Developing a Computational Model of Mental Rotation Guided by VR Experiments

Mental rotation operators in the brain are more flexible than previously thought

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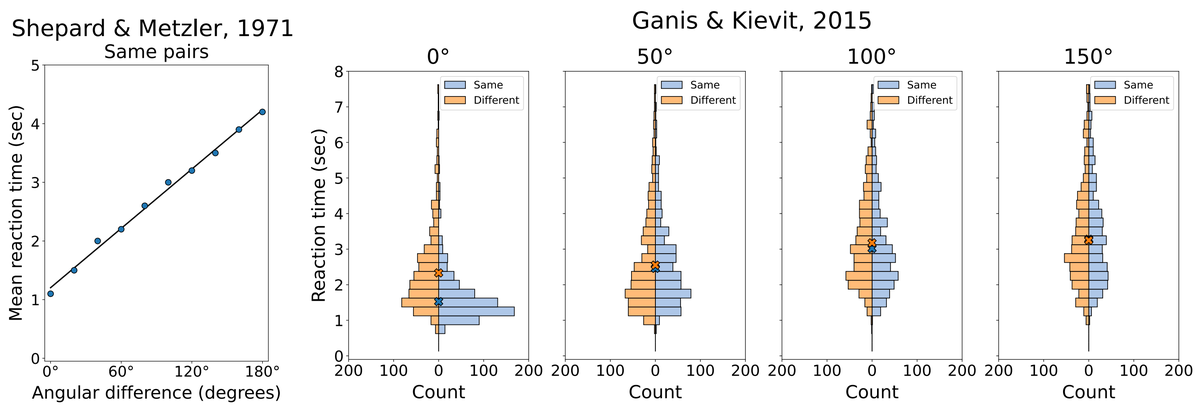
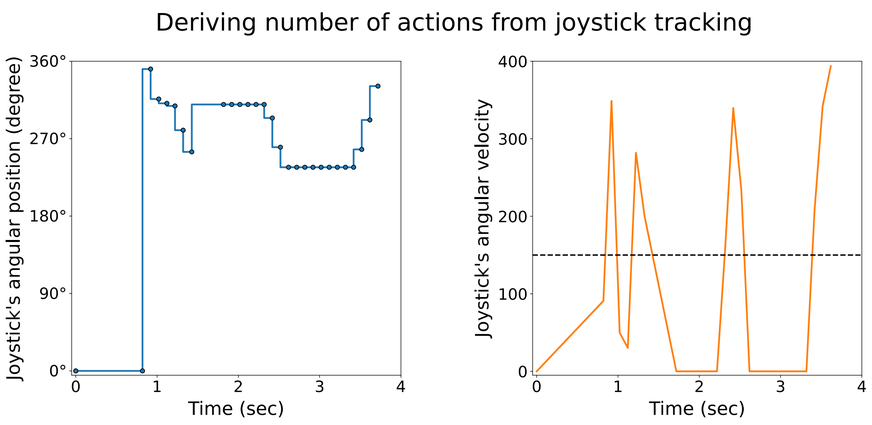
Mental rotation remains unsolved

Mental rotation refers to the ability to rotate 3D objects in imagination. Early studies of mental rotation by Shepard R. N. and Metzler J. (1971) report that the time associated with the comparison of two 3D objects, seen from different angles, increases linearly with their angular difference, which led to the speculation that the mind is constrained by a fixed and limited rotation speed. However, in the recent reproduction of these experiments by Ganis G. and Kievit R. (2015), the hypothesis of a constant rotation speed is inconsistent with the observed distribution of reaction times.



