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Mental Rotation and its Relationship with Motoric Accessibility: An ERP study assessing the effects of a physical barrier on spatial discrimination

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelors of Arts in Psychology from The College of William and Mary

by

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Abstract

Considered the hallmark for research on mental rotation, Shepard and Metzler’s (1971) experiment constructed the foundation for the investigation into cognitive processes guiding rotational movement of objects in a space. Their data showed that behavioral reaction time increases as a monotonic function of angular disparity, indicating that participants, upon viewing a spatially-altered object, mentally rotate a comparison figure in order to discriminate for the purposes of matching. Later research conducted on rotation of human body parts (i.e. hands) indicates that this particular motor rotation requires the influence of egocentric proprioceptive (i.e fine muscle movement) information (Parsons, 1995) Based on a study conducted by Thayer and Johnson (2006) to investigate the cerebral structures involved in mental rotation, the current study utilized ERP technology to measure the cortical activation between a hand barrier and a hand non-barrier group. Thirty undergraduate participants were randomly assigned equally to the two above-mentioned groups and given a right versus left hand discrimination task. Behavioral results indicate an increase in reaction time with angular departure from conical orientation, while the ERP data reveal significant late negative complex (LNC) and N1 activation increases for the occipital and parietal cortices in the barrier compared to the non-barrier group. This finding suggests that physical barriers inhibiting motoric cueing can significantly modulate cortical activity associated with the performance of a biomechanical - possible anatomical movement - rotation task.
Mental Rotation and its Relationship with Motoric Accessibility:

An ERP study assessing the effects of a physical barrier on spatial discrimination.

Spatial rotation of stimuli elicits specific cortical activation that affords the onlooker to make judgments concerning these objects in the visual array once they have been altered in space. Though visual information may be disturbed in the visual array, humans still can use information from the characteristics of the objects to make accurate discriminations. The cognitive ability of visuospatial discernment has been under increasing investigation since Shepard and Metzler’s (1971) study of three-dimensional spatial rotation. The findings of their experiment indicate that a participant’s reaction time increases as a monotonic function of the angular disparity between two objects; concluding that the participant was engaging in mental rotation of one figure in space to correspond to the other (Thayer & Johnson, 2006) – elaboration on this particular experiment will follow. Since then, investigation into human appendages (e.g. hands) has obtained a growing interest concerning the cognitive processes that underlie the anatomical mental transformation. Anatomy-based models are the successors of previous studies of abstract characters. The present work examines mental rotation of hands, and the role in which current body positions (i.e. hands bound or unbound) influence cognitive and cortical response.

In the following study, the researchers employed a mental rotation task similar to that used by Thayer and Johnson (2006), whereby participants were asked to discriminate between right and left hands that were presented either palm-up or palm-down and
rotated varying degrees in a two-dimensional array. Unlike the experiment used by Thayer and Johnson, the participant pool was bifurcated into two groups: (1) a control (non-barrier) and (2) an experimental (barrier). The barrier group was physically unable to use egocentric motor information to make informed judgments concerning the type of hand they were viewing. Employing this binding method, the researchers intended to simulate physical incapacity.

Spatial Processing: The Mind and Object Rotation

Mental rotation paradigms are the clearest examples of viewpoint dependence (Overney, 2005), given that this perceptual task requires a participant to normalize an otherwise familiar object with an unfamiliar view and cognitively match it to a stored representation of that object. Viewpoint dependence of object recognition, as described by Overney, postulates that unfamiliar views must be normalized before they can be matched to a store representation of that object. The general outline of a mental rotation paradigm is as follows: a subject is presented with a visual stimulus such as blocks (Cohen, 1996), alphanumeric characters (Alivisatos, 2001), or body parts (Kosslyn, 1998; Thayer & Johnson, 2006; Sekiyama, 2000) rotated a set number of degrees in the y-plane and asked to make a discrimination between stimuli – such as the right hand versus left hand discrimination used in this study – or compare the stimulus to a non-rotated object such as seen in parity tasks.

Metzler and Shepard’s (1971) parity task sparked a great deal of intellectual curiosity in the realm of mental rotation and is often cited as the first profound achievement in terms of defining the relationship between angular disparity and reaction
time as a linear function. In their task, a subject was asked to compare a three-dimensional, cube-based, angular structure to a rotated version of this object and state whether or not the two objects were the same. The angle of discrepancy ranged from $0^\circ$ to $180^\circ$ with intervals of $20^\circ$ shifts. Findings from this experiment illustrate the existence of a significant relationship between reaction time and angular disparity; indicating that participants do engage in mental rotation. A key feature to this study was the comparison of perspective line drawings in a mental rotation task to the three dimensional figures previously mentioned. Both stimuli elicited the linear function of increased reaction time to rotation (depth or picture-plane).

