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The Mental Cutting Test "Schnitte" and the Picture Rotation Test—Two New Measures to Assess Spatial Ability

Claudia Quaiser-Pohl
Institute of Psychology
Otto-von-Guericke-University Magdeburg, Germany

Two new measures to assess spatial ability are presented: the mental cutting test "Schnitte" (Fay & Quaiser-Pohl, 1999; English version: Fay, Quaiser-Pohl, & Rönicke, 2003), a test for selecting people with extraordinary spatial abilities, and the Picture Rotation Test (Hinze, 2002; Hinze & Quaiser-Pohl, 2003), a mental rotation test for preschool children. Both overcome some of the limits of traditional spatial ability testing: (a) Most spatial problems are also "visually" and "analytically" solvable, and (b) there is a lack of standardized tests for preschool children. The ideas of both tests are described as well as their developmental processes. In addition, the results of the first evaluations of both tests are reported.

From the beginning of psychometric intelligence testing (Binet & Simon, 1905), spatial tasks have been included in many intelligence tests. Moreover, spatial abilities have been considered an important component in many influential intelligence models (e.g., Guilford, Fruchter, & Zimmerman, 1952; Thurstone, 1938). Also, contemporary intelligence theories point to the importance of spatial intelligence in contrast to, for example, verbal or bodily-kinesthetic intelligence (e.g., Gardner, 1993). The weak evidence of construct validity of the so-called spatial abilities, however, has often been discussed (e.g., Caplan, MacPherson, & Tobin, 1985), and besides theoretical considerations, this has also led to criticism concerning the way they are operationalized through spatial tests.

In the following pages two new spatial ability tests are introduced that can overcome some of the limits of contemporary spatial ability testing. They are the mental cutting test "Schnitte" (Fay & Quaiser-Pohl, 1999; English version: Fay,

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Requests for reprints should be sent to Claudia Quaiser-Pohl, Institute of Psychology, Otto-von-Guericke-University Magdeburg, P.O. Box 4120, D – 39016 Magdeburg, Germany. E-mail: claudia.quaiser@gse-w.uni-magdeburg.de

Quaiser-Pohl, & Rönicke, 2003), a test for selecting people with high spatial abilities, and the Picture Rotation Test (Hinze, 2002; Hinze & Quaiser-Pohl, 2003), a mental rotation test for preschool children.

THE MENTAL CUTTING TEST "SCHNITTE"

The Mental Cutting Test "Schnitte" was developed by Fay and Quaiser-Pohl (1999; Quaiser-Pohl & Fay, 2000) and is a new method for assessing extraordinarily high spatial abilities. Its measuring range is *spatial visualization*, which is based on complicated, multistep manipulations of spatially presented information (Linn & Peterson, 1985; Thurstone, 1938). Subjects have to mentally cut three-dimensional geometrical figures (e.g., pyramids, cones) that are hollow. These figures must be cut by a plane or another geometrical figure and the two-dimensional mental-cut surfaces (e.g., triangles, rectangles) resulting from the given cutting operations must be determined. For instance, any cut through a sphere will always produce a cut surface with a circular shape. More complex forms result from cutting more complex geometrical figures.

Item Construction

Items were constructed by applying generative rules and on the basis of classical test theory. Item construction was based on a given set of three-dimensional geometrical figures (F), the mental cutting operation (O), and a set of products (P), that is, two-dimensional figures as cut surfaces (see Figure 1).

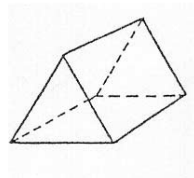
Instruction

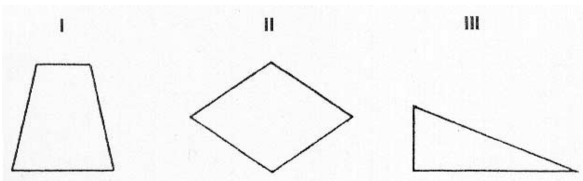
It takes 15 min to give the detailed written instruction (see Fay & Quaiser-Pohl, 1999). In the instruction the problem that has to be solved (i.e., the cutting operation) is introduced as well as the three-dimensional geometric figures and the two-dimensional cutting views.

