



# Violation of pure insertion during mental rotation is independent of stimulus type, task, and subjects' age

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## Abstract

The experiment validated and extended the finding of Ilan and Miller (1994) [A violation of pure insertion: mental rotation and choice reaction time. *Journal of Experimental Psychology: Human Perception and Psychophysics* 20, 520–536] that the mental rotation process is not purely inserted into a mirror-normal discrimination task. In contrast to their work we used other experimental stimuli (drawings of animals instead of characters), a different task (same/different comparison) and investigated this effect under a developmental perspective. Adults and children between the age of 8 and 10 took significantly longer to respond to upright drawings of animals in conditions containing rotated stimuli than in conditions containing only upright stimuli, indicating a violation of pure insertion. In general, we found evidence that the violation of pure insertion during a mental rotation task itself can be generalised across stimulus type, task, and subject populations. However, for children this effect was independent of the format of the stimuli, while for adults the effect was larger for mirror-imaged than for identical objects. This suggests that the violation of pure insertion might occur at different processing stages as a function of age.

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## 1. Introduction

The cognitive process of imagining the representation of an object turning around is called mental rotation (Shepard & Metzler, 1971) and constitutes an important aspect of the general class of spatial transformations as well as a critical ingredient in spatial intelligence. Thanks to the many fields dealing with mental rotation, a bulk of evidence has accumulated suggesting, e.g., that mental rotation is implemented in the parietal cortex (e.g., Jordan, Heinze, Lutz, Kanowski, & Jäncke, 2001) and works in a continuous, analog way (e.g., Heil, Bajric, Rösler, & Hennighausen, 1997).

The mental rotation process is typically studied in the mirror-normal discrimination task (Cooper & Shepard, 1973) with stimuli presented in different orientations. Participants are required to decide whether e.g., an alphanumeric character is presented in its normal form or as a mirror image. The overall finding is an approximately linear increase of reaction time with increasing angular departure from the upright. It is assumed that participants rotate a stimulus back into the upright position before a mirror-normal judgement can be made. The processing stages involved in a mental rotation task at least include stimulus identification, mental rotation, parity judgement, response selection and motor processes (see, e.g., Heil, 2002), with the duration of the mental rotation process being a function of stimulus orientation. If the stimulus is upright, no mental rotation should be involved at all. The mental rotation process is needed when subjects have to decide on the parity of visual stimuli from different viewpoints (e.g., Vanrie, Beatse, Wagemans, Sunaert, & Van Hecke, 2002) but not necessarily when viewing three-dimensional objects from different viewpoints (e.g., Gauthier et al., 2002; Willems & Wagemans, 2001).

The question arises whether mental rotation fulfils the requirements of “pure insertion” in that kind of task. Donders (1868/1969) assumed pure insertion, which means that a mental process can be added or omitted without altering the speed of other processes like stimulus identification or response selection. He concluded that if the validity of the pure insertion assumption is given, then the subtraction method can be used to measure the speed of mental processes. If two tasks requiring the same composition of identical sub-processes differ only in that one task requires an additional mental process, then the difference in reaction time (RT) of the two tasks would measure the duration of the extra mental process.

Donders’s assumption was massively criticized for a number of reasons (for a review, see e.g., Ilan & Miller, 1994; Sternberg, 1969), based both on introspective reports (e.g., Külpe, 1909) as well as on empirical data (Ulrich, Mattes, & Miller, 1999). The assumption of pure insertion, however, might be correct for some mental processes in some tasks but not for other processes or for the same processes in other tasks. It is, therefore, an empirical question whether pure insertion is satisfied for mental rotation or not.

This question was addressed by Ilan and Miller (1994) in detail. In their first experiment, participants had to solve a mirror-normal discrimination task with normal versus mirror image characters in two different experimental conditions: In the SU-condition (sometimes upright), the stimuli were presented sometimes upright and sometimes rotated in different orientations. In the AU-condition (always upright) the stimuli were presented always upright. The results clearly revealed that subjects took substantially longer to respond to upright characters in conditions containing rotated stimuli (SU) than in conditions containing only upright stimuli (AU). Furthermore, the authors showed that this “rotational uncertainty” effect was not caused by the need to determine stimulus

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