*Spatial Processing: The Mind and Body Rotation*

A caveat to the Metzler and Shepard task when discussing rotational trajectory schemes is its application to human biophysics and anatomical movements; in the real world not all objects can be freely twisted. Hands, for example, tend to be attached to bodies and are consequently limited in rotation. Furthermore, more time might be required from participants to internalize the mental representation of a three-dimensional object from a two-dimensional picture of that object. The consequent manifestation of this change in dimensionality is of course a disparity in reaction time (Shepard & Metzler, 1988) as well as cognitive output. Fundamentally, mental rotation of objects provides a valuable foundation concerning behavioral and cognitive functioning; however, the influence of one’s own body elicits a striking influence to the ability to perform spatial rotation.
A study conducted by Sekiyama (2000) presented participants with line drawings of left and right human hands in one of five rotation in which finger position and wrist rotation varied. Behavioral results indicated that participants’ reaction time in determining either right hand or left hand depended on the orientation of the stimulus. Sekiyama suggests that the reaction time was a reflection of the kinesthetic information concerning the physical biomechanical constraints of muscles movement; physical constraint increases the likelihood of increased reaction time when engaging in mental rotation of body parts. Parsons (1987, 1995) found that individuals can mentally rotate images of body parts more easily if the parts move in natural ways.

Thayer and Johnson’s (2006) study on cerebral processes during visuo-motor imagery provides further evidence for mental rotation using kinesthetic cues one employs when making a discrimination during a rotation task. In their study, participants were presented with a series of stimuli and told to make judgments, as quickly as possible, concerning the type of hand they were viewing. The stimuli, simple line drawings of hands palm-down or palm-up, were presented in one of five clockwise angular departures from the upright (0°): 60°, 120°, 180°, 240°, or 300°. Their design was 2 x 2 x 6 (right or left hand [2 hands], palm-up or palm-down [2 facings], 6 total orientation possibilities [the five clockwise rotations and 0°]). Using ERP technology, Thayer and Johnson recorded latency as well as neurological components involved with the mental rotation paradigm. Their results are similar to those found by Sekiyama. Specifically, Thayer and Johnson found for the palm-down condition, reaction time data showed a
monotonic increase as a function of orientation with a maximum of 180°, and a monotonic decrease in angles larger than 180°.

Psychophysical evidence suggests that the time to mentally simulate an action matches the time needed to execute the corresponding motor act – motor simulations are constrained by the physical limitations evaluated and experienced by the participant. Jeannerod (1997) states,

“…motor images are experienced from within, as the result of a first person process where the self feels like an actor rather than a spectator. During motor imagery the subject feels himself executing the action, whether it involves the whole body (as in running for example) or it is limited to a body part.” In essence, actions one engages in daily are driven, in large part, by internally represented goals as opposed to the external environment (Petit, 2005). Executed and imagined actions appear to share the same properties as evidenced by Decety (1992), who posits the shared spatio-temporal characteristics and laws of anatomical movement control between these actions. The parallelism in motor initiation and mental simulation is quite evident once the motor system is impaired.

Mental Transformation in Patient Population

As previously addressed, Sekiyama’s research ascertains a relationship between a participant’s egocentric kinesthetic information and his or her reaction time during a mental rotation task. These results are explained in terms of manageable direction: the shape of the reaction time function agrees with the anatomical constraints or deficits of hand movements that would be necessary to solve the task physically (Petit & Harris,
Consequently, the mental transfer of body parts interacts with spatial transformation of one’s own hand. An experiment measuring the cortical activity of imagined motor movement for amputees found striking results in terms of rotation assessment (Nico, 2003). When upper limb amputees were asked to make a discrimination of a right and left hand stimulus, left/right handedness judgments were slower and less accurate after loss of the dominant limb than those handedness judgments for the non-dominant limb. However, given an aesthetic (non-moving) prosthesis, performance on the identification task was significantly slower for amputees not wearing the prosthesis. Two subjects given a myo-electric prosthesis allowing for thumb opposition and wrist rotation by means of muscles contraction of the residual forearm muscles exhibited slightly better performance than those utilizing the non-mechanic, foam-rubber prosthesis (Nico, 2003).