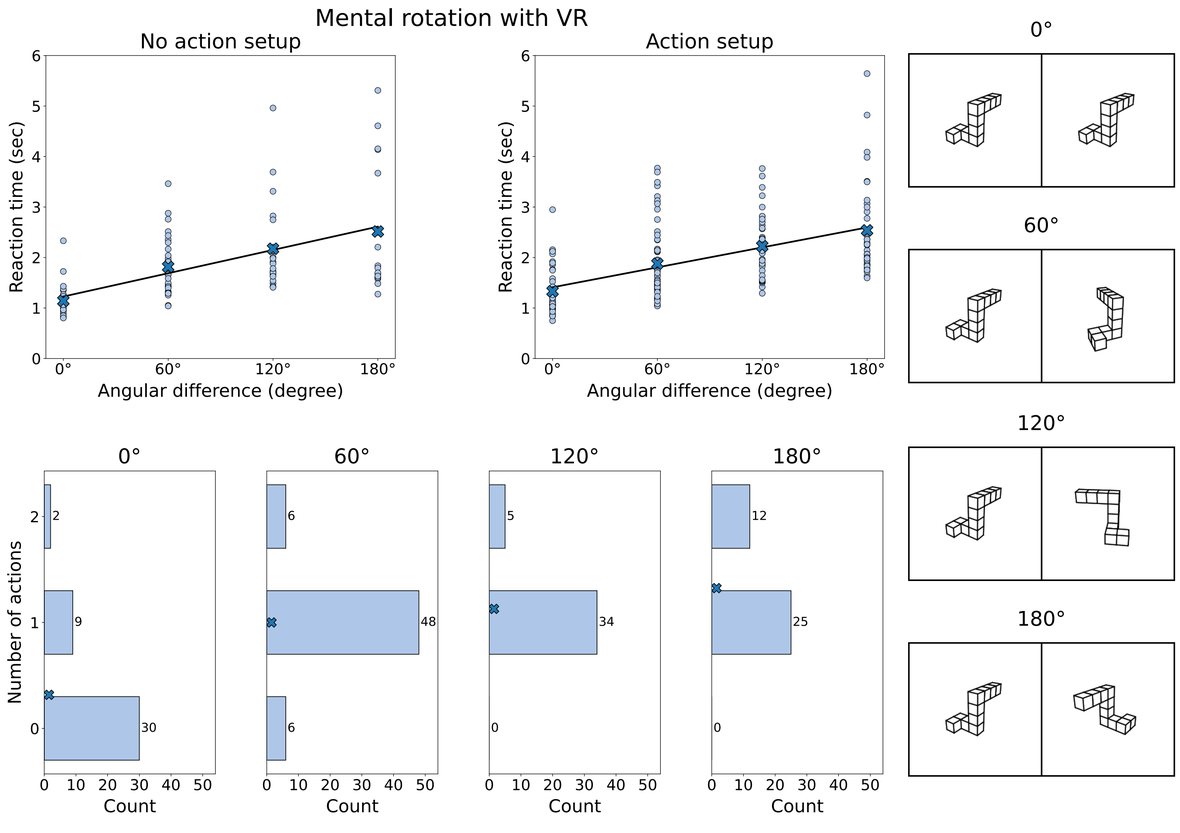
Augmenting mental rotation with VR

We have developed the VR interface for mental rotation which supports hand engagement via a joystick. By tracking the joystick movement, we derive the number of actions that are taken when rotating the object. This information may provide a new insight into the internal process behind mental rotation.