Answer Format and Scoring

The tests consist of 17 items; answers have to be chosen from a multiple-choice format. For each item there are five given answer alternatives, only one of which is correct. The scoring system gives subjects one point for each item with the correct answer. So the maximum attainable score is 17. An example of a "Schnitte" problem, including the proposed answers, is given in Figure 2.

A prism, consisting of three rectangles and two Equilateral triangles at the ends (as seen on the right) is going to be cut by a plane.
Which of the following cut surfaces can result?





(A) only I and II
(B) only II and III
(C) only I and III
(D) I, II, and III
(E) none of those cut surfaces can emerge

FIGURE 1 Example of a `Schnitte` problem. Only one of the five possible answers given is correct. In this example the correct answer would be C (only I and III).

Objectivity

Objectivity is ensured because of the standardized answer sheet and the detailed written instruction. A stencil sheet, in addition, helps to analyze and count the correct answers. The comparative values in the form of test norms guarantee interpretation objectivity.

Reliability

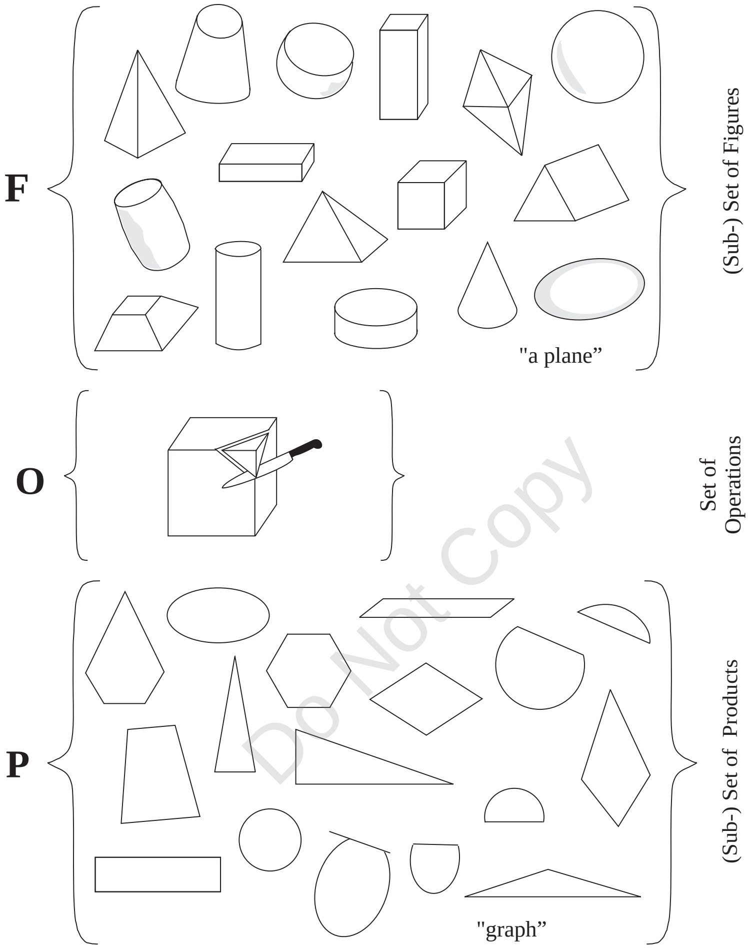
Retest-reliability after 15 weeks was .72 and, thus, satisfying. Item homogeneity measured as internal consistency (Kuder–Richardson Formula 20) was also good and ranged from .75 to .80.

Validity

Face validity of the test was ensured by self-trials and by thinking aloud protocols during task solving (Quaiser-Pohl, 1998). They all indicated that the subjects were doing mental cuttings in a multistep visualization process.

Correlations with external criteria showed convergent and discriminant validity. There were moderate or high correlations with other spatial tests, for example, r = .64 with the Cube Perspective Test (Stumpf & Fay, 1983) and r = .46

ITEM CONSTRUCTION



Cut two elements out of **F**:
Which elements out of **P** can result ?

One or several elements out of **P** are given:
When cutting which element out of F can $\mathbf{P_1} \ldots \mathbf{P_n}$ result ?

