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# The truth-telling motor cortex: Response competition in M1 discloses deceptive behaviour

Aviad A. Hadar*, Stergios Makris, Kielan Yarrow

*Department of Psychology, City University London, United Kingdom*

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ABSTRACT

Neural circuits associated with response conflict are active during deception. Here we use transcranial magnetic stimulation to examine for the first time whether competing responses in primary motor cortex can be used to detect lies. Participants used their little finger or thumb to respond either truthfully or deceitfully regarding facial familiarity. Motor-evoked-potentials (MEPs) from muscles associated with both digits tracked the development of each motor plan. When preparing to deceive, the MEP of the non-responding digit (i.e. the plan corresponding to the truth) exceeds the MEP of the responding digit (i.e. the lie), whereas a mirror-reversed pattern occurs when telling the truth. This give away response conflict interacts with the time of stimulation during a speeded reaction period. Lies can even activate digit-specific cortical representations when only *verbal* responses are made. Our findings support neurobiological models which blend cognitive decision-making with motor programming, and suggest a novel index for discriminating between honest and intentionally false facial recognition.

## 1. Introduction

Deception is commonplace in human communication, engaging multiple cognitive processes (Ekman, 2009; Spence, 2004). Social interactions often involve deceptive behaviours, used to maximize personal gain or avoid punishment (Nardini, 1987; DePaulo et al., 2003). At present the most widely used tool for lie-detection is the polygraph (Pollina et al., 2004) which is based on indirect peripheral physiological measures. Recent imaging studies have demonstrated that neural circuits associated with response conflict and response inhibition are strongly implicated in deception (Abe et al., 2006, 2007; Bhatt et al., 2009; Kozel et al., 2004; Lee et al., 2010; Langleben et al., 2005; Nunez et al., 2005; Schumacher et al., 2010). Indeed, cognitive models of deception posit the activation of the truth as one of the early processes underlying deception, which could lead to conflict. However, to date the involuntary activation of a population of neurons representing the truth in lying has not been demonstrated.

Several researchers have noted the consistent involvement of the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC), areas associated with cognitive control and conflict monitoring, in deceptive behaviour (Abe et al., 2006; Bhatt et al., 2009; Lee et al., 2010; Nunez et al., 2005; Schumacher et al., 2010). Abe et al. (2006) used positron emission tomography (PET) to show that the activation of conflict monitoring areas such as the ACC is specific for denying knowledge of an event rather than confabulating knowledge of an event. In a study by Nunez et al. (2005), increased activation within the ACC and DLPFC was found particularly when participants falsified autobiographical facts. They also found parallel behavioural effects expressed in increased reaction time (RT) for deceptive responses, which they attributed to interference from a potent true response, similar to the effects found in traditional conflict paradigms such as the Stroop and the Flanker tasks (Eriksen and Eriksen, 1974; Stroop, 1935). More recently Bhatt and colleagues (2009) asked participants to deliberately misidentify familiar faces in a format similar to police ‘line-ups’ used with crime suspects. Triads of faces, with one face being shown prior to the task, were streamed, and participants were instructed to deny recognition of the familiar face and instead indicate familiarity of an alternative novel face. As in previous work with verbal questioning, imaging data showed that increased activation in a network of areas, including the ACC and DLPFC, was associated with deceptive behaviour.

To the extent that the act of deception entails suppression of a potent true response and the generation of an alternative, it is not surprising that the ACC and the DLPFC appear to be highly active. Both of these areas have been strongly implicated in error processing, response competition, and conflict monitoring (e.g. Botvinick et al., 1999; Braver et al., 2003; Carter et al., 1998). However, despite the wealth of literature on response conflict, and the emerging

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* Corresponding author at: Social Science Building, City University London, Northampton Square, London EC1V 0HB, United Kingdom. Tel.: +44 020 7040 4597; fax: +44 020 7040 8580.

*E-mail address:* Aviad.hadar@city.ac.uk (A.A. Hadar).

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literature on lie detection, to date, no empirical attempts have been made to utilise the cortical dynamics of response conflict for the detection of a lie. Seymour and Schumacher (2009) have perhaps come closest to such an attempt, by using electromyography (EMG) to detect conflict at the motor output level. In their task, which is similar to intentional false responding in facial recognition, participants had to falsely indicate that some previously presented words were new, whilst responding truthfully to a second group of previously presented words. Additionally a third 'filler' group of unseen words was also shown, requiring a truthful ('new') response. In this experiment, responses were given with either the right or the left hand and EMG was recorded from two corresponding muscles. Analysis of correct trials revealed a greater number of partial errors (partial activation of the incorrect response) in the first condition, in which false responding was required. The authors interpreted this pattern as evidence for a conflict in the response preparation stage within a serial model incorporating competition between (1) automatic familiarity and (2) a slow level-headed recollection process. Thus, falsifying information reliably resulted in conflict between responding muscles.

The transformation of an abstract cognitive conflict (induced by deceptive behaviour) into a tangible motor conflict opens new avenues for the development of lie detection techniques, and can also shed light on the mechanisms underlying motor decision making. Verbal yes/no responses, which serve as the basis for most lie detection research, can be easily substituted with manual responses, requiring consistent activation of two distinct muscles. Cisek (2006, 2007) constructed a model, based upon single-cell recording experiments in the macaque brain, simulating how plans for moving a digit in two opposing directions compete in pre-motor areas. According to the model the selection of a single motor output is achieved via mutual inhibitory competition between neural populations representing different directions for movement. He speculated that motor decision-making processes are constantly biased by projections from other brain areas. Importantly Cisek's computational simulations and the confirmatory neural data suggest that response selection entails parallel response preparation for multiple candidate responses. Therefore, the process of selecting a response does not necessary entail a discrete selection mechanism. Indeed, in the past decade evidence has accumulated in favour of such parallel activation views of response conflict which cast doubt on the traditional idea (Pashler, 1991) of a serial selection process with discrete stages of selection and motor preparation (e.g. Desoto et al., 2001; Fleming et al., 2009; Taylor et al., 2007; Verleger et al., 2009).

