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## Title

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# Thinking More Lowers Hand Waving: Dual Task Damps Hand Movements During Mental Rotation

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## Abstract

We report a dual task experiment investigating complementary actions (such as hand movements) that arise during cognitive tasks (such as counting). The 'orphan model' of the mechanism underlying such parallel actions predicts that a dual task would raise the frequency of such actions. However, rather than leading to more complementary actions, the dual task actually lowered usage of hands during mental rotation. This result fits models that consider motor area activation to be modulated by working memory load, such as models where motor area recruitment is initiated and driven by mental rotation, rather than by movement perception, as assumed by the orphan model. But studies on mental rotation show that there is no activation of the motor area during mental rotation of objects. Given this conflict, we propose two models that explain the dual task's damping effect on hand activation, and outline current experiments to test these models.

**Keywords**: Complementary Actions; Orphan Model; Mental Rotation; Situated Cognition; Ideomotor Theory

## Introduction

Once upon a time, there lived a naïve hen and a wily fox on the edge of a forest. The sight of the hen made the fox drool, but as soon as the hen saw the fox, she flew to the branch of a tree. The fox tried many times to coax the hen to come down, but she was never enticed by his sweet words. The fox then hit on an interesting idea: instead of persuading the hen to come down, he decided to run round and round under the tree. The hen, following the fox's movement intently, grew dizzy and fell down, and became the fox's dinner.

This Indian folktale illustrates how observing an action can have the same effect as doing an action (going round and round can make you dizzy, but equally, watching something go round and round can also make you dizzy). The ideomotor principle (Prinz, 2005), first outlined by William James, explains this effect:

> *Every representation of a movement awakens in some degree the actual movement which is its object; and awakens it in a maximum degree whenever it is not kept from doing so by an antagonistic representation present simultaneously in the mind (James, 1890)*

The ideomotor view argues for a common coding between actions (motor activation) and observation of actions (perceptual activation). This common coding allows the latter to generate the same physical effects as the former. Models that draw on this idea postulate that the brain automatically mimics perceived *movements* in the world (Brass & Heyes, 2005; Prinz, 2005). This automatic activation of movement is considered to usually stay covert due to inhibition, but this covert 'simulation' of movement is believed to contribute towards cognition.

In some cases, the automatic activation does not stay covert – it leads to the execution of overt actions that are complementary to the perceived movement. We have developed a model to explain how such overt actions are generated, using a mental rotation task where such complementary actions compatible to the observed stimuli are naturally activated (Chandrasekharan, Athreya & Srinivasan, 2006). The model assumes the ideomotor idea that the *observation of movement* leads to the brain automatically activating actions compatible with the observed stimuli, but these actions remain covert due to inhibition. However, in our model, as cognitive load rises, processing resources move away from this 'caretaker' inhibitory process, which keeps the actions covert. This results in the 'orphaning' of the covert activation, leading to overt execution of the action.

This 'orphan' model of complementary action generation extends the ideomotor idea beyond automatic activation and inhibition, to cognitive-load-modulated inhibition. It explains two puzzles related to complementary actions: 1) why are such actions generated mostly in high cognitive load conditions? and 2) why are non-compatible actions never generated? It also explains why actions non-compatible with cognitive tasks lower performance (see next section for a brief review).

In this paper, we report an experiment that investigated the orphan model further, using the same mental rotation task. The objective of the experiment was to see whether there is a threshold of cognitive load, beyond which covert activation of movement becomes overt action. We used a dual task paradigm to investigate this question. Surprisingly, rather than generating more overt actions, the dual task actually lowered the overt activation of action.

The paper is organized as follows: section 1 outlines the complementary action problem, the experimental paradigm used to investigate it, and a summary of earlier results.

Section 2 presents the dual task experiment, and a discussion of the results. We conclude with current work.

