Note

Executive functioning and imitation: Increasing working memory load facilitates behavioural imitation[☆]

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ABSTRACT

If perceptual and bodily states are closely linked and if perceiving action automatically leads to corresponding activations in one's own motor system, then why do not we imitate all the time? There is evidence suggesting that executive functioning (EF) may play a moderating role in inhibiting overt imitation [e.g. Luria, A. R. (1966). *Higher cortical functions in man*. New York: Basic Books]. In an experiment we tested this idea. 48 participants received either a high or low working memory (WM) load and were instructed to respond to either a finger cue or spatial cue with a finger movement. Results indicate that occupying WM facilitates reaction times to finger cues while responses to simple spatial cues are unchanged. The findings suggest that imitation is indeed a dominant response and EF is needed to inhibit the spontaneous tendency to imitate.

Humans are born to imitate. Our biological and social systems make it possible to perceive others actions and behaviours and consequently execute them ourselves. For example, novel tool learning is partly dependent on being able to imitate someone wielding the instrument in question for the first time. It certainly seems unlikely that humans would have been able to develop the complex skills of language and technology without the ability and inclination to imitate the actions of other people. More subtle, but of no less impact for our social interactions, is our non-conscious tendency to imitate our conversation partners' speech manner, nonverbal behaviour and posture, especially if we have a vested interest in this particular person.

The study of imitation and mimicry in animals and humans has become increasingly popular since the discovery of mirror neurons in monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; see Hurley & Chater, 2005 for current reflections on imitation). Recently, several neuroimaging studies in humans have proposed a similar mirroring network in humans where action perception influences corresponding activation in the perceivers motor system (Decety et al., 1997; Grezes, Costes, & Decety, 1999; Iacoboni et al., 1999; Jacksons, Lafleur, Malouin, Richards, & Doyon, 2001; Knoblich & Flach, 2003; Parsons, 1994; Parsons & Fox, 1998; Nishitani & Hari, 2000) which is sometimes dubbed the perception–behaviour expressway (e.g. Dijksterhuis & Bargh, 2001).

Moreover, the tendency to imitate other people is widely acknowledged by diverse behavioural demonstrations from neonates spontaneously imitating their mothers' facial expressions, tongue protrusion and novel action sequences (e.g. Gergely, Bekkering, & Kiraly, 2002; Meltzoff & Moore, 1991), to spontaneous behavioural imitation in adults copying facial expressions (e.g. Dimberg, 1982; Zajonc, Pietromonaco, & Bargh, 1982), face touching, foot movement, pen playing (e.g. Chartrand & Bargh, 1999; Van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003) and posture (Bernieri, 1988). Further solidifying this, it has been shown that perceiving an actor grasping an object activates similar motor responses in participants as those produced when they themselves perform the action (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). Altogether there seems to be a strong tendency in the literature to claim the automaticity of imitative responses. Obviously however, we do not always find ourselves copying each and every movement or action performed by others, something that would be highly inefficient, especially if we are involved in goal-directed behaviour. There must be a mechanism that limits our spontaneous inclination to imitate any behaviour that is observed.

The obvious place to begin looking for the source of inhibition of imitation are the executive and control functions associated with the frontal lobes. Already in 1966, Luria showed that patients with frontal brain damage could not help but repeat the experi-

menter's movements, something he called echopractic responding. Lhermitte, Pillon, and Serdaru (1986) corroborated these findings by also demonstrating spontaneous imitative behaviour in frontal lobe patients, but later investigation into this phenomenon, suggested that the occurrence of this type of overt imitation in frontal lobe patients was less frequent than previously assumed (De Renzi, Cavalleri, & Facchini, 1996).

Recent research, however, has elegantly shown that spontaneous imitative behaviour indeed often persists in these patients, but can be observed on a more subtle level (Brass, Derrfuss, Matthes-von Cramon, & von Cramon, 2003). In this study, frontal lesion patients were more prone to spontaneous imitation compared to post-central lesion patients and matched controls. These effects were most pronounced in patients with fronto-lateral damages, an area that several researchers have claimed is important for executive processing including, but not limited to, information retention, response selection, information verification and other processes dependent on working memory (Owen, McMillan, Laird, & Bullmore, 2005). Additionally, it has been demonstrated that frontal lesions are related with diminished inhibitory functioning (Passingham, 1993; Smith & Jonides, 1999).

Following this reasoning we hypothesize that executive inhibition plays a crucial role in suppressing automatic imitation (but see Brass, Derrfuss, & von Cramon, 2005 for non-executive control regions involved in the inhibition of imitation). While previous studies have only focused on patient populations with damage to related brain regions we hypothesized that increasing working memory load should also lead to a similar effect in a healthy population sample. By occupying working memory, executive capacities normally free to control automatic behavioural imitation will be reduced, and therefore possibly result in facilitated perception–action priming.

