for digital citizens. The ability to estimate quantities, as the cornerstone of mathematical cognition, has increasingly highlighted its research value. Quantity estimation ability is a core element of children's quantity processing ability and a key foundational indicator for the development of children's mathematical abilities. Therefore, in order to clarify the current research status of children's estimation ability, this article summarizes and reviews the characteristics and limitations of current research based on a systematic review of existing achievements, and provides certain suggestions for future research.

1 Review of Research on Children's Quantity Estimation Ability

1.1 Concept and Types of Quantity Estimation

Quantity estimation is the cornerstone of human mathematical cognitive system, and its essence is the psychological transformation process of converting non symbolic quantity information into numerical symbols. Unlike precise counting, quantity estimation relies on approximate representation systems, involving the synergistic effects of spatial mapping, proportional inference, and working memory. This ability runs through the entire process of mathematics learning: after children master the meaning of numerical symbols, they construct psychological numerical lines through quantity estimation - that is, the systematic correspondence between numbers and spatial positions, which provides a cognitive framework for arithmetic operations and problem-solving.

The formation of psychological number lines marks a qualitative change in children's mathematical cognition. The psychological number line of 6-year-old children is limited to the range of 0-10, mainly relying on overall perception to determine the number position. After the age of 7, it expands to the range of 0-100 and develops a proportional judgment strategy - improving estimation accuracy through multiple reference points such as starting point, midpoint, and endpoint[1]. The innovation of measurement technology promotes theoretical breakthroughs: the M-shaped error distribution caused by traditional bounded digital line tasks (0-100) confirms that adults compress the middle region through reference points; After eliminating endpoint constraints in unbounded tasks, the fundamental support of working memory for direct estimation strategies is exposed[2].

The quantity estimation strategy exhibits significant hierarchical development characteristics. Young children (3-6 years old) rely on logarithmic compression strategies, manifested as a systematic overestimation of the small values at the right end of the numerical line; At the age of 7-8, there is a differentiation in strategies, with high ability children turning to linear representation and proportional judgment, while math challenged children still adhere to exponential function strategies. Research shows that children aged 3-6 have a 23% improvement in accuracy in physical set estimation tasks with reference conditions compared to without reference conditions, demonstrating the shaping effect of environmental cues on early strategy development. The flexibility of the strategy system increases with age, manifested as children being able to dynamically switch between overall perception and segmented estimation based on task characteristics.

1.2 Development model and evaluation mechanism for estimating the number of children

The development of children's ability to estimate numbers follows a universal cross-cultural pattern, but cultural background has a moderating effect on the speed of development. Chinese children show an advantage in numerical symbol estimation around the age of 4, and their accuracy surpasses the turning point of non symbol estimation earlier than Western children[3]. This may be related to the visual characteristics of the Chinese character numerical system and the intensity of early mathematical training. Although both Chinese and American children have experienced a transition from logarithmic representation to linear representation, Chinese children have a greater advantage in integrating feedback experiences and transferring strategies, as evidenced by the rapid linearization of the number line estimation model in primary school and a more significant correlation with math grades. This cultural difference suggests that the educational environment accelerates the reconstruction process of psychological digital lines by strengthening the connection between symbolic representation and spatial mapping.

The evaluation mechanism of digital line estimation has shifted from a single accuracy indicator to multidimensional cognitive diagnosis. Traditional error analysis (such as percentage absolute error) can reflect the overall level, but cannot distinguish between strategy types. The dynamic evaluation based on error distribution patterns (such as the use of M-type distribution marker proportion strategy) significantly improves diagnostic validity. Further integrating composite indicators such as numerical range and frequency of reference point usage can accurately identify the characterization defects of children with mathematical difficulties. The introduction of neuroscience techniques, such as eye tracking, reveals the micro mechanisms of strategy execution: children with high quantity estimation abilities exhibit regular visual attention allocation in tasks, while those with low quantity estimation abilities exhibit fixation drift.

1.3 Factors influencing the estimation of the number of children

The development of children's quantity estimation ability is significantly influenced by the interaction between symbolic system characteristics and cognitive resources. Research has shown that there are essential differences in the cognitive pathways of symbolic and non symbolic processing: studies have found that training with numerical comparison is more effective in improving symbolic approximation arithmetic ability than training with numerical line estimation[4]. This echoes the strong predictive power of symbol comparison tasks on mathematical achievements [5]. This difference is particularly prominent in the field of scores. Research has found that integer estimation can predict score performance in fifth and sixth grade children, indicating that higher grade students have formed an integrated representation system across quantitative dimensions. Non symbolic processing relies more on embodied cognitive mechanisms.

Space processing and language proficiency are key influencing factors. Research has found that spatial skills are the core mediating variable for estimating gender differences on the number line, while the deficits in sequential processing in children with mathematical difficulties directly affect their efficiency in using reference points. The language system exerts influence through a dual pathway: research has found that language ability has a sustained predictive effect on the estimation of the number of young children, while relational language (such as "bigger/smaller") can significantly predict the adoption of subsequent quantity order strategies[6]. This language space interaction is manifested in task execution as children need to convert numerical knowledge into spatial mapping through analogical reasoning. Research has found that young children rely more on previous estimates as dynamic reference points due to working memory limitations[7].