## Action Supporting Cognition

Many studies have reported that actions compatible with cognitive tasks play a beneficial role in cognition. Kirsh & Maglio (1994) showed that players use actions to lower computational load in the Tetris videogame (maneuvering falling shapes into slots on screen). Players execute actions on the falling 'zoids', to expose information early, to prime themselves to recognize zoids faster, and to perform external checks and verifications to reduce the uncertainty of judgments. It is argued that such actions are executed "not for the effect they have on the environment as much as for the effect they have on the agent".

Another influential experiment is Wexler et al. (1998), which showed that unseen motor rotation leads to faster reaction times and fewer errors, when the motor rotation is compatible with the mental rotation than when they are incompatible. In some cases the motor rotation made complex mental rotations easier. Also, speeding (slowing) the motor rotation speeded (slowed) the mental rotation. Similarly, manipulating virtual objects have been reported to improve subsequent mental rotation and recognition of such objects (Wexler & van Boxtel, 2005).

Besides the above direct evidence, Kosslyn (1994) reports extensive indirect evidence for the role of action in mental rotation, including an experiment where participants required more time to perform mental rotations that were physically awkward, and another study where incompatible movements disrupted memory. Kosslyn also refers to a brain-damaged patient who consistently reached for the screen and tried to 'twist' the stimulus in a rotation task.

On a different vein from mental rotations, Kirsh (1995) reports higher accuracy in a coin-counting task when participants pointed at the stimulus, compared to a no-pointing condition. Gestures during cognitive tasks have been shown to lower cognitive load and promote learning (Goldin-Meadow & Wagner, 2005). Humans and other animals exploit head and eye movements to better perceive depth, absolute distance, heading and 3D objects (Wexler & van Boxtel, 2005). Bergen et al. (2004) reports that processing time for sentences involving actions increases when participants perform incompatible actions in parallel.

All the actions reported in the above brief review do not meet the 'epistemic action' criteria set out by Kirsh & Maglio (1994), so we use the more general term 'complementary actions' to refer to such actions generated during cognitive tasks.

How are such actions generated? In previous work, we extended two models from imitation research to investigate this question. A recent review (Brass & Heyes, 2005) succinctly captures the central problem in imitation: "When we observe another person moving, we do not see the muscle activation underlying the movement, but rather the external consequences of that activation. So how does the observer's motor system 'know' which muscle activations will lead to the observed movement?"

This question was used to frame the generation question for complementary actions: how does the participant's motor system 'know' which muscle activations will lead to 'compatible' actions in a task? Further, how does it 'know' when to generate such actions?

One possible answer is: it doesn't 'know'. In imitation, this view is termed Associative Sequence Learning (ASL), and it postulates that visual and motor components become linked through Hebbian learning, and imitation is an automatic activation of motor representations when observing an action (Brass & Heyes, 2005).

A large body of imaging evidence shows the automatic activation of motor representations while observing actions (see Metzinger & Gallese, 2003; Svenson & Ziemke, 2004; Brass and Heyes, 2005, Gallese, 2005). Behaviorally, there is only indirect evidence for the automatic activation model. Most experiments are based on an interference paradigm similar to the one used by Wexler et al. (1998). An example is the finger-tapping paradigm, which illustrates a variant of the Simon Effect (Simon, Sly, & Villapakkam, 1981), where movement execution is faster when accompanied by observation of a congruent movement than with an incongruent movement (Brass, Bekkering & Prinz, 2002). Even planning another action can interfere with mental rotation (Wohlschlager, 2001).

The ASL model of action generation is generalist, and would predict that such activation of motor components is automatically triggered by perception, therefore "they are not expected to be restricted to situations where imitation is intended." (Brass & Heyes, 2005) This is in contrast to a specialist view, termed Active Intermodal Matching (AIM), which postulates a special mechanism mediating imitation, where a supra-modal representation of the action to be imitated is generated. This mechanism would allow the "switching on" of the motor module only when imitation is intended (Brass & Heyes, 2005; Heyes et al., 2005).

We applied these two models of the mechanisms underlying imitation to the question of how complementary actions are generated. A generalist model would predict that compatible actions would be automatically activated while executing visual tasks involving movement. Therefore this activation would not be limited to situations where the actions contribute beneficially to the tasks. In contrast, a specialist model would predict a "switching on" of the motor module only when the action is beneficial.

