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# *A review of research on mental rotation*

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***Abstract:*** Based on the metrological analysis, it is found that domestic and international studies on mental rotation have focused on five aspects, namely, the connotation and doctrinal hypothesis of mental rotation, the measurement method, the developmental value, the ability of mental rotation in different populations, as well as the intervention and training methods of mental rotation. A conceptual consensus on mental rotation has been formed, its important value and plasticity for individual learning and development have been affirmed, and some assessment and intervention training programmes have been developed, but there are still controversies in terms of gender differences and age characteristics. In the future, we should deepen the empirical research on psychological rotation in education and enhance the application value of the research results.

## 1. Key elements of national and international research on mental rotation

### 1.1 Connotation and mechanism of mental rotation

#### 1.1.1 The meaning of mental rotation

Many scholars at home and abroad have defined the meaning of mental rotation. In terms of time, this concept can be traced back as far as Shepard and Metzler's three-dimensional mental rotation experimental study in 1971, who regarded mental rotation as an analogous process, arguing that the mental rotation that subjects perform in their minds on the reflections of visual stimuli is similar to the physical rotation of objects in the real environment, and stating that it is an ongoing process. [1]It was further stated that the ability to mentally rotate is a spatial thinking ability in which the individual mentally imagines the perceptual object rotating around one or more axes.In short, mental rotation is an important part of spatial ability, and its basic meaning has already achieved a certain consensus in the academic community and become a basic concept in the field of psychology, which has been established in the relevant tools.

#### 1.1.2 Mechanisms of mental rotation

Researchers have the following views on the intrinsic occurrence of mental rotation: the first, the apparent rotation hypothesis. Shepard and others proposed the apparent rotation hypothesis, also called the analogue hypothesis, which suggests that in a mental rotation task, subjects first mentally imagine a visual stimulus representation with a tilted angle, thus rotating the representation to an upright position in physical space. [2]The second, postcorrection processing hypothesis. In a mental rotation task, subjects are presented with a number of comparison pictures (current stimulus) and a

standard picture, which is the antecedent stimulus. The third, reference frame hypothesis. Roberston, a representative of the hypothesis, argued that in the mental rotation task, subjects do not rotate the current representation with a certain tilt angle, but rather rotate the subjective reference frame already existing in their minds. [3]The fourth type, the propositional representation hypothesis. This hypothesis is the position of cognitive psychology on the issue of mental rotation, which holds that propositional representation systems can represent non-word information such as spatial relations in addition to word information.[4]

### 1.2 Measurement of mental rotation ability

Depending on the subject and the purpose of the study, mental rotation is measured in different ways. On the one hand, when the subject of the study is an infant who is unable to actively provide information for measurement by verbal or motor manipulation, or when it is necessary to investigate the internal mechanism of the occurrence of mental rotation in the study, observation with the aid of technological means is used. On the other hand, when the subjects were individuals who were able to actively provide measurement information through verbal or manipulative actions, task measures were used to assess mental rotation ability in a variety of forms, mainly using various images.

### 1.3 Developmental value of mental rotation skills

#### 1.3.1 Mental rotation is related to the development of spatial and mathematical abilities

Academics believe that mental rotation is most closely related to spatial and mathematical abilities among many others. Tzuriel pointed out that mental rotation ability has a very obvious and significant relationship with an individual's IQ due to the fact that mental rotation ability itself is a basic spatial thinking ability of an individual. Spatial ability is an important component and assessment indicator of mathematical intelligence, and thus there is also a close correlation between mental rotation and mathematical ability, including mental arithmetic, numerical analysis, and logical deduction in mathematical learning.[5]

#### 1.3.2 Mental rotation is predictive of the development of other abilities

Yan Mingstated that visually impaired students' mental rotation ability is related to orientation ability and participation in group ball activities. Zhang Xiaomei used the Seston's Spatial Test and the Chinese Wechsler Intelligence Test to show that mental rotation ability is important for the intellectual development of young children, the establishment of neural circuits in the brain, as well as their future career choices or achievements in certain disciplines. Song Yang et al. found that mental rotation ability constrained orienteering athletes' map recognition efficiency, and that map recognition efficiency decreased with increasing rotation angle.[6][7]

### 1.4 Research on the mental rotation capacity of different populations

#### 1.4.1 Age profile of mental rotation capacity

Mental rotation in preschoolers. Hou Gonglin et al. found that young children already possessed mental rotation ability at age 4. It has also been argued that infants actually already have mental rotation ability, but only because younger children are unable to fulfil the requirements of existing mental rotation ability measurement tasks. Some groups of scholars have realised that the shortcomings of the research instrument limit the scope of the study, leaving room for further

research.[8]

Mental rotation ability of primary school students. Cai Huajian and Chen Quan found that mental rotation ability showed a steady increase during childhood. Shangjie found that children aged 6-8 years old were able to complete the measurement task, but only with varying efficiencies of completion.

Mental rotation ability of secondary school students. Cai Huajian pointed out that an individual's mental rotation ability reaches the highest level of development between the first and second years of junior high school. [9]Zhou Zhen and Lian Siqing found that there was no significant difference between the mental rotation ability test scores of first and second year student.[10]

Mental rotation ability of college students and adults. Lin Zhongxian found that there were significant differences among different age groups, in which the young people's group was better than the other groups in terms of both speed of judgement, practice and accuracy.

