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# Applications of mental rotation figures of the Shepard and Metzler type and description of a mental rotation stimulus library

Michael Peters [*,1], Christian Battista

*Department of Psychology, University of Guelph, Ont., Canada N1G 2Z5*

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**Abstract**

The 3D cube figures used by Shepard and Metzler [Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171*, 701–703] have been applied in a broad range of studies on mental rotation. This note provides a brief background on these figures, their general use in cognitive psychology and their role in studying spatial behavior. In particular, it is pointed out that large sex differences with the 3D mental rotation figures tend to be observed only in particular tasks, such as the Vandenberg and Kuse test [Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, *47*, 599–604] that involve multiple figures within a single problem. In contrast, pairwise presentation of the same 3D figures yields either small or no significant sex differences. In the context of the very broad range of ongoing research done with 3D figures, and the desirability of uniformity in the stimulus material used, we introduce a library of 16 cube mental rotation figures, each presented in orientations ranging from 0 to 360 degr in 5 degr steps, and with its mirror image, for a total of 2336 figures. This library, freely available to researchers, will help in the creation of mental rotation tasks both for presentation on the computer screen and for pencil and paper applications.


*Keywords:* Mental rotation; Stimuli; Test; Sex differences; Shepard and Metzler; Vandenberg and Kuse

## 1. Introduction

This short note contains two separate parts. First, there will be a very brief coverage of the nature and applications of three dimensional cube figure mental rotation figures in psychological research and, second, there will be a description of a library of such figures that will allow researchers to address the entire spectrum of research questions touched upon in the first part.

## 2. Part I

In Linn and Petersen's (1985) meta-analysis of spatial ability, mental rotation was considered a category that was separate from spatial perception and spatial visualization. The mental rotation of visual objects can be studied with a variety of figures, both two dimensional and three dimensional. Two dimensional stimuli, such as letters or nonsense figures of varying complexity, can only be rotated in the picture plane while three dimensional stimuli can be rotated in depth as well. The vast majority of mental rotation studies with three dimensional stimuli have been based on figures composed of cubes and the seminal study using such figures was published by Shepard and Metzler in Science, in 1971 (Shepard & Metzler, 1971). The figures are presented as two-dimensional visual images that are constructed of 10 cubes and are perceived as three dimensional figures. They are generally referred to as 3D figures even

* Corresponding author. Fax: +1 519 837 8629.
*E-mail address:* mpeters@uoguelph.ca (M. Peters).
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though a more correct description would label them as "quasi - 3D" figures because the figures are rendered only in two dimensions (Deregowski, 1979). In the Shepard and Metzler paradigm subjects were presented with a pair of cube stimuli where one figure was rotated with respect to the other, and one of the figures could be identical to or a mirror image of the comparison figure. The task for subjects was to decide, quickly and accurately, whether the two figures were the same or different. Much of the research based on Shepard and Metzler's work asked the question of how subjects rotate figures in their mind's eye and was thus directed at fundamental neurocognitive mechanisms (cf. Kaushall & Parsons, 1981; Shepard & Metzler, 1988; Thomsen et al., 2000; Waszak, Drewing, & Mausfeld, 2005) of spatial perception.

A different application of the Shepard and Metzler figures was introduced by Vandenberg and Kuse (1978). They used the S/M figures to create a pencil and paper test for spatial abilities. One consequence of the availability of a paper and pencil test was the facilitation of studies of individual and group differences, with a focus on the testing of larger groups of subjects. Much of the work done with this or similar tests is correlational in nature, where the research question takes the form "does performance on this test correlate with specific individual characteristics or performances on other tasks"? Examples for this type of research are: is there a relation between mathematical/scientific interests and spatial ability (Casey, Nuttall, & Pezaris, 1997; Geary, Gilger, & Elliott-Miller, 1992; Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006), does mental rotation performance predict choice of field of surgery and ability in surgeons (Anastakis, Hamstra, & Matsumoto, 2000; Brandt & Davies, 2006; Hedman et al., 2006; Wanzel et al., 2003), or are changes in hormone levels during the menstrual period reflected in mental rotation performance (Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Gunturkun, 2000)? However, by far the most common application of the Vandenberg and Kuse test is as prototypical test for sex differences in spatial ability. The sex differences reported initially by Vandenberg and Kuse proved to be reliable and large. Linn and Petersen (1985) summarized the findings of their meta-analysis of sex differences by stating that "We found larger effects at all ages for the Vandenberg and Kuse (1978) version of the Shepard–Metzler mental rotation test than for the other measures of mental rotation "(p. 1487). This conclusion has stood the test of time (Voyer, Voyer, & Bryden, 1995). In much of the research that has followed the original Vandenberg and Kuse paper, it is the sex difference, be it in the context of cultural influences (Quaiser-Pohl & Lehmann, 2002), multicultural comparisons (Peters et al., 2006), or hormonal influences on mental rotation performance (Yang, Hooven, Boynes, Gray, & Pope, 2007), that has received most attention.

While Linn and Petersen provided an extensive discussion of the work done by Shepard and Metzler and others who worked with the "pairwise" presentation paradigm, they did not note the fact that sex differences were not commented upon in these earlier studies. In seeking reasons for the discrepancy between the "pairwise" presentation paradigm and the presentation used in the Vandenberg and Kuse test, a partial explanation can be found in the experimental designs that are favored in studies that examine basic mechanisms as opposed to individual and group differences. In most of the studies by Shepard and Metzler and their successors, small numbers of subjects were given large numbers of trials. Due to interindividual differences in performance and the small number of subjects, it would have been more difficult to detect sex differences under these conditions and this may account for part of the discrepancy. However, even when larger numbers of subjects are tested, the sex differences on the "pairwise" (henceforth referred to as "S/M") presentation tend to be either nonsignificant or notably weaker than for the "V/K" presentation (Butler et al., 2006; Peters, 2005; Voyer et al., 2006). One possible explanation for the weaker effects for sex with the S/M presentations lies in the individual problems used in this and the Vandenberg and Kuse test. In the V/K presentation, subjects are shown a target figure derived from the Shepard and Metzler figures, and four comparison figures that are arranged to the right of the test figure. Two of these figures are rotated versions of the test figure and two are not. Thus, in performing mental rotations with the comparison figures, subjects have to identify which comparison figures match the target figure and which do not.

The most salient differences between the S/M presentation and the V/K test are as follows. In the pairwise presentation, eye movement travel is limited to travel between the two figures. In contrast, solution of the V/K problems requires more extensive eye movement travel between the five figures because the solution of each of the V/K problems (Vandenberg & Kuse, 1978) is based on multiple comparisons rather than only one. At the very least, the target figure has to be compared with each of the comparison figures and subjects have to ascertain that they do not make false positive choices or false negative choices for each of the four figures, and in each case the eye travel trajectory is farther than is the case for the pairwise S/M presentations. To the extent that for each comparison some processed version of comparison figure has to be kept in memory so that it can be compared to the target figure, the memory load for such comparisons must be appreciably higher for the V/K problems than for the S/M presentation. In particular, while the S/M presentation allows the subject to concentrate on two figures only, with no requirement to inhibit interference from a previous stimulus pair, the V/K presentation requires rapid switching between stimulus pairs that have to be "assembled" from the range of choices available, with active inhibition of interference from other stimulus pairs that are in play for the duration of dealing with a given problem.

There also is the factor of time in the solution of mental rotation problems. Traditionally, in the Shepard and Metzler paradigms, the reaction time is noted whenever a decision is made. Thus, subjects perform a given number of