To explore this hypothesis, we adapted an imitation paradigm introduced by Brass, Bekkering, Wohlschlager, and Prinz (2000)[1] by including an executive function (N-Back) secondary task with either a high or low working memory load manipulation (Owen et al., 2005). The experiment involved participants watching an image of a hand on a computer screen and making movements with their own fingers. In baseline trials, the participants' had either to imitate a finger movement showed onscreen (finger cue) or move the finger on which an "X" appeared onscreen (spatial cue). In non-baseline trials, both an onscreen finger movement and an "X" appeared, and depending on the instructions of a given block, participants had to respond to one (e.g. the finger) and ignore the other (e.g. the "X"). These response cues (finger or "X") could be either congruent or incongruent; e.g. when having to respond to a finger movement but ignore the "X", an "X" would appear on the moving finger (congruent), or on the finger not moving (incongruent).

Crucially, the imitation of finger movements presented on a computer screen falls in the domain of natural imitative behaviour. That is, people are spontaneously inclined to perform this imitative behaviour. However, moving your finger upon seeing a spatial cue ("X") on a corresponding finger on the screen, is not a spontaneous process, but must be learned (following specific instructions). Taking into account the research discussed above we hypothesize there is still always some latent amount of inhibition of spontaneous imitative actions. Therefore, reducing executive control capacity by increasing working memory (WM) load should undermine the usual inhibitory suppression of spontaneous finger movement imitation, thereby facilitating the instructed finger movement imitation. At the same time, load should interfere with

executing spatially cued finger movements because it is not an automatic response. This way load could result in an interaction between the baseline execution of imitative movements (the finger cue) and baseline execution of spatially cued finger movements. On the basis of this argument, in the baseline condition (where there are no simultaneous irrelevant congruent or incongruent cues), we expected imitative responses to finger movements to be faster under high working memory load than low working memory load compared to finger responses to spatial cues. By the same token, load should increase distraction by incongruent finger movements when executing spatially cued finger movements, and reduce distraction from incongruent spatially cued finger movements when executing finger-cued movement imitation. If these predictions are confirmed, it would suggest a facilitating effect for perception–action coding under high working memory load and a debilitating effect for non-automatic responses.

1. Method

1.1. Participants

We recruited 48 participants for this study in return for course credit or €6. All were right-handed students at the University of Nijmegen, who had normal or corrected vision and were naive towards the purpose of the study.

1.2. Materials and procedure

The images used for cueing finger responses consisted of a sequence of two pictures; a hand seen from the front in resting position, succeeded by one of several possible movement cue pictures. Baseline finger cues were indicated by either a lifted index or middle finger with no spatial cues appearing. Baseline spatial cues were indicated by a black "X" on the nail of either index or middle finger with no simultaneous finger movements. Congruent finger cues show a lifted index or middle finger with a black "X" on the nail. Incongruent finger cues showed a lifted index or middle finger with a black "X" on the nail of the other finger (see Fig. 1). Congruent and incongruent spatial cue images were identical to the congruent and finger cue images. All movement cues were preceded by a hand in resting position for 560 ms.

Participants were instructed to seat themselves in front of the computer with their right hand centred 50 cm from the screen, mirroring the resting hand presented in the image. Depending on block they were told to either respond to finger movements and ignore the black "X" or to respond to the black "X" and ignore the finger movements.

In the finger cue block they were told to move the same finger as the one that moved onscreen. A black "X" was sometimes to appear on either one of the fingers, it was made clear this was of no importance and should be ignored. Conversely, in the spatial cue block participants were told they had to lift the finger corresponding to the one on which there appeared a black "X" onscreen. Sometimes either the index or middle finger of the hand presented would also move; it was made clear this was of no importance and should be ignored.

Simultaneously one of two different auditory N-back tasks were used to manipulate working memory (Owen et al., 2005), half of the participants were presented with a low WM load, and half with high WM load. The goal of the N-back task is to remember the letter for a certain period so it can be compared to letters presented later. The number of letters having to be remembered online defines the amount of working memory load.

The letters were presented through headphones and could be either "g", "b", "t", "v" or "j". In the low working memory condition they were told to verbally respond with "yes" every time they heard a "g", and with "no" to any other letter (0-back). In the high working memory load condition they were instructed to respond with "yes" whenever the letter they heard was identical to the letter presented two trials earlier (2-back). If this was not the case they should respond with "no". Letters were created by a text-to-speech program and all auditory presentations lasted 0.5 s with identical volume, pitch and intonation. Participants' verbal responses were recorded by the experimenter.

The finger movement and working memory task ran parallel. Participants completed both a finger cue block and spatial cue block, or of which was counterbalanced. Half of the participant received the low and half the high WM load. A block lasted 270 s and consisted of 90 randomized trials (30 baseline, 30 congruent and 30 incongruent) and each block was preceded by 30 practice trials. All trials lasted 3 s and consisted of a focus "+" on a black screen (1840 ms), then a hand in resting state (560 ms) followed by the experimental stimulus (baseline, congruent or incongruent). N-back letters were presented 250 ms before the movement cue (see Fig. 2). Finger movement onsets where measured with an Optotrak system (Northern Digital) at 100 samplings/s.

Practice trials included both the visual finger response task and the auditory N-back task. After the experiment participants were debriefed, paid and thanked for their participation.