Given is an element out of **F** and one or several elements out of **P**:
Which other elements out of **F** can be cut with the given one that $\mathbf{P_1} \ldots \mathbf{P_n}$ results?

FIGURE 2 Item construction of the “Schnitte” items applying generative rules with the Mental Rotations Test (MRT) by Vandenberg and Kuse (1978) in a redrawn version by Peters et al. (1995). This shows “Schnitte” on the one hand to be a spatial ability test but on the other hand to measure a different spatial subfactor than these tests.

There were also high correlations with mechanical comprehension tests, such as the Mechanical Comprehension subtest of the Aptitude Test Battery of the German Federal Armed Forces (r = .53) and the Mechanical Technical Comprehension Test (MTVT) by Lienert (1963; r = .64); moderate correlations were found with the Figure Reasoning subtest (r = .41) and the Arithmetic subtest (r = .40) of the Aptitude Test Battery of the German Federal Armed Forces.

Low-to-zero correlations were found with verbal tests, such as a word relations test (r = .20); with a spelling test (r = .19); with attention and concentration tests, such as the Test d2 (Brickenkamp, 1981; r = .04); with a signal-detection test for visual differentiation (r = .17); and with an acoustic discrimination test (r = .03); low correlations were found with a reaction speed test (r = .16).

The correlations with school marks were also as expected (Quaiser-Pohl & Lehmann, 1999). In a sample of 10th- to 13th-grade German high school students, high correlations were found with physics (r = .51–.81) and mathematics (r = .58), moderate correlations with other sciences (biology: r = .30; chemistry: r = .37), and low correlations with languages (English: r = .14; German: r = 06).

Moderate gender differences in “Schnitte” test performance favoring male subjects were found. Their moderate effect sizes ranged from η^2 = .104 in a sample of Canadian university students to η^2 = .143 with German university students (Rönicke, 2003). This is in line with other findings of gender differences in tests measuring the visualization subfactor (Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995).

In addition, a study with computational visualistics[1] students showed extremely high “Schnitte” performance in this group and also compared with other tests such as the Mental Rotations Test (Peters et al., 1995; Vandenberg & Kuse, 1978). The performance even increased with the year of study (Quaiser-Pohl & Lehmann, 2002; Quaiser-Pohl, Lehmann, & Schirra, 2001). So it can be assumed that the mental cutting test “Schnitte” is a valid instrument, especially for measuring the mental process of visualization.

Test Duration

The completion of the test takes 45 min; there is a 30-min testing time and another 15 min for the detailed instruction.

[1]Computational visualistics is a degree program lately introduced at the Otto-von-Guericke-University of Magdeburg, Germany, combining computer science knowledge with studies on pictures in the humanities and with applied knowledge, for example, in medicine.

Test Difficulty

The mental cutting test "Schnitte" is a very difficult spatial ability test. The mean item difficulty ranges from .39 to .48 in different subgroups, which is very high compared to other spatial tests. This and the results of a study with 10th- and 11th-grade students from high schools in Sachsen-Anhalt, Germany, accentuating the mathematical-scientific profile (Lehmann, 2000; Quaiser-Pohl & Lehmann, 1999) indicate the test to be appropriate to measure high ability or even giftedness in mathematics and science.

Test Norms

Test norms exist from a total sample of more than 1,500 persons. There are comparable values in the form of percentage ranks for different subgroups (e.g., German college students, German and Canadian university students majoring in various subjects) and different ages (e.g., 10th-, 11th-, 13th-grade students, adults), each separated for gender (see Fay & Quaiser-Pohl, 1999).

Applications

The mental cutting test "Schnitte" can be used for aptitude testing in areas where extraordinary spatial ability is needed—for example, for college or university entrance examinations, especially for physics, computational and mathematical sciences, or for engineering. It is also appropriate as a vocational aptitude test—for example, for pilots, designers, architects, for technical professions such as electrician, and for IT professions.

Advantages

Compared to other spatial tests measuring visualization ability (e.g., 3DW, Gittler, 1990; DAT Paper Folding subtest), the "Schnitte" problems are not solved by looking at visually presented stimuli. Subjects have to mentally produce solutions by themselves, imagining the three-dimensional figures as well as the cutting operation and the possible resulting cutting views in a dynamic process. Because there are no visually presented stimuli, the problems also cannot be solved by just reasoning.

