

# EVENT-RELATED BRAIN POTENTIALS DURING THE VISUOMOTOR MENTAL ROTATION TASK: THE CONTINGENT NEGATIVE VARIATION SCALES TO ANGLE OF ROTATION

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**Abstract**—Perceptual judgments about the angular disparity of a character from its standard upright (i.e., mental rotation task) result in a concurrent increase in reaction time (RT) and modulation of the amplitude of the P300 event-related brain potential (ERP). It has therefore been proposed that the P300 represents the neural processes associated with a visual rotation. In turn, the visuomotor mental rotation (VMR) task requires reaching to a location that deviates from a target by a predetermined angle. Although the VMR task exhibits a linear increase in RT with increasing oblique angles of rotation, work has not examined whether the task is supported via a visual rotation analogous to its mental rotation task counterpart. This represents a notable issue because seminal work involving non-human primates has ascribed VMR performance to the motor-related rotation of directionally tuned neurons in the primary motor cortex. Here we examined the concurrent behavioral and ERP characteristics of a standard reaching task and VMR tasks of 35°, 70°, and 105° of rotation. Results showed that the P300 amplitude was larger for the standard compared to each VMR task – an effect independent of the angle of rotation. In turn, the amplitude of the contingent negative variation (CNV) – an ERP related to cognitive and visuomotor integration for movement preparation – was systematically modulated with angle of rotation. Thus, we propose that the CNV represents an ERP correlate related to the cognitive and/or visuomotor transformation demands of increasing the angular separation between a stimulus and a movement goal. © 2015 IBRO. Published by Elsevier Ltd. All rights reserved.

**Key words:** action, event-related brain potential, contingent negative variation, reaching, movement, visuomotor mental rotation.

## INTRODUCTION

When we reach to touch an icon on a computer tablet the spatial overlap between the icon and the endpoint for the reaching response permits the evocation of maximally effective and efficient motor output (henceforth referred to as standard task: see [Fitts and Seeger, 1953](#)). The optimized performance of standard tasks reflects their mediation via visuomotor networks residing in the dorsal visual pathway that operate largely independent of top-down (i.e., cognitive) control ([Goodale, 2011](#)). It is, however, important to recognize that the spatial relations between a stimulus and a response (SR) can be flexibly decoupled allowing an individual to complete their movement to a location that deviates from the stimulus (henceforth referred to as non-standard task). As a real world example of this issue, a novice performer must understand that anterior-posterior movement of their finger on a computer trackpad leads to up-down movement of a cursor appearing on the computer's screen. Thus, non-standard tasks represent an important line of inquiry because they provide a framework to understand the neural mechanisms related to the top-down control of actions ([Rossetti et al., 2005](#)) and the early learning of novel SR mappings ([Fitts and Seeger, 1953](#)).

The visuomotor mental rotation (VMR) task is an example of a non-standard task and requires that performers complete a center-out reaching movement to a location that deviates from a visual target by a predetermined angle. A consistent finding from the VMR literature is that reaction time (RT) for *oblique* angles increase linearly with increasing angle of rotation ([Georgopoulos and Massey, 1987](#); [Pellizzer and Georgopoulos, 1993](#); [Neely and Heath, 2010a, 2011](#); for saccades see [Fischer et al., 1999](#))<sup>1</sup>. Moreover, single-cell recording work in non-human primates has shown that

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**Abbreviations:** CNV, contingent negative variation; EEG, electroencephalography; ERP, event-related brain potential; MD, movement direction; PPC, posterior parietal cortex; RT, reaction time; rTMS, repetitive transcranial magnetic stimulation; SR, spatial relations between a stimulus and a response; VMR, visuomotor mental rotation.

<sup>1</sup> The VMR task produces RTs that systematically increase with increasing oblique angles, however, RTs for the cardinal axes (i.e., 90° and 180°) do not give rise to a linear rise in RT. In particular, 90° and 180° (also referred to as antipointing) VMR tasks results in shorter RTs than intermediary angles of 5° or greater ([Neely and Heath, 2010a, 2011](#)). The basis for this effect is that familiarity with cardinal angles results in a movement planning process that does not require the systematic rotation of a movement vector.

VMR responses are associated with the analog rotation of directionally tuned motor cortical neurons from the location of the target to the instructed response location (Georgopoulos et al., 1989). As such, Georgopoulos et al. assert that VMR planning times are defined by the temporal costs associated with the *motor-related* rotation of a movement vector (i.e., the mental rotation model: MRM; for a review see Georgopoulos and Pellizzer, 1995).