Asymmetric, right-handed Parkinson’s patients display motor imagery favoring the left hand (Dominey et. al, 1995; Thobois, et al, 2000). Behavioral conclusions from both studies indicate that reaction time for affected limb and associated limb stimuli were slower than non-affected limb and non-affected limb stimuli. Further evidence for the motoric degradation and the affiliated behavioral disturbance is provided by Sirigu’s (1996) investigation into mental representation of hand movements following parietal cortex damage. Lesion to the parietal cortex produces apraxia, a neurological disorder that inhibits an individual from producing or initiating movement formulae in the absence of elementary sensory or motor deficits. Those suffering from apraxia are characterized by an inability to engage in motoric cue ideation; individuals cannot often recognize the
meaning of a witnessed gesture. Sirigu concludes that the storage and acquisition of mental motor representations resides together in the parietal cortex. Mental rotation tasks require the same integrity of specific cortical-subcortical motor systems involved in motor planning and execution (Ionta, 1998; Bruzzo, 2008).

The mental rotation of objects, however, affords an individual the opportunity to reason about the consequences of the corresponding physical manipulation (Shepard & Cooper, 1982; Kosslyn, 1998). Kosslyn’s theory of motor processes pertaining to mental rotation states that visual mental images arise via the same mechanisms that prime the representation of expected objects during perception; therefore, a spatial pattern is reconstructed from visual memory. The basis for neurological correlate in his theory stems from Parson’s (1987, 1995) findings which indicate that an individual’s ability to rotate body parts is more easily obtained provided that the movement follow an anatomically natural trajectory.

Inquiry into the functional capabilities of object versus body part rotation indicates a dissociation concerning deficits of the two functions in patients with brain damage (Tomasino, 2003). Described by Rumiati, Tomasino, Vorano, Umilta, a De Luca (2001), patient MT suffered from left fronto-temporo-parietal damage. This particular neurological insult selectively inhibited MT’s ability to discern between a right and left hand stimulus. Patient JB, described by Sirigu (2001) suffers from a bilateral infero-temporal lesion which induced a deficit in three-dimensional external object rotation while leaving the ability to perform imagined hand movement intact. Indeed, several studies on mental rotation indicate the existence of particular neurological cortices that
allow for this rotational behavior to occur. Ambiguity as to the precise cortical facilitators of mental rotation remains a point of contention for many researchers; however, there appears to be some progressive standardization of functional localization.

Neurological Correlates to Mental Rotation Task

Topographic analysis of functional activation during mental rotation experiments has produced diverse results concerning the exact neural mechanisms influencing this task. The variety of studies previously mentioned requires participants to undergo differing procedures; however, the basic behavioral data mentioned above seems to be very consistent with the monotonic shift due to angular departure from 0°. The neural mechanisms underlying this process are certainly not quite as clear.

Historically, research suggests cerebral lateralization of the parietal cortex as the top-down process mediating mental rotation. Important to spatial ability, mental rotation in a non-computational and non-symbolic process; therefore, it would appear likely that this act is mediated by right hemisphere activation (Francis & Irwin, 1997). The three-dimensional block rotation paradigm employed by Shepard and Metzler indicate the activation of bilateral parietal cortex, whereas other studies have suggested unilateral activation of the parietal cortex.

Positron emission tomography (PET) analysis conducted by Kosslyn (1998) provides compelling evidence for locating neural correlates of mental rotation. As previously mentioned, Kosslyn used Shepard and Metzler’s cube figures as well as two-dimensional photographs of hands. PET analysis for the cube figures rotation revealed activation in the inferior and superior parietal lobes bilaterally similar to that found by
Shepard and Metzler’s study. Analysis of the two-dimensional hand stimulus, however, produced a unilateral left activation of the motor and premotor areas. Specifically, the hand stimulus condition revealed activation in the left precentral gyrus corresponding to the primary motor cortex, left premotor cortex (M1, Area 9), and Area 17 along the midline. Kosslyn suggests that this final location of activation could be the result of participants encoding visual information in the rotation condition or top-down priming mechanism that may underlie mental rotation. A striking contrast to Shepard and Metzler’s findings was that no right hemisphere activation was found during the hand condition. The strongest activations during this study were found in M1 and Area 6. Pairing these two neural mechanisms with superior parietal Area 7, which Kosslyn indicates is activated during mental rotation of hands, may act as the primary motivators for preparing an individual to initiate hand movement.