We conducted two experiments to test these two models of complementary action generation, using a mental rotation task where participants tended to significantly generate hand or head rotations (Chandrasekaran, Athreya, & Srinivasan, 2006). Briefly, the experiments consisted of showing participants a rotation operation, which they had to remember. They were then presented a target pattern, along with four rotated versions of the same pattern (answers). The participants were then asked to mentally execute the remembered rotation operation on the target pattern, and choose the right answer from the four options. The rotation operation had two levels of complexity, low and high.

In contrast to reported work, our results showed that complementary actions not only did not improve performance, but actually hindered it. This supported automatic activation (generalist model). However, the actions were activated mostly in the high complexity condition. To explain this, we postulated that when cognitive load rises in the high complexity task, resources are taken away from the inhibition process that keeps the automatic motor activation under check, and this 'orphaning' of the covert activation leads to the covert action getting executed overtly.

To investigate this idea of cognitive-load-modulated activation of action further, we developed a dual task experiment. If complimentary actions are just covert actions moving to overt status because of rise in cognitive load, a rise in processing load should see more such overt actions.

## Experiment

In the following experiment, participants executed the mental rotation task while reciting the English alphabet backwards. We presented participants with the stimuli while they did the dual task, keeping track of 1) the trials where participants rotated their hands (and heads), and 2) the accuracy for the action and no-action cases. The experiment had two objectives: one, see whether overt actions were activated in the low complexity condition, and at which point; two, see in which point of increasing complexity the actions became activated.

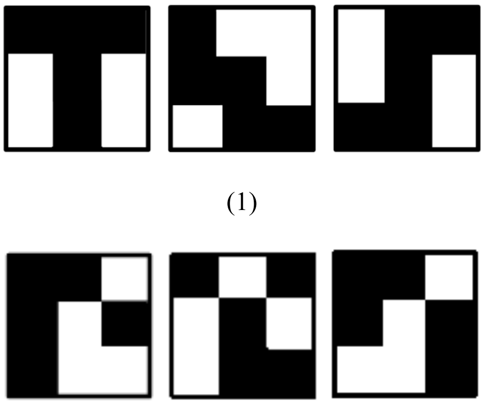
On objective one, if actions were generated in low complexity trials in the dual task, this would indicate that the rise in cognitive load is driving the activation of action. But if they were executed mostly in the high complexity trials even in the dual task, that would indicate that it is not just cognitive load that is involved in the overt execution. Objective two was driven by an ambitious agenda. If overt generation of action resulted from the orphaning mechanism, it may be possible to identify the point of complexity where the orphaning happens, given that the complexity of our stimuli rose in graded steps. If this point could be identified, we could track the neural correlates of the orphan process by tracking that complexity point.

### Method

**Participants**: Nineteen student volunteers from University of Allahabad, with normal or corrected-to-normal vision participated in the experiment. None had prior laboratory experience with mental imagery.

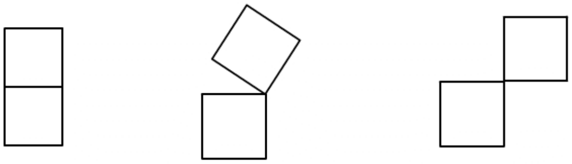
**Apparatus**: A computer screen, microphone and keyboard, placed on a table in front of the subjects. The screen was parallel to participants' frontal plane, at eye level and approximately 75 cm from the participant.

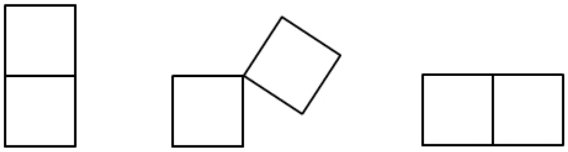
**Stimuli**: A set of six small 2D patterns within a white square (frame) were prepared on a 3x3 matrix with only five cells being filled, as illustrated in Fig. 1. The visual angle was 1.5 o x 1.5o. With each of these patterns, three more patterns were generated by rotating the original four patterns by 90°, 180° or 270°. Any one of the four orientations of a particular stimulus pattern was randomly used as a stimulus in a particular trial. Out of the six patterns used, three were symmetric and three were asymmetric.