### 1.4.2 Gender differences in mental rotation capacity

On the one hand, some scholars believe that there are gender differences in the development of mental rotation ability, and they have also indicated the age point at which the differences occur.[11] Li-Hua Zheng found significant gender differences in the development of mental rotation skills among students in grades 7-11.Moore showed that gender differences in the development of mental rotation can occur as early as the early childhood years. Levine found that there were significant gender differences in performance on a spatial information transfer task involving mental rotation in children.

On the other hand, there are scholars who believe that there is no gender difference in the development of mental rotation ability. Based on brain waves, Pan Yu and others found that there is no significant gender difference in young individuals' representational and mental rotation abilities. Quaiser and Neuburger found no significant gender differences in mental rotation accuracy, although there was a slight male advantage.[12]

### 1.4.3 Mental rotation capacity of special populations

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental disorder centred on narrow interests, repetitive stereotyped behaviours, and social communication deficits, which generally occurs in early childhood.[13] In a study, Souli ères found that children in the autism group performed better than the normal group in terms of the speed and accuracy of their cube design scores on a mental rotation task. [14]Based on the theory of mind deficit hypothesis, Bennie Wang conducted an experiment with 4-7 year old children with autism and noted that children with autism lagged behind normal children in both direction perception and mental rotation.

The ability of visually impaired people to mentally rotate first originated in Marmor's 1976 study of congenitally totally blind, acquired totally blind, and blindfolded sighted people, which showed that congenitally totally blind people had the same ability to mentally rotate as the other two groups of subjects.[15] Rovira and others found that the overall response time of sighted people was significantly higher than that of congenitally blind people under the touch condition using vision but that the visually impaired people were richer and more flexible in terms of their touching strategies. Impaired people were more rich and flexible.[16]

There is no academic consensus on the definition of children with learning disabilities, in which the DSM-IV-TR manual issued by the APA organisation in the United States divides learning disabilities into dyslexia, dyscalculia and dysgraphia and other types of disorders (Zhou Luping, Shuyan Zhou found that children with learning disabilities were less efficient than normal children in responding to short-term memory extraction and mental rotation activities.

### 1.5 Intervention training methods for mental rotation skills

Firstly, mental rotation ability is improved through teaching and training.[17] Chen Xinying pointed out that by learning angles and coordinates in geometry, the mental rotation ability of first-year students and adults can be improved. Zhang Xiaomei believes that we should follow the principle of "physical operation-concrete situation-semi-abstract-abstract" to create vivid teaching situations for children and guide them to experience the practical meaning of things after rotation.

Second, mental rotation can be enhanced through gaming experiences. Quaiser found that both children and adults can improve mental rotation performance through action and stimulation-based computer games. Kang Dan and Wen Xin and mathematical abilities of young children.[18]

Finally, mental rotation development can be intervened through sport-specific training. Jansen P et al. found that girls learning acrobatics had significantly faster reaction times in a mental rotation task compared to their physically trained peers. Liu Jingru et al.[19][20]

## 2. Comments and perspectives on existing research

### 2.1 Review of existing research

The large body of research on mental rotation at home and abroad has made important contributions in two broad ways: firstly, the research that has been conducted has gradually developed a consensus on many aspects, which provides a solid foundation for us to recognise and understand mental rotation and to consider its translational applications in the field of education. These include: the development of a conceptual consensus on mental rotation; the affirmation of the high correlation between mental rotation and spatial ability and mathematical learning, and hence its value for individual learning development; and the recognition of the malleability of the ability to make mental rotations, and the development and design of a number of inspiring assessment and intervention training programmes. Secondly, the ingenious research designs and tools developed in many of the studies have provided important inspiration for subsequent research in this and even related fields.

Despite the remarkable achievements, there are still some issues in the existing research that deserve reflection and improvement. Firstly, there are still obvious contradictory understandings about whether there are gender differences in mental rotation. Secondly, there is still ambiguity in the academic understanding of the occurrence and development of mental rotation and age characteristics.

### 2.2 Prospects for future research

In order to enhance the contribution of psycho-rotational research results, we should focus on two aspects in the future: First, from the academic perspective of the research, it is currently mainly focused on psychology (mainly cognitive psychology and developmental psychology) and medical perspective, and in the future, we can consider more use of brain imaging and other technical means to strengthen the exploration of basic issues such as the principle of its occurrence and development from the perspectives of cognitive neuroscience, and to further clarify the understanding of the divergence of the gender difference; it is also necessary to pay attention to the use of it in the field of education and its role in individual learning from the perspectives of learning science and other perspectives.

Second, deepen the educational empirical research. There are abundant empirical studies on mental rotation, but there is a lack of empirical studies on education, and the existing empirical studies on education lack actionable experimental results. It has been proved that mental rotation

ability can be improved through educational means such as teaching games and intervention training. Therefore, it is suggested that while continuing to strengthen the exploration of the theory of mental rotation, we should conduct a more in-depth investigation of the theory of mental rotation in the light of the development of society and history and culture.

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