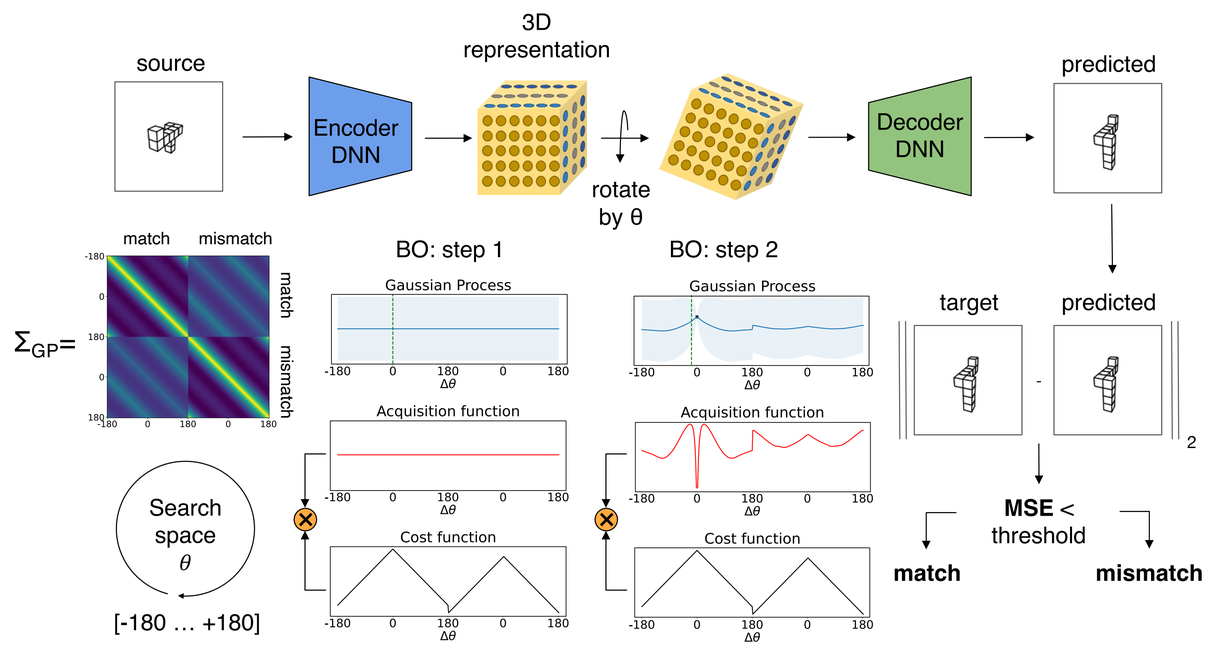
Experimental results

In our VR experiments, we have reproduced the results obtained by Shepard R. N. and Metzler J. across two different experimental setups: with and without a joystick.

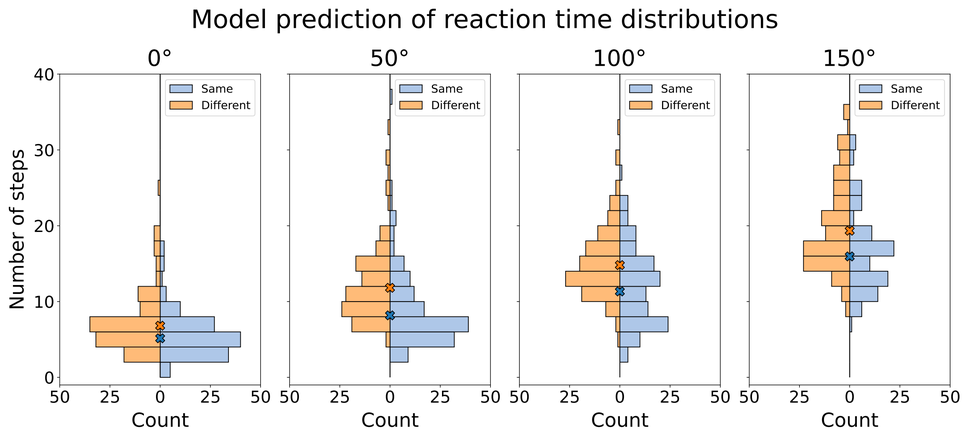


Model of mental rotation

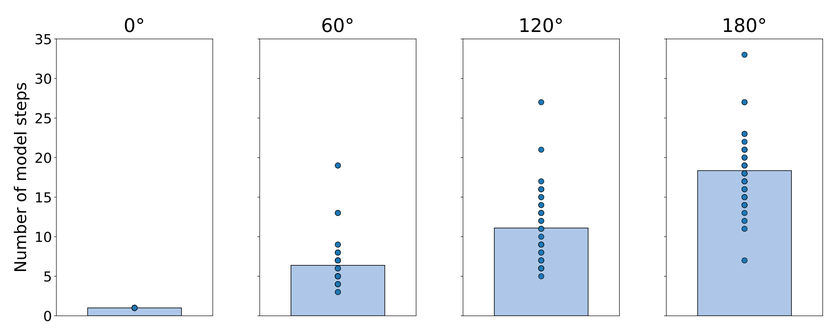
We propose a new computational model of mental rotation compatible with the data collected by both Shepard R. N. & Metzler J. and Ganis G. & Kievit R. The model is composed of (1) an equivariant neural renderer by Dupont et al. (2020) (2) a Bayesian optimization search, which performs a trial-and-error search on rotation angle until a match is found with the target object orientation.



Our model reproduces the shape of the distribution of reaction times across different angles of rotation



There is a huge disparity between model and human in the number of steps / actions



Mental rotation with skeleton encoding

Based on our experimental results obtained from mental rotation with a joystick in the VR environment, we consider an alternative hypothesis that suggests a comparison of skeleton descriptions of two objects, which are produced by placing the object in one of the four possible viewing quadrants.