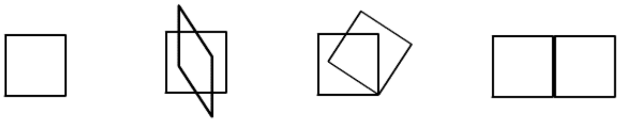

(1)

(2)

Figure 1: The (1) symmetric and (2) asymmetric basic patterns used in the study


90° Rotation


180° Rotation


Horizontal flip followed by 90° rotation

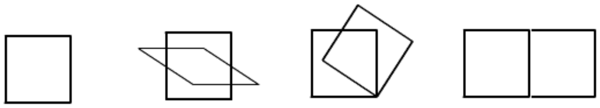

Vertical flip followed by 90° rotation

Figure 2: Snap shots of the rotation operations

There were eight rotational operations (see Fig. 2) with two levels of complexity (low or high). Each level of complexity had four operations. Low complexity operations were rotations of 90° (right and left) and 180° (right and left). High complexity operations were vertical and horizontal flips followed by a rotation of 90° (left or right).

The rotational task was given a reference by providing an empty-blank white square (frame). To demonstrate the operations, video clips were created using Flash (sample files at: http://www.sce.carleton.ca/~schandra/CAflash). Each rotation in the low complexity condition took twenty seconds of display time.

In the high complexity condition, each flip operation took twenty seconds in addition to each rotation operation, which also took twenty seconds to complete. There was a two second gap between flip and rotation. The end position (frame), after the rotational operation completed, stayed for five seconds.

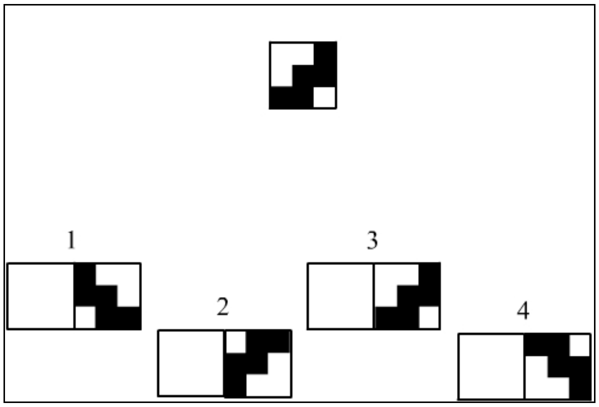


Figure 3: The screen during the second phase

**Procedure**: The experiment consisted of forty eight trials (8 operations x 6 patterns), presented randomly. Each trial had two phases. In the first phase, a rotation was demonstrated using a video clip. Participants were asked to remember the rotation they saw, apply the same operation on the pattern coming up in the second phase and select the answer that best fitted the mentally rotated pattern.

The second phase started after four seconds, during which the screen was blank. This phase presented a pattern to be mentally rotated, along with four possible answers (as shown in Fig. 3), which remained on screen until participants pressed a key following which a text box appeared in which the participants typed their choice (1, 2, 3 or 4). They then pressed the Enter key to initiate the next trial, which started after two seconds. In addition to the mental rotation task, the participants were instructed to recite the letters of the English alphabet backwards, starting with Z. The participants were instructed to do the task at a comfortable speed without compromising accuracy. Commercially available software (DirectRT, running on a PC with a VGA monitor) was used for stimuli presentation and data collection.

The experimenter sat beside the participant and used a chart to document the trials in which the participant generated complementary actions. There were three kinds of actions -- finger, wrist and elbow movements. There were no head movements in relation to the mental rotation task.