A limitation of the current VMR literature is the paucity of work examining the neural mechanisms associated with task performance in humans. Of course, we recognize that an extensive literature has examined the electroencephalographic properties of the mental rotation task (MR) (for a review see Heil, 2002). Notably, the MR task requires the classification of a character (i.e., letter or number) presented in different orientations and results have shown a linear increase in RT as a function of the character's angular disparity from a 'standard' upright position (Cooper and Shepard, 1973; see also Shepard and Metzler, 1971). What is more, the amplitude of the P300 event-related brain potential (ERP) is systematically modulated as a function of the character's angular disparity (Peronnet and Farah, 1989; Wijers et al., 1989; Heil, 2002; Milivojevic et al., 2009). More specifically, the P300 amplitude becomes increasingly negative with increasing rotation. The P300 is identified as a parieto-central positive deflection in the electroencephalography (EEG) with a peak 250–500-ms post stimulus onset (for a review see Polich, 2007). Moreover, one interpretation of the waveform is that it reflects the revision of a 'mental model' when a mismatch exists between a stimulus and a required response (i.e., context-updating) (Donchin and Coles, 1988; Nieuwenhuis et al., 2005). As such, modulation of the P300 in the MR task may reflect the demands of rotating a stimulus until it matches the performer's mental model (i.e., the character's standard upright position). It is, however, important to recognize that the MR task differs from the VMR task in at least three important respects. First, the MR task does not entail a goal-directed response and is therefore not constrained by speed-accuracy relations in movement planning (for a review see Elliott et al., 2011). Second, the MR task does not require the transformation of visual coordinates into a motor response (i.e., visuomotor transformation). Third, the MR task requires obligatory classification of the presented character, whereas no such classification is required for the VMR task. Thus, it remains unclear as to whether the electroencephalographic correlates of the VMR task correspond to their MR counterparts.

To our knowledge Bestmann et al.'s (2002) repetitive transcranial magnetic stimulation (rTMS) study represents the only work to examine the cortical areas involved in the VMR task in human participants. In that study, participants completed standard (0°) and VMR (35°, 70°, 105°, and 140°) tasks in conditions wherein rTMS was applied to the left and right posterior parietal cortex (PPC) and the vertex (i.e., the control condition) during response planning. Results showed that RTs were longer when rTMS was applied to the left or right PPC for the extreme angles of rotation (i.e., 105° and 140°). The authors proposed that the PPC supports the top-down coupling between the

process of rotation and the required motor output. Although Bestmann et al.'s findings provide an initial understanding of the neural mechanisms supporting the VMR task, their work was not designed to identify a psychophysiological marker for the task's onset. Moreover, there is no electroencephalographic or neuroimaging evidence from humans examining whether the VMR task is selectively related to: (1) the motor-related rotation of a movement vector (i.e., the MRM model), (2) an early visual rotation akin to that reported in the MR literature (i.e., P300 scaling to angle of rotation), and (3) the cognitive and/or visuomotor demands associated with increasing the angular separation between a stimulus and an intended motor goal. Indeed, in the latter case it may be that the concurrent cognitive and visuomotor demands of the VMR task render a movement planning process that is entirely distinct from the visual rotation supporting the MR task. As such, the contingent negative variation (CNV) may be sensitive to the cognitive and visuomotor demands supporting the VMR task. The CNV was first identified by Walter et al. (1964) and reflects an early frontocentral and a later centroparietal component that comprise a sustained negativity during the preparation period of a goal-defined action. The early and late components are thought to respectively represent the orienting properties of a stimulus (Loveless and Sanford, 1974) and the cognitive and visuomotor properties that support response preparation (Brunia, 1988; see also Zaepffel and Brochier, 2012). Further, the component originates in cognitive, visuomotor and motor structures (i.e., M1, supplementary motor area, premotor area and parietal cortex) (see Lamarche et al., 1995; Bares et al., 2007) linked to the preparation of standard and non-standard reaching movements (Connolly et al., 2000). As such, the CNV represents a candidate ERP component to index the cognitive and/or visuomotor demands of an upcoming response (for a review see Gómez and Flores, 2011).

The present study examined the ERPs associated with the VMR task wherein participants were provided advanced information regarding the nature of an upcoming response (i.e., 0°, 35°, 70° and 105°). For each trial, a single target was presented and EEG data were time-locked to its onset. Notably, and in contrast to previous VMR studies, the onset of the target stimulus did not serve as the movement imperative (see Georgopoulos and Massey, 1987; Heath et al., 2009; Neely and Heath, 2009, 2010a,b, 2011; Maraj and Heath, 2010); rather, responses were cued between 900 and 1100 ms following target onset. Such a methodology was used to: (1) dissociate the ERPs associated with movement planning (e.g., P300) from those associated with movement execution (i.e., the Bereitschaftspotential)<sup>2</sup>, and (2) accurately identify onset of the neural processes associated with the VMR task. In terms of research predictions, if the VMR task is selectively mediated via a motor-related rotation than neither the P300 nor the

<sup>2</sup> The late CNV and Bereitschaftspotential share many common neural generators; however, the late CNV differs importantly from the Bereitschaftspotential in terms of its modulation by non-motoric factors such as task difficulty (Bajric et al., 1999) and sensorimotor demands (Brunia, 1988).

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