Data gathered from the cube paradigm suggests that specific cortical activation can be used to guide action but not actually prime the motor program to produce a movement. This line of research affirms the existence of two mental rotation schemes: one that is rooted in embodied cognition (preparing the motor system to act) and one that does not influence the motor representation. Of course, neither model is mutually exclusive in terms of neural correlates. Some overlap inherently exists for neural activation. The majority of studies bolster the view of parietal activation as the locus of mental rotation, suggesting that the nature of mental rotation behaviour occurs along a canonical or orthogonal plane (Jagaroo, 2004). The data suggest that mental rotation neural activation occurs primarily in bilateral parietal and occipital cortices. Given that
the ability to perform mental rotation is related to one’s own representation of biomechanical scheme (Ionta, 2007), anterior cortical structures may provide ongoing information about biomechanical constraints on rotation trajectories (Thayer & Johnson, 2006). Object rotation through trajectories due to constraints imposed by the motor system does not imply that the observer’s own motor system must be manipulating the object (Kosslyn, 1995). It could simply be the result of imagining another committing the rotation.

ERP research conducted by Thayer and Johnson reveal amplitude modulations as early as 170 ms, indicating that participants were most prominent at a latency of approximately 600 – 800 ms. There exist obvious technological dissimilarities between PET, fMRI and ERP. The most relevant functional difference is the long temporal resolution produced by PET and fMRI technology. In order to strategically examine the relationship between mental rotation and amplitude modulation, one must investigate the temporal aspects characterized by cognitive processes. To capitalize on this aspect as well as the electrophysiological correlates, the high temporal resolution provided by ERP is an absolute necessity which PET and fMRI are unable to provide (Alary et. al, 1998; Heil, 2002;).

Chronophysiology

One of the most fundamental tasks to achieve for cognitive electrophysiology is to establish the functional components of the ERP (Heil, 2002). Certainly it is possible to understand behavioral data in term latencies and pinpoint neurological regionality from activation points. Chronophysiology, on the other hand, acts as a tool with which to
understand the cognitive region employed while a participant engages in a mental rotation task. There are two main components of interest: (1) the P1-N1-P2 Complex and (2) the Late Negative Complex (LNC). ERP analysis reveals that the amplitude of positively is inversely related to the character of orientation – the amplitude becomes relatively more negative with increasing angular disparity from the upright position (Heil, 2006). In terms of mental rotation, effect of the N1 and LNC should be a systematic increase in negative amplitude over the central and parietal lobe (Rosler, Roder, & Heil, 1993).

The onset of the P1 component (onset at about 90 - 130 ms) followed by the N1 component (onset at about 130 - 150 ms), followed by the P2 component (onset at about 150 – 200 ms) post-stimulus represents an attention marker than spans across the anterior occipital region. Any time one visually attends to some stimulus, this complex should emerge in the electrophysiological data. Historically, these three components were described in terms of one another, but electrophysiological investigation has shown that this is not a strict relationship and has attempted to describe the characteristics of these this functional complex (Vogel & Luck, 2000). The onset of the P1 component indicates that the attentional processing of the stimulus (Luck, 200). Moreover, P1 is found to increase systematically in amplitude with increasing intensity of sensory stimulation (Foxe, 2001). Larger P1 amplitude is understood to reflect increased or more efficient processing.

The N1 visual component has been shown to reflect the operation of a discrimination process (Luck, 1995). Luck and Vogel propose the attention
discrimination characteristic of this functional component based on studies indicating the N1 amplitude is greater for attended-location stimuli compared with stimuli presented under neutral or distributed attention conditions as well as studies showing the N1 component emergence when a participant is asked to make a visual discrimination such as in our procedure. Finally, the P2 component, characterized by a longer latency, suggests a correspondence to a late phase cognitive processing of somatosensory stimulation (Alary et al., 1998).

The LNC component (broad latency onset of approximately 600 ms lasting until about 12000 ms; maximum voltage onset at about 700 to 1000 ms) represents an attentional component that is highly correlated with the mental rotation operation. Research into the LNC suggests that this particular component possibly reflects processing requirements that are peculiar to the mental rotation of body parts and that have a direct impact on RTs (Thayer & Johnson, 2006). Furthermore, it can be inferred that the manifestation of this prolonged negative complex indexes increases in activity of the underlying parietal cortex.