Task parameter settings affect estimated performance by adjusting cognitive load. Research has found that limited range numerical tasks require activation of proportional judgment and computational processing, and their correlation with mathematical ability is significantly stronger than unbounded tasks. This difference is further highlighted in the perceptual bias caused by graphic arrangement - the study found that top students can effectively suppress the overestimation of quantity caused by regular graphic arrangement[8]. The grade differences in strategy selection are particularly significant: studies have found that lower grade children use more concrete strategies (such as finger representation), while higher grade children turn to abstract proportional reasoning, which leads to a non-linear correlation between number line estimation and arithmetic performance.

1.4 Cognitive neural mechanisms for estimating the number of children

The study of cognitive neural mechanisms for estimating the number of children reveals the dynamic interaction between strategy selection and neural representation. In the bounded number line task, individuals actively anchor endpoints or midpoints through a proportional judgment strategy, which is accompanied by collaborative activation of the prefrontal parietal network, resulting in a significant increase in the number of annotations to the reference point[9]. In contrast, the unbounded digital line task weakens the dependence on proportional strategy, resulting in a monotonic decrease in gaze patterns with increasing numerical values. This difference suggests that the task type affects the visual spatial processing path by changing cognitive load [10]. Further neuroimaging evidence shows that the improvement in score level processing induced by digital line training is directly related to the enhancement of neural markers in the intraparietal sulcus distance effect, confirming that strategy optimization can reshape the neural basis of quantitative representation.

The cognitive ecological validity of task design significantly moderates the evaluation results. There are grade differences in the representation patterns of 0-100 and 0-1000 digit lines among Chinese children, and this hierarchical development suggests that the task scope should be matched with the cognitive development stage of children. By adjusting task parameters (such as highlighting the midpoint), the utilization rate of proportion strategies among lower grade students can be successfully improved, proving that interface design can guide cognitive strategies in a targeted manner. It is worth noting that although unbounded tasks can reduce spatial representation bias, their potential representation consistency with bounded tasks in lower grade children suggests age specific limitations on the impact of task form differences on evaluation validity.

2 Limitations of the Study on Children's Quantity Estimation Ability

In the field of cultivating children's quantity estimation ability and cognitive development research, scholars have delved into cognitive patterns and strategies, revealing the impact of factors such as numerical comparison and numerical line estimation on quantity estimation ability. The research on numerical line estimation focuses on numerical line estimation ability and its influencing factors, exploring key factors and strategies in cognitive development such as psychophysical models, proportional judgment strategies, and psychological rotation ability. In addition, research on digital line estimation has revealed cognitive mechanisms and educational applications, such as task presentation, digital representation, spatial visual skills, etc., providing important references for optimizing mathematical cognitive theory and educational practice. However, there are still unresolved issues:

For example, there is insufficient research on the dynamics and complexity of the development process of quantity estimation, and a lack of in-depth exploration of the characteristics and influencing factors of different stages. The research method is single, mostly focused on cross-sectional studies, lacking longitudinal studies to reveal continuity and stages. On the one hand, the underlying psychological mechanisms of digital representation have not been fully revealed, such as the neural basis and cognitive processes of digital representation; On the other hand, there is insufficient research on the differences in digital representation under different cultural backgrounds and their impact on the development of quantitative abilities. Although educational interventions have achieved certain results in enhancing the development of numerical perception, existing intervention measures still have limitations. Firstly, the intervention measures lack specificity and often adopt a single strategy, lacking personalized intervention plans tailored to individual differences. Secondly, the evaluation methods for intervention effectiveness are single and rely heavily on mathematical scores, lacking assessment of other related abilities in the development process of quantity estimation. Furthermore, the implementation effect of intervention measures lacks long-term tracking research, making it difficult to evaluate the long-term impact of intervention measures on the development of logarithmic perception. In terms of intervention strategies, although existing research has proposed some specific strategies for cultivating quantitative estimation abilities, the evaluation criteria for intervention effectiveness are not unified, making it difficult to form a reliable evaluation system.

3 Prospects for the Study of Children's Quantity Estimation Ability

3.1 Cognitive neural mechanisms

The current research consensus is that the development of children's ability to estimate numbers is a product of the combined effects of the neurocognitive system, educational environment, and task characteristics. Basic cognitive abilities such as psychological rotation and spatial mapping affect mathematical performance through strategic mediation, while the effectiveness of educational interventions is constrained by individual strategic development stages[11]. Future research needs to focus on breaking through the following directions:

Research has found that digital line training can optimize score level processing by enhancing the connections between the parietal prefrontal network, but the age sensitive period of this process is not yet clear. In the future, longitudinal brain imaging techniques (such as fMRI) need to be combined to track the neural changes in 5-10 year old children during proportional reasoning training and identify key window periods. For example, the effectiveness of midpoint reference training in second grade suggests that the maturity of prefrontal executive function may be a prerequisite for successful intervention[12].

3.2 Educational Policy Implications in the Context of Globalization

The cross-cultural transplantation of advantageous educational elements requires caution. In the future, a balanced approach needs to be explored: retaining non symbolic estimation games in kindergarten and gradually strengthening symbolic spatial connections in lower primary school grades. The establishment of an international comparative database is imperative. By collecting cross-border data through standardized testing, cultural specificity and universality development milestones can be identified.

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