THE PICTURE ROTATION TEST (PRT)

Mental rotation, as the ability to "rotate a … three dimensional figure rapidly and accurately" (Linn & Peterson, 1985, p. 1483), is an important spatial ability. However, although its development and its gender differences as well as the influencing factors are interesting and well-studied topics, there are no standardized tests for its assessment in younger children.

Test Idea

The Picture Rotation Test (PRT) is a mental rotation test for pre- and early primary school children (ages 4–6). It was constructed in analogy to other well-known mental rotation tests for adults (e.g., Peters et al., 1995; Vandenberg & Kuse, 1978), all using the experimental paradigm invented by Shepard and Metzler (1971) in a paper-and-pencil format. In this paradigm, subjects had to compare pairs of three-dimensional cube figures with each other. And as a linear relation was found between reaction time and rotation angle, it was concluded that subjects solving the problem mentally rotated the figures (Cooper & Shepard, 1973).

The development of the Picture Rotation Test was also based on earlier studies on spatial ability and mental rotation with children (e.g., Dean, Scherzer, & Chabaud, 1986; Hatekayama, 1989; Kerr, Corbitt, & Jurkovic, 1980; Marmor, 1975, 1977). These studies dealt with Piaget's assumption that children are not capable of kinetic imagery before reaching the concrete operational stage in cognitive development. According to Piaget, children in the preoperational stage, between 1.5 and 7 years of age, only "remember the initial and final state of an object in motion but are unable to recognize or reproduce the intermediate states" (Kerr et al., 1980, p. 55). So children at this age would not be able to do mental rotations because they can only produce static representations of spatial objects. Piaget and Inhelder (1971) further postulated that at the age of 7 or 8 years a capacity of "imaginal anticipation makes its first appearance, enabling the subjects to reconstitute kinetic and transformation processes, and even foresee other simple sequences" (p. 358).

Although some studies could confirm this assumption (e.g., Kerr et al., 1980), others found children much younger than 7 years of age being able to do mental rotations (e.g., Estes, 1998; Marmor, 1975, 1977). In sum, the results of these studies revealed that mental rotation ability in children depends on some features of the stimuli that have to be rotated, such as their familiarity, their concreteness, and their salience, as well as on circumstances of the test administration, for example, test situation, instruction, answering format, time limit (Rosser, Ensing, & Mazzeo, 1985). These considerations were taken into account for the construction of the Picture Rotation Test.

Test Material and Items

Test stimuli are colored three-dimensional pictures of humans and animals (see Figure 3) that have to be rotated in the plane. In each item one target figure and three comparison figures are given, two of which are mirror images and one is rotated in the plane. Children have to identify the rotated stimulus as identical with