Present Study

As stated above, a variety of studies measure the effect of mental rotation for anatomically based stimuli. These studies suggest that egocentric cuing plays a fundamental role in the ability to transmit the stimulus transformation. Inota’s (2007) behavioral study tests the postural effects on behavioral data but proceeds no further beyond that. In order to bring the physical constraint of posture and mental rotational transfer – viewing the behavioral and ERP results – the current study employed a barrier
paradigm which restricts the anatomical hand movement of the participant. Essentially, the barrier method biomechanically simulates physical impairment in an otherwise healthy participant.

In the following study, the researchers employed a mental rotation task similar to that used by Thayer and Johnson (2006) whereby participants were asked to discriminate between right and left hands that were presented either palm-up or palm-down and rotated various degrees in an two-dimensional array. Unlike the experiment used by Thayer and Johnson, the participant pool was bifurcated into two groups; a control (non-barrier) and an experimental (barrier). The barrier group was physically unable to access egocentric information compared to how they are normally accustomed to make informed judgments concerning the type of hand they are viewing. Unique in this research is the marriage of the biomechanical constraints and the cortical measurements.

**Methods**

*Participants*

Thirty undergraduates (15 males, 15 females, mean age = 18.8 years) from the College of William and Mary were recruited as participants. During the first two months, during a summer school session, 12 participants were recruited from public posting and given economic incentive of thirty dollars to participate. The participants in the final two months of research were drawn from an online recruiting pooling from the introductory psychology courses and received class credit for their participation. All thirty individuals were right-handed as evaluated by the Edinburgh Handedness Inventory (Oldfield, 1971).

*Stimuli*
Each participant was presented with 512 stimuli over the course of a single testing session. The stimuli consisted of black and white photographs of human hands (right and left) and were arranged in eight clockwise rotations deviating by $45^\circ$: $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ, 270^\circ, 315^\circ$. Together, there were 32 unique stimuli (2 hands x 2 sides x 8 rotations). The hands were arranged in eight random presentations within a stimulus sequence which was presented twice over. In total, there were 256 left hand stimuli and 256 right hand stimuli accounting for the above-mentioned 512 stimuli. Figure 1 presents the palm-down for left hand and right hand stimuli in each of the angular rotations from canonical position. Figure 2 presents the palm-up left hand and right hand stimuli in each of the angular rotations from canonical position.

**Procedure**

Upon entering the laboratory, participants were greeted by two researchers; the head researcher and a research assistant. The participant sat in an adjacent classroom and filled out a standard research consent form as well as the Edinburgh Handedness Inventory. Once completed, the participant is then brought into the lab and sent through pretest preparation procedures.

Prior to entering the laboratory, each participant was issued a participant ID that relegated them into one of two categories – a barrier category or a non-barrier category. Barrier category participants had both their hands wrapped in medical bandage in such a fashion where digits 3, 4, and 5 were bound together with digit 1, thus leaving the second digit of both hands free for stimuli discrimination purposes as seen in Figure 3. Participants’ hands were placed on a foam board that covered the keyboard of the
computer with the exception of the two discrimination keys. Using another sheet of foam board, the participants’ hands were occluded to limit the amount of visual comparison cues. Finally, two, 5-lbs leg weight were strapped to the top of the foam board as to limit any movement from the participant as shown in Figure 4. Non-barrier participates had a foam mat place on top of the keyboard with the exception of the same two discrimination keys as mentioned above. To limit visual information cues, as used with the bound categories, a piece of foam board was fixed atop the participant’s hands, but left unweighted. Essentially, non-barrier participants had more physical movement possibility, but only made stimuli discriminations using the distal phalanx 1.

Both sets of participants were given explicit instruction regarding the protocol. They were given further instruction to limit any physical movement during the experiment. While conducting the experiment, participants sat in a dimly lit room in isolation while researchers sat in an adjacent laboratory monitoring the computer feedback. Each stimulus was preceded by a small, white fixation cross centered in the middle of a black screen for 1500 ms. Participants were instructed to indicate with their free finger whether or not the hand was right or left – right index finger to select a right stimulus, left index finger to select a left stimulus.

To measure response time, the stimuli progressed as at the rate each participant was able to make his or her discrimination. Therefore, each participant was instructed to progress as quickly as possible, but to not sacrifice accuracy. After a selection was made, the stimuli disappeared from the screen immediately, and the next fixation cross appeared
500 ms later. Experimental sessions typically lasted for approximately 30 min. STIM2 software recorded accuracy and reaction time data for all trials.

