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Ideomotor Compatibility: Investigating Imitative Cortical Pathways

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Introduction

Humans' capacity to imitate has been extensively investigated through a wide-range of behavioral and developmental studies. Yet despite the huge amount of phenomenological evidence gathered, we are still unable to relate this behavioral data to any specific neural substrate. Specifically, we address the principle of **ideomotor compatibility**, by which *observing the movements of others influences the quality of one's own performance* and develop two neural models which account for a set of related behavioral studies [1].

Related Experimental Study The study in which we are interested here is a stimulus-response experiment designed to verify two hypotheses of the ideomotor theory [2]. These two hypotheses are based on the neural correlate that neural circuits devoted to the recognition of movements performed by others are likely to be shared by the motor preparation circuits [3]. The first hypothesis states that *if a subject was requested to respond to the motion of a demonstrator then (s)he would experience a motor facilitation*, giving faster reaction times compared to if the subject was asked to make the same movement in response to a spatial cue. The second hypothesis states that *the facilitatory effect would be greater if the movements of the demonstrator and subject were very similar (ideomotor compatible) than if they were of a different type (ideomotor incompatible)*. The experimental stimuli consisted of a combination of a finger-lifting movement (either index or middle finger) and of a spatial cue consisting of a cross painted on the corresponding or opposite fingernail (see Fig. 1). Each stimulus type

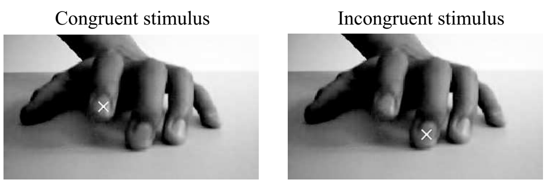

Figure 1: Stimuli as used by [2]. Congruent condition: a left (right) finger movement with a cross on the left (right) fingernail. Incongruent condition: a left (right) finger movement with a cross on the right (left) fingernail.

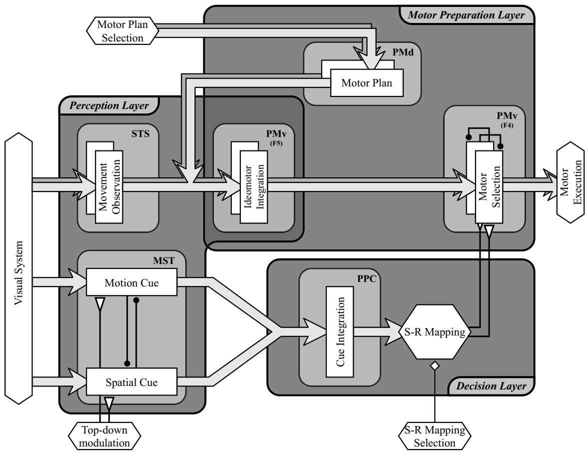

Figure 2: Architecture of the model which is endowed with a direct-mapping from movement observation to motor execution.

was considered either as task-relevant or as a distractor. The subjects were then asked to perform a spatially compatible finger lifting or tapping movement in response to congruent or incongruent stimuli. The authors' results were in agreement with their hypotheses, as responses to finger movements were faster than responses to spatial cues, and ideomotor compatible pairs of observed/executed movements generally produced better reaction times [2].

Models

The two models which we propose to replicate the cited behavioral study mainly rely on the same principles. First, the two networks consist of three major parts: the perceptual, decisional and motor preparatory layers, which respective tasks are to represent visual information, to determine the right response to external stimuli, and to prepare and trigger motor execution (see Figure 2 for an illustration). In our models, **perception** is only considered in its final stage, in that we assume visual information to have already been processed by highly specialized circuits and represented in a manner relevant for the task. Nevertheless, **active processes** are involved in the perceptual level of our models. For instance, task instructions produce a top-down modulation of cortical activity that enhances the relevant stimulus type for the task. In addition, motivated by psychological and neurophysiological considerations, a natural preference for certain stimulus types and competitions between neural representation are also part of our models. Then, as the main task of the proposed models is to perform a selection among different sources of stimulus, the perceptual information is then fed to a **decisional process**. And as soon as it is performed, the network transforms information from stimulus space to motor space by means of stimulus-response associations. Considering now **motor preparation**, it consists of three areas, coding respectively for the motor plans, for the shared representation between movement observation and motor execution (*the ideomotor region*), and for the final motor selection. The motor plans are fed either directly or indirectly through the ideomotor area to the final motor selection layer which is waiting for the execution signal coming from the decisional process. Indeed, the key difference that distinguishes between our two models is that one assumes shortcuts in the decisional process mediated by a direct-mapping between movement observation and execution (*direct-matching model*), whereas the other is designed using an information bottleneck in the decisional process (*single route model*).

Implementation The neural implementation of the two models is inspired by neurophysiological evidence suggesting a continuous representation of stimuli in feature maps [4]. In such neural populations, neurons generally respond to external stimuli with broad tuning curves of activity. Therefore we adopted the **dynamic neural field approach** [5] which integrates the principles of continuous representations endowed with a metric, and can account for temporal dynamics of stimuli interactions. Indeed, the important **dynamical properties** of such networks include abilities for stimulus enhancement, for cooperative and competitive interactions within and across neural representations.

Results & Discussion

The behavioral experiments were simulated by the two models using the same initial conditions as those used in the behavioral study [2]. The results of the two models are in good agreement with the original data. Since the reported simulation results are barely distinguishable, it shows us that this experimental paradigm cannot clearly discriminate between these two networks. Therefore, we devised a method for determining which model best reflects the information pathway in the brain. To achieve this, we once again took inspiration from the literature on stimulus-response compatibility and decided to confront our models with an incompatible stimulus-response mapping, i.e. the subjects should respond to a left (right) cue with a right (left) finger movement. Under this experimental paradigm, the models now exhibit clearly different behaviors (see Fig. 3).

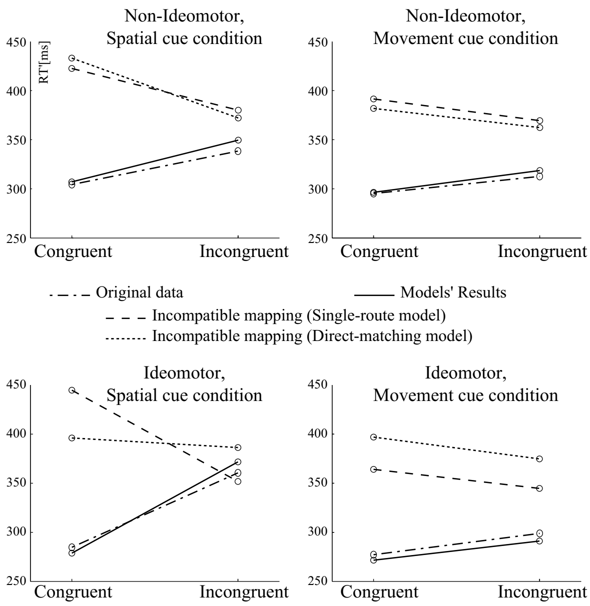

Figure 3: Original behavioral data, results and prediction of the models under different experimental conditions.

To conclude, we present two biologically inspired computational models capable of reproducing the experimental results obtained by [2]. These models are in line with other computational models addressing imitation mechanisms in both humans and monkeys such as [6], in that they all assume a shared representation between movement observation and action execution which is mediated by competitive interactions.

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References

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