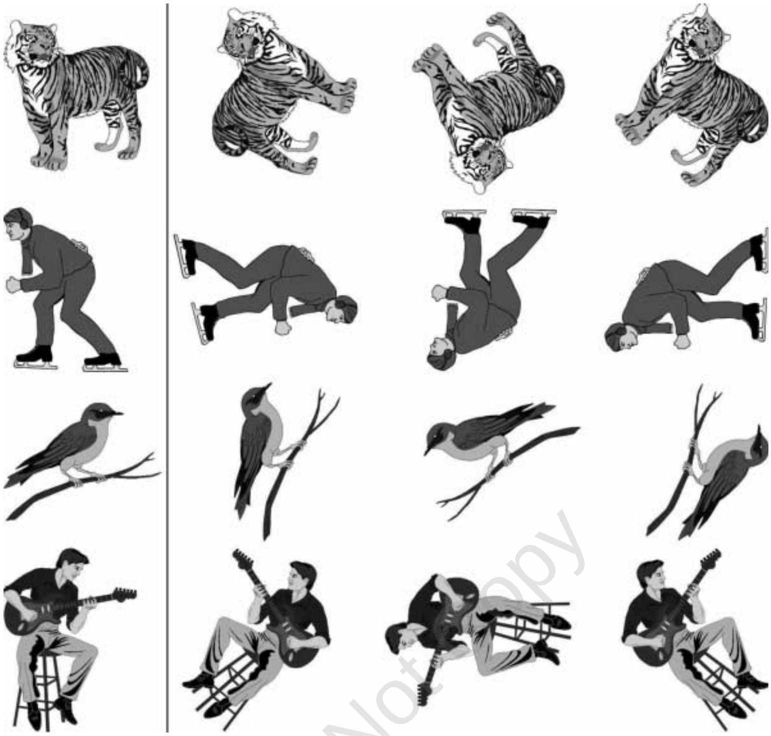


FIGURE 3 Picture Rotation Test (PRT); Example Items

the target figure. The test consists of 12 of these items (6 human items and 6 animal items) plus 2 example items.

Instruction

Many studies have shown that when children are tested, a detailed instruction is necessary to make sure that they have understood what they were asked to do. So in the Picture Rotation Test children are led to the problems step by step (see Hinze, 2002, pp. 54–56). The detailed verbal instruction starts with the demonstration of the rotation process using concrete gum toy animals (i.e., crocodiles) and includes the completion of the two example items. There is always given feedback about whether the answer was correct or not.

Item Construction

To present concrete objects that are familiar to children, pictures of humans and animals were chosen as stimuli (see Figure 3). In addition, colored instead of black-and-white pictures were used because in pretests such test material had proved to be more attractive and motivating for children of this age group. As studies have shown that the salience of the stimuli and the existence of orientation markers are important for mental rotation tasks for children (Courbois, 2000; Rosser et al., 1985), pictures were chosen that had these features.

Another element of the test material to be chosen was the dimensionality of the stimuli (two- or three-dimensional figures) and of the rotation (in-depth or in the plane). Similar to the mental rotations tests for adults, three-dimensional figures were chosen. Shepard and Cooper (1982) found no difference in reaction time between two- and three-dimensional mental rotation, and in other studies with younger children (Estes, 1998; Marmor, 1975, 1977), objects had to be rotated in the plane. So we decided to rotate the stimuli in the plane too.

The item order was deliberately chosen; one human item and one animal item alternated with each other. This was done to prevent an association between testing time and type of item.

The rotation angle between target figure and identical comparison figure also varied systematically in 45° steps—there are seven different rotation angles from 45° to 315° clockwise. This was done to increase task variety and to be able to measure the relation between rotation angle and item difficulty. The rotation angle of the 12 items as well as the position of the identical figure in each item was randomized. The rotation angle of the two distractor stimuli was given by chance.

Answer Format and Scoring

Because guessing probability is high (50%) with pair comparisons and in analogy to the Mental Rotations Test (MRT; Peters et al., 1995; Vandenberg & Kuse, 1978), a multiple-choice answer format was chosen with one target stimulus and three comparison stimuli, one of which was an identical stimulus and two were distractor stimuli. All distractors are mirror images of the target figure. The scoring system gives subjects one point for each item with the correct answer. So the maximum score is 12.

Objectivity

Objectivity is maximized due to the detailed written instruction. A stencil sheet, in addition, helps to analyze and count the correct answers. Test norms in the form of percentage ranks guarantee interpretation validity.

Reliability

Reliability was satisfying; item homogeneity measured as internal consistency (Cronbach's alpha) was .751, and split-half reliability was .737. Stability in the form of retest reliability has not been studied, and there are no parallel forms yet.

Validity

Mean test scores were above guessing probability for the 5-year-olds (*M* = 5.76; *SD* = 2.85) and the 6-year-olds (*M* = 5.63; *SD* = 2.87) and for second-grade dyslectic children (*M* = 6.1; *SD* = 2.86).

Significant performance differences between age groups ($F = 4.67$, $p = .011$, $\eta^2 = .08$) and dyslectic and nondyslectic children ($F = 16.11$, $p < .011$, $\eta^2 = .20$) were observed. This is an indicator of PRT's validity because spatial ability is still discussed as one cause of dyslexia.

As expected, and in line with other studies on mental rotation, item difficulty increased with the rotation angle (see Figure 4), when taking into account that figures can be rotated in both directions (clockwise and counterclockwise).