**Electrophysiology**

During preparation, each participant was fitted with the appropriately sized NuAmps 40-Channel Quick-Cap; all research used an abrasion technique to administer the gel into the cap. The six areas where the electrode made direct contact with the skin (The right and left mastoid [A2 and A1 respectively], the right lateral and left lateral peripheral of the eye sockets [X2 and X1 respectively], and the superior and inferior edges of the left eye socket [X3 and X4 respectively]), were sterilized with alcohol prep-pads prior to electrode placement. A visualization of the electrode placement can be seen in Figure 5.

Prior to experiment commencement, impedance rates were calculated and adjusted to be below 10kΩ. Data were digitized at a sampling rate of 500 Hz using the NuAmps amplifier system. A1 (left mastoid), was used as a reference source during the experiment and was later re-referenced during analysis. Neuroscan 4.3.1 software was used for the recording and analysis of all data.

After all the data had been collected, research developed a data sheet on EXCEL to mark correct and incorrect trials based off the DAT file. Following this, research went through each participant’s CNT file and rejected block of artifacts (e.g. any non-intraorganic cognitive activity such as muscle movement, eye blinks, breaches to the electrical field, and channel drift) as well as rejected trials that were deemed from prior analysis to be incorrect. Data were then re-referenced to linked mastoids. Channel
VEOG was created to assess all vertical eye movements, specifically blinks, while channel HEOG was created to assess all horizontal eye movements. Data files developed from a composite of the re-reference and the VEOG/HEOG were then analyzed for ocular artifacts using an algorithm programmed into the software which was initiated by the subjective discrimination of eye-blinks by the researcher. The subjective discrimination on two to approximately five trials allowed for the development of a prototype which the SCAN software used to rapidly expunge all ocular artifacts. Data was then sent through a low-pass filter (zero phase shift, 45 Hz, 6 dB/oct) as well as a high-pass filter (zero phase shift, 0.5 Hz, 6 dB/oct).

EEG files were segmented time intervals of 1200 ms epochs. This time interval consisted of the 100 ms immediately preceding each stimulus presentation and the 1100 ms following each stimulus presentation - as previously mentioned, files up until epoching had undergone previous analysis. At the conclusion of epoching, the data file was baseline corrected using a standard baseline and then bifurcated into two average groupings (left hand stimuli average and right hand stimuli average). Finally, a grand average for left and right hand stimuli for barrier and non-barrier participants was calculated. Data from the grand average was used to manually select peak values.

Results

**Behavioral Data**

Two participants were excluded from behavioral analysis as a result of enormously deviating latencies that defined them as outliers. Participants performed the behavioral task with a mean accuracy of 97.37% - the barrier condition performance with
an average accuracy of 97.62% while the non-barrier condition performance was 97.37%
percent. The respective average latency and with angular departure from canonical position
can be seen in Figure 6 where reaction times were collapsed across left and right hands. In Figure 7, the angular departure from canonical position collapses the participants;
parsing the two conditions with disregard to left hand versus right hand identification.

An ANOVA revealed no main effect of hand or group. Essentially, the presence of the
barrier had no effect on decision time for the task.

The minute discrepancy in latency period for the barrier and non-condition may indicate that relevant motor cues may be indicative of influencing the reaction times. As a result of forced impairment of hand flexion, extension, adduction, abduction, and opposition (especially from the thumb), the barrier condition participants perhaps engaging in longer discrimination periods. Concerning the discrepancy of hands, the participants were all primarily right-handed individuals. The Edinburgh handedness questionnaire offers participants a series of daily, mundane activity to select from and indicate which hand, or hands, they use to complete the task (e.g. writing, drawing, using scissors, striking a match, etc.). Given that the participants are more use to using their right hand to manipulate the physical world, express intention, and achieve biological needs, such as feeding, these participants are primed on a daily basis in terms of their hands, but these results were not significant.

Further results reveal that there exists a significant main effect of angle $F(1,28) = 67.200, p < .001$. This analysis of latency and angular significance indicates that the participants are engaging in mental rotation of the hand in space. More specifically,
Mental rotation is a strategy employed to allow the participant to make the decision between right and left hands. As seen with Thayer and Johnson (2006) analysis, there is a departure from canonical orientation indicating that participants are rotating the images through an anatomically parsimonious trajectory.