## Results and Discussion

**Use of hands**: Out of nineteen participants, only six used their hands extensively (used hands in more than 50% of trials: high-action-generation group) and the remaining thirteen did not use their hands (used hands in less than 50% of trials: low-action-generation group). The high-action-generation group used their hands in 75% of the trials, while the low-action-generation group used their hands in only 10% of the trials. Occasional head movements were ignored in this analysis.

A two-way within ANOVA (task complexity: low, high; stimulus complexity: symmetric, asymmetric) was performed on the percentage of trials in which hands were used by the participants. Among the high-action-generation group, there was no significant difference in hands usage in terms of task complexity as well as stimulus complexity. Note that the number of participants in the high-action condition is small (n=6).

Among the low-action-generation group, there was no significant difference in hands usage as a function of task as well as stimulus complexity.

**Accuracy**: The accuracy results are shown in Figure 4. A 2 between (action: high-action-generation, low-action-generation) x 2 within (task complexity: low, high) x 2 within (stimulus complexity: symmetric, asymmetric) ANOVA was performed on the accuracy values from all the participants. The results also show that performance in the low task complexity condition (0.49) was significantly better than performance in the high task complexity condition (0.31), *F* (1, 17) = 10.354, *p* = 0.005. No other effect was significant. However, there is a trend (F (1, 17) = 1.509, p=0.236) with better accuracy in the low-action generation group (43%) compared to the high action-generation group (34%). There is also a trend with the three-way interaction (F (1, 17) = 1.979, p=0.177) which indicates that all the factors may interact with each other.

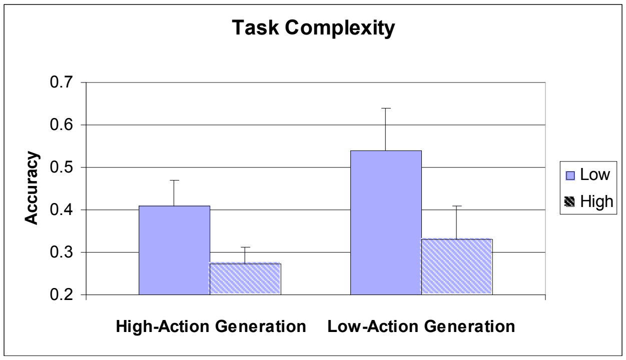


Figure 4: Accuracy with High-action-generation and Low-action-generation with Dual Task

In a total reversal of our earlier experiment results, hands usage actually came down significantly in the current dual task experiment. While majority of participants used hands extensively (17 out of 23) in the non-dual task experiment, with a dual task, the majority of the participants (13 out of 19) did not use hands extensively. In addition, the actual amount of hands usage for both the high-action and low-action generation groups came down in the dual task experiment. Note that task complexity affected hands usage in the non-dual task version, with more hands usage in the high complexity condition. However, with the dual task, high complexity did not increase hands usage.

In terms of accuracy, one common factor was task complexity. Accuracy was better with low task complexity, compared to high task complexity. The introduction of the dual task produced a significant decrement in performance. In the previous experiment, those who did not use hands performed better than the ones who used hands. This advantage is reduced with the dual task. While not significant at this point, the trend again indicates that performance is better with the low-action generation group compared to the high-action generation group.

## Varieties of Motor Activation

Since we are interested in the mechanism underlying action generation, we will ignore the accuracy results, and focus on why hand movements came down in the dual task. The orphan model assumes the ideomotor view that motor area is automatically activated by the perception of movement, and the recruitment of the motor area happens at the point of *perceiving* the rotation of the square. According to this model, this motor area activation is usually inhibited, but the inhibition takes up processing resources. In high cognitive load conditions, the inhibiting process loses processing resources, and this leaves the motor activation orphaned, leaving it to move towards execution. This view predicts that increasing the processing load should lead to more hand movements, as the load would affect only the inhibition process, and not the activation process, as the latter is automatic.