Correlations with external criteria showed convergent and discriminant validity. In the second-grader group, there were high correlations with mental rotation tests (i.e., $r = .727$ with a letter rotation test and .572 with a cube-figure rotation test). Only moderate correlations were observed with other spatial ability tests for children of this age group—for example, $r = .341$ with the subtest "Muster legen" (pattern forming) of the Vienna Developmental Test (Kastner-Koller & Deimann, 1998) and $r = .398$ with the Embedded Figures subtest of the Leistungsprüfsystem (LPS; Horn, 1983). This confirms that the construct validity of the Picture Rotation Test really measures mental rotation ability.

The correlations with kindergartners' ratings of children's development in different areas were also as expected (Quaiser-Pohl & Lehmann, 1999). Low correlations were found with ratings of language development ($r = .273$) and with the ability to concentrate; moderate correlations were found with motor development ($r =$

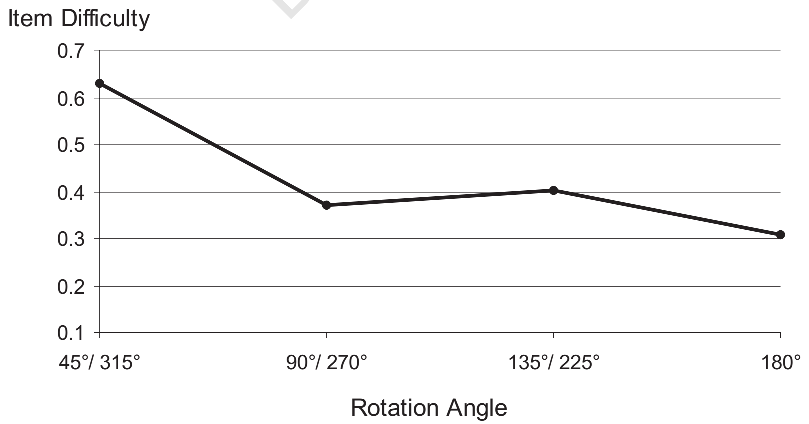


FIGURE 4 Relation between item difficulty and rotation angle.

.337). A significant effect of the kindergartners' rating of general development on PRT performance was observed ($F = 7.826$, $p = .001$, $\eta^2 = .13$).

Only descriptive but not significant differences in PRT test performance were found. This might be a consequence of the fact that the PRT is administered as a power test. Many studies have shown that in spatial tests without a time limit, the gender differences vanish. But it can also be due to the age of the children because it is still not clear at what age gender differences in spatial abilities appear; some authors think that this does not occur before puberty.

Test Duration

Because preschool children usually are not able to concentrate on a task for a long time, the number of items was reduced to 12. The Picture Rotation Test is a power test, that is, it has no time limit. In general, the completion of the test takes 10 to 15 min; there is 5- to 10-min testing time, and another 5 min for the detailed instruction.

Test Difficulty

The mean item difficulty increases with age and ranges from .32 (3 years, 11 months–4 years, 5 months) to .50 (5 years, 7 months–5 years, 11 months). No ceiling effect was observed in a sample of 111 kindergarten children from 3 years, 11 months to 6 years, 3 months but in a group of nondyslectic second graders.

Test Norms

There are test norms (percentage ranks) for 5- and 6-year-old children. Studies with larger samples and with first graders are planned.

Applications

The Picture Rotations Tests can be used for developmental assessment and aptitude testing in spatial abilities (i.e., mental rotation). This is especially interesting not only for the early assessment of retardation but also for giftedness in this area. As there is a close relation between spatial and mathematical abilities, the PRT can also be used as an early screening of dyscalculia or mathematical giftedness. The observed differences between dyslectic and nondyslectic children make the test an appropriate means for early screening of dyslexia.

Studies on gender differences in spatial abilities have always revealed the largest and most consistent differences favoring males in mental rotation (Linn & Peterson, 1985; Voyer et al., 1995). But the contributions of biological factors to this finding, in contrast to learning and socialization, still remain unclear (Harris, 1981; McGee, 1979; Quaiser-Pohl et al., 2001; Self, Gopal, Golledge, & Fenstermaker, 1992). To answer this question, mental rotation must be studied very early in life, which has been impossible so far because there are no mental rotation tests appropriate for younger children. With the Picture Rotation Test (PRT) such studies can be easily done now.

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