**ERP**

An independent measures t-test was run on the P1-N1-P2 complex for the O1, OZ, O2, P3, PZ, P4 electrodes. Results indicate a significant main effects for N1O1 \( t(28) = 2.860, p = .008 \); N1OZ \( t(28) = 3.177, p = .004 \); N1O2 \( t(28) = 2.559, p = .016 \); N1P3 \( t(28) = 3.474, p = .002 \); N1PZ \( t(28) = 3.071, p = .005 \). As can be observed in the electrode mapping on Figures 8 - 14, these six topographic locations are on the posterior of the head – in the parietal and occipital regions. Research indicates that these two structures are the primary generators underlying the imagined spatial transformations of hands.

Observation of the mean statistics indicates a greater negative score for those participants allocated to the barrier condition. As previously discussed, the N1 component primarily is indicative of an attentional effect. Specifically, the N1 component reflects an attentional operation applied to location in space. Given that the barrier group has a larger negative component, the experiment suggests that increase attention is necessary given the hand constraint; a decrease in motoric cueing perhaps inspires an increase in stimuli attention.

Independent measures t-test for the LNC was performed on electrodes CZ, P3, PZ, and P4. All electrode sites were significant \( t(28) = 2.329, p = .027 \); \( t(28) = 1.804, p = \)
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.082; \( t(28) = 1.814, p = .080; t(28) = 2.029, p = .052 \) respectively. LNC components are more correlated with a mental rotation operation as indicated by the increase in negativity by the results of the barrier condition. The index of neural activity related to the LNC is closely tied to neural operations that would support mental hand rotation. Once again, the LNC is higher for the barrier condition.

General Discussion

Regardless of the non-significant findings for hand stimuli discrimination as well as latency and angle, there is evidence found from the study suggesting that in fact, the participants were rotating through a biophysical trajectory. This evidence manifests itself with the occurrence of the angular departure from canonical orientation. Moreover, the data from electrophysiology not only provides significant results but indicates localization of function in the parietal and occipital cortices.

Mean scores for percent correct was a nearly perfect statistic, which is a cause for concern, especially with consideration to the mean averages of both groups. Though not significant, the barrier group was statistically more accurate than the non-barrier group. On average, the barrier group had a higher latency, but whether or not this is proportional to the discrepancy of physical limitation between the two groups is left unaccounted for in the research.

Based on task behavior, the results indicate that the experiment in and of itself was far too easy for the participants in both groups. The negative wave increase has been defined in terms of task complication. The more mental effort one uses to make a
discrimination or attend to a stimulus, then the more negative one would expect to see the wave. Overall, perhaps this is the result of the task parameters.

The participants were divided into two groups, even the control was visually unable to use information about his or her hand. They were, however, able to use the egocentric information such as motor twitching. It appears that even minor muscle moments can provide enough information about a rotated object, which leads the current researchers to believe that the barrier task was not as well controlled for as possible. The binding for the hands was loose enough as to not constrict blood flow. The participants usually took thirty minutes to complete the task; therefore, the binding had to be comfortable enough to afford the participant enough comfort to last through until the end of the task. The comfort of the binding may have facilitated the egocentric movement cueing that may have not been as accessible as the non-barrier group, but accessible all the same. A future study on this particular experiment may want to control for movement by increasing the (1) the barrier restriction, (2) altering the digit choice for task discrimination, (3) altering the resting hand posture, or (4) adding two varying barrier groups.

Instead of binding with only medical bandage, it may be adventitious to use a series of rubber bands to inhibit the initiation of movement. Extra weighting belts may also be a consideration to enhance physical movement restriction. Both the weight and rubber bands would restrict flexion and extension as well as opposition and abduction and adduction. Any one of these five cues is enough to provide information about the stimulus. Furthermore, as opposed to using the index finger as a selection device,
perhaps another digit that is not as necessary and, therefore, not as often used as commonly in daily task performance would add to task difficulty such as digit 4 and 5.

Stevens and Kent (2007) have demonstrated the effect of posture on cognitive tasks – they have demonstrated the existence of distinct spatial influence on cognitive processing. Anatomical positioning affects mental formulations of an object. As opposed to typical resting hand position for participants, perhaps crossing hands during task performance would further add to the deficits in muscles coordination and force additive effort upon the participant. Instead of one full-barrier and one full non-barrier, maybe creating half-barrier left and half-barrier right, where one hand is bound and the other is left free, would add to the results of this task. Certainly it would provide more information when doing analysis. To increase power, perhaps in the future, it would be wise to collapse dependent measure into four levels of rotation.