However, there is another view where the dual task result would not be surprising. If we assume that the motor area recruitment happens *only later* in the process, i.e. only during the mental rotation of the patterns, the dual task would be expected to lower hand movements. The reason is that both processing resources and attention are split by the dual task, and this would mean lower mental rotation, and hence lower recruitment of the motor area, as motor recruitment is triggered *only* by mental rotation in this view. Such a model considers motor recruitment to be mediated by working-memory, and it would predict the lower hands usage in the dual task, as the dual task uses more working memory.

We believe this model is not plausible, because of two reasons. One is that at least two imaging studies have ruled out motor recruitment during mental rotation of objects (Windischberger et al., 2003; Wraga, et al., 2003; see also Vingerhoets et al., 2002). Though motor areas do get activated when the rotated stimuli is hands or tools. Since our stimulus was a box frame, the above results suggest that motor area activation would not be initiated by the mental rotation. The second reason is experiments showing that perception of movement activates motor components. So it is improbable that motor activation happens *only* at the mental rotation stage.

This leaves two other possible hypotheses. One is a combination view: the motor area recruitment is initiated by perceiving the moving stimulus (as assumed by the orphan model), but this recruitment is 'carried over' to the mental rotation phase and mental rotation is coupled with motor area activation (as assumed by the working memory view). This is plausible, because in the Wraga study, motor area activation for rotation of hand stimuli and neutral object stimuli were compared. It was found that when the hand stimuli came first, followed by the object stimuli, motor areas were activated for the object cases as well. However, when objects stimuli followed object stimuli, there was no activation of the motor area.

Even though the stimuli in our experiment were both objects, a similar 'carryover' effect could lead to the mental rotation of patterns in the second stage 'keeping alive' the motor recruitment initiated by the rotating square. In such a mechanism, this carryover motor recruitment would be driven by the rate of mental rotation. This mechanism would explain the dual task results, as in this view, the dual task lowers the resources available for mental rotation, and since mental rotation is keeping alive the carryover motor recruitment, this also takes away resources from motor area activation, thus lowering the chances of hands being activated.

The above hypothesis considers cognitive load as generic, and does not consider the *form* of the load. However, it is possible that the form of the dual task may have had an impact on hand movement, as the reverse alphabet task is linear while the rotation stimulus is circular. A possibility is that the linear task interferes with the rotation task. In this view, the activation of the motor area happens only at the perceptual level, but since the dual task we used is of a different format from the rotation task, it interferes with this automatic activation – it 'dampens' the motor recruitment process. In effect, the alphabet task is acting like a non-compatible action, and is inhibiting the automatic activation of movement, similar to the damping in the finger-tapping experiment and the mental rotation experiments reviewed earlier (Brass et al., 2003, Wexler et al., 1998).

## Current Work

We are currently developing experiments to test these two hypotheses. If the latter hypothesis is true, a dual task with a circular nature would bring back hand activation, as its form is compatible with the mental rotation task. We are currently developing such a dual task. If the former 'carryover' hypothesis is true, raising working memory load, or distracting attention, by any means would lead to hands usage going down, as in this view lowering of mental rotation is what lowers hands usage. We are running dual tasks using memory (remembering alphabets, numbers, emotions etc.), and sounds, to test this hypothesis.

Regardless of the mechanism involved, our results show that raising cognitive load at times has the beneficial effect of lowering actions that hinder cognitive tasks (remember higher hands usage actually lowers performance in the rotation task). On the application front, this result opens up the possibility of more fine-grained engineering of multi-tasking in complex environments such as cockpits and control rooms of nuclear reactors.

Interestingly, since the ideomotor view is modality-neutral and can apply to auditory perception, the orphan model and the dual task explains a common experience: why your head, hand or leg starts moving unconsciously in rhythm to dance music, but the movement suddenly stops when you attend to another task.

A better understanding of how actions are generated from perceived and simulated movements may have other implications as well. For instance, in the case of a recent shooting incident in a Canadian college campus, it was reported that the gunman played violent videogames involving shooting. He also posted fantasies on the Internet about shooting people. At which point does such internal simulations of actions move to real actions, and how? Understanding the control mechanism underlying action generation may throw light on this question.

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