Here, we examine whether the dynamics of response competition, as expressed in primary motor cortex (M1), can be used to reveal deceptive behaviour, by making use of single-pulse transcranial magnetic stimulation (TMS). In this approach, muscular responses induced by TMS, known as motor evoked potentials (MEPs), are used to index the strength of an action tendency in M1 or adjacent premotor areas (cf. Bestmann et al., 2008; Gandevia and Rothwell, 1987; Kiers et al., 1997). Single pulses, given at different moments prior to response execution but after stimulus presentation, can provide information about the dynamics of the interaction between two responses. For instance, Verleger et al. (2009) used a bimanual flanker task to compare the strength of incorrect premature response representations (activated by the flankers) with that of correct representations. Participants moved their left or right index fingers, as directed by a central arrow, whilst ignoring compatible or incompatible peripheral stimuli. Ipsilateral and contralateral M1 were stimulated at various moments prior to response execution. MEPs were found to be larger for the responding hand compared with the non-responding hand. However, this effect was modulated by the irrelevant flankers, e.g. MEPs in the responding hand were larger in compatible conditions compared with incompatible or neutral conditions. Crucially, MEPs of the non-responding hand decreased closer to response execution and the reverse pattern was evident for MEPs of the responding hand. Thus, the relationship between the MEP amplitude of two responses can in principal be used to reveal how premature or even concealed response tendencies evolve during motor preparation.

In the current series of studies, binary choices concerning the facial recognition of famous and non-famous people were used to frame the cognitive act of deception within a response-conflict paradigm. Participants used their right little finger or thumb (or an associated verbal response in Experiment 3) to deceptively or truthfully indicate facial familiarity. By administering TMS prior to response execution in both truthful and deceitful conditions, we could compare the MEPs linked to the two competing responses. We predicted that the MEP of the non-responding digit should be larger when lying, particularly in the period immediately after stimulus onset, because of automatic activation of this objectively correct motor response. Such a finding would demonstrate the potential of highly localised motor activity to reveal deceitful behaviour. It would also help elucidate how stimulus presentation triggers the preparation of multiple responses within a single effector, casting further doubt on the notion of an isolated serial selection stage during motor decision making.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Participants

Eight right-handed participants (5 male; mean age = 26, SD = 3.4) were tested. Participants were screened for contraindications for TMS, and also their ability to relax their muscles fully between manual responses. They were compensated financially for their time. The study was approved by the City University Psychology Department Ethics Committee.

#### 2.1.2. Stimuli

Sixteen faces served as stimuli. Four were of famous politicians and four were of famous film actors/actresses (in both cases half male, half female; pictures found online). For each famous person, the face of a non-famous person from the Karolinskaor NimStimstimulus sets (Lundqvist et al., 1998; Tottenham et al., 2009) was matched on sex, skin colour, gaze direction and facial expression. All faces were presented as greyscale 100 × 130 pixels portraits (∼4.94 × 5.81° visual angle).

#### 2.1.3. Apparatus

E-Prime 2.0 (Schneider et al., 2002) ran on a lab PC to present stimuli and control TMS pulses. Subjects sat 50 cm in front of a 19-inch CRT monitor refreshing at 100 Hz. The right hand rested on a foam pad, positioned palm down with thumb and little finger each touching digital response keys (Fig. 1). Electromyography and TMS were combined to measure MEPs from two intrinsic muscles of the right hand (the Abductor DigitiMinimi, or ADM, and first dorsal interosseous, or FDI) using standard methods (cf. Makris et al., 2011).

*EMG recording.* Two 22 mm × 28 mm surface Ag/AgCl EMG electrodes recorded from the Abductor DigitiMinimi (ADM) of the right hand. Two others recorded from the first dorsal interosseous (FDI) of the same hand. EMG (bandpass filtered 20–450 Hz) was collected at 1000 Hz via a 13 bit A/D Biometrics Datalink system (version 7.5, Biometrics Ltd., Ladysmith, VA, U.S.A., 2008) and stored on a dedicated PC. EMG was also passed to a speaker to provide a warning when muscles were not fully relaxed. Participants were prompted to monitor their motor activity by relaxing their muscle whenever loud muscle noise persisted between responses.

*TMS protocol.* Pulses were applied using a 70 mm figure-of-eight coil (external casing diameter ∼90 mm for each loop) connected to a MagstimRapid$^2$ biphasic stimulator (The Magstim Co. Ltd., Whitland, Carmarthenshire, U.K.). The coil was held tangentially to the skull, over the optimal spot at the left M1 to elicit MEPs in both the ADM and FDI, with the handle pointing backwards/laterally approximately midway between the saggital and coronal planes. Intensity of pulses was set around 110–117% of resting motor threshold (RMT) in order to elicit MEPs of around 1 mV amplitude in both the ADM and the FDI. Individual RMTs were determined prior to the experiment as the minimal intensity required to elicit an MEP ∼50 μV in amplitude (peak to peak) in at least 3 out of 6 single pulses when the hand was fully relaxed. A post-report form was used to document any adverse effects of TMS (suspected seizures, syncope, headaches, muscular discomfort and anxiety) which are reported elsewhere (Hadar et al., in press).