By identifying the cortical loci for mental rotation, one can further investigate neurotherapeutic research for groups suffering from hemi-paresis, phantom limb pain, and physical degradation due Parkinson’s disease and neurological degradation of schizophrenia. The research conducted in this experiment has further application – application in a practical world setting and application concerning emergent scientific research.

The current global crisis in the Middle-East has produced mass amounts of critically injured soldiers. Survivors of sustained injuries that require medical amputation or those who have been maimed will, as suggested by this and current research, experience a deficit in mental rotation ultimately affecting how they engage
with the their environment. Understanding the functional components that address mental rotation will allow the medical community to better address the issues face by war-injured soldiers and provide adequate cognitive rehabilitation for these individuals.

Finally, research into HIV-1 and HIV associated dementia (HAD) indicates functional damage resulting in deficits of visuospatial orientation (Olsen, Schendan, Amick, & Cronin-Golomb, 2007). During the asymptomatic phase of infection, HIV-1 has been found to cause impairment in cognitive functionality specifically regarding mental rotation. Compared to a paired matched HIV-negative group, the HIV-positive group showed impaired performance on a hand mental rotation task similar to that conducted by Shepard and Metzler. The cognitive insult on the basal ganglia bears a striking similarity to deficits in Parkinson’s disease patients and elicits similar rotational deficits. The visuospatial problems found by Olsen, Schendan, Amick, and Cronin-Golomb in asymptomatic HIV-1 positive participants suggests that processing in posterior parietal regions is dysfunctional even at the earliest stage of the disease and will manifest itself in mental rotation degradation as well as other cognitive abilities utilizing proprioceptive processing.

Overall, mental rotation offers the science community a wealth of information about the complex relationship between egocentric proprioception and environmental engagement. As mentioned before, the ability to mentally rotate an object provides an onlooker with specific qualities of that object. In terms of one’s one anatomy, the ability to mentally rotate an appendage is a subtle indication of one’s physical capability. Mental rotation indicates that the mind and body are not two dissociated entities.
Predicated upon unique cortical activation, cognitive processing involves a personally relevant, egocentrically driven mechanism.
References


*Psychophysiology, 39*, 414 – 422.


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Brain and *Cognition, 51*, 368 – 371.


Figure Captions

*Figure 1.* Hand stimuli examples: left and right hands, palm-down, in the eight canonical orientations. Stimuli during testing are consistent in terms of size.

*Figure 2.* Hand stimuli examples: left and right hands, palm-up, in the eight canonical orientations. Stimuli during testing are consistent in terms of size.

*Figure 3.* Representation of the participant hand binding. The left hand represents the barrier condition, while the right hand represents the non-barrier condition.

*Figure 4.* Representation of the participant barrier condition – ocular occlusion of the hand as well as physical weighing.

*Figure 5.* Topographic map of electrode for NuAmps 40-Channel Quick-Cap.

*Figure 6.* Behavioral results for angular departure from canonical orientation. Mean reaction times for left and right hand stimuli discrimination for both conditions are plotted as a function of angular orientation.

*Figure 7.* Behavioral results for angular departure from canonical orientation. Mean reaction times both barrier and non-barrier conditions are plotted as a function of angular orientation.

*Figure 8.* Grand averaged ERP depicting electrode P3 with P1-N1-P2 complex. Barrier and Non-barrier conditions are compared.

*Figure 8.* Grand averaged ERP depicting electrode PZ with P1-N1-P2 complex. Barrier and Non-barrier conditions are compared.

*Figure 9.* Grand averaged ERP depicting electrode P4 with P1-N1-P2 complex. Barrier and Non-barrier conditions are compared.
Figure 10. Grand averaged ERP depicting electrode O1 with P1-N1-P2 complex and LNC. Barrier and Non-barrier conditions are compared.

Figure 11. Grand averaged ERP depicting electrode OZ with P1-N1-P2 complex and LNC. Barrier and Non-barrier conditions are compared.

Figure 12. Grand averaged ERP depicting electrode O2 with P1-N1-P2 complex and LNC. Barrier and Non-barrier conditions are compared.

Figure 13. Grand averaged ERP depicting electrode CZ with P1-N1-P2 complex and LNC. Barrier and Non-barrier conditions are compared.
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Angular Depart from Canonical Orientation

Reaction Time (ms) plotted with Orientation (in degrees)
Angular Depart from Canonical Orientation

Reaction Time (ms) plotted with Orientation (in degrees)