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[1] See also Brass et al., 2000 (exp 3), demonstrating that effects are due to ideomotor compatibility. For a critical exploration of the paradigm see Berthenthal, Longo, and Kosobud (2006).
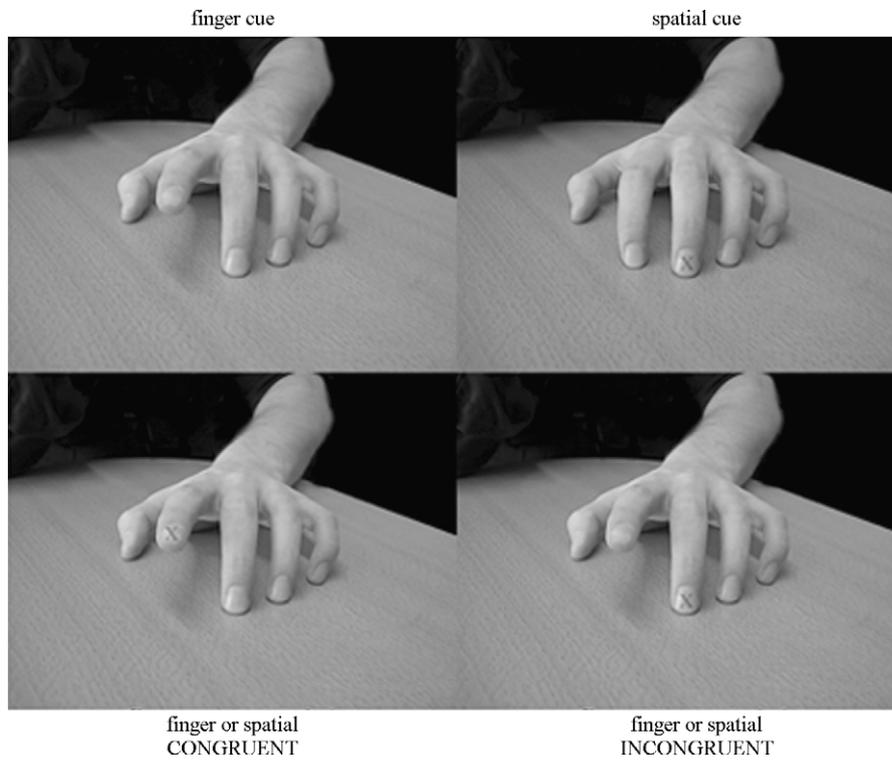
finger cue   spatial cue

finger or spatial
CONGRUENT

finger or spatial
INCONGRUENT

Fig. 1. Example images used for response cueing. Top panel: finger and spatial baseline movement cues. Lower panel: congruent and incongruent movement cues. Note that identical images were used for finger and spatial cues in the congruent and incongruent conditions, the only difference was what cue should be reacted to. Cues could be either (on) index or middle finger. Pictures were originally presented in colour resulting in increased contrast compared to the example images.
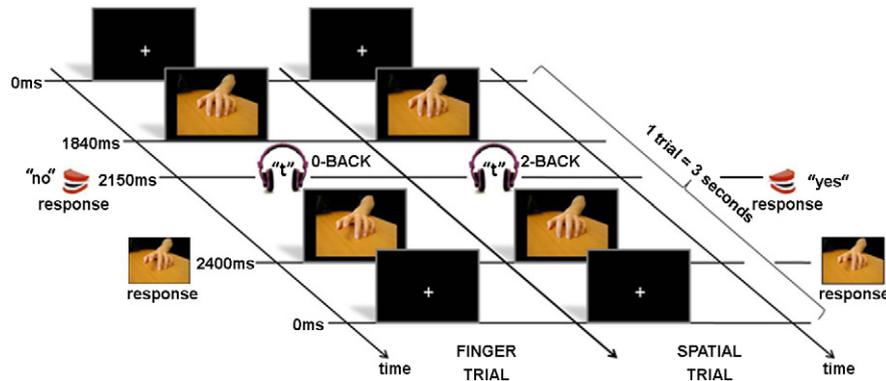

Fig. 2. Baseline trial timing examples. A finger-cued trial with a simultaneous 0-back task is presented left and a spatially cued trial with a simultaneous 2-back task right. Oral and movement responses are registered from the onset of the auditory letter and visual movement cue respectively. In this example the two previous N-back letters were "t" and "g".

2. Results

All raw data was pre-processed with Matlab 7.0 in order to calculate finger movement onset times. Movement onset threshold was set at 5% of maximum upwards movement speed, at a minimum of 0.5 cm.

2.1. Baseline analysis[2]

Movement onset of the baseline responses response was subjected to a 2 (response cue: finger vs. spatial) as within subject factor × 2 (WM load: low vs. high) × 2 (block order: respond to finger cue vs. respond to spatial cue) as between subject factors in a repeated measures analysis of variance. Three participants with means higher than 2.5 SDs from the group mean were removed from further analysis. All analyses are on log transformed reaction times.[3] For ease of interpretation reaction times will be reported in milliseconds.

Replicating earlier findings (Brass et al., 2000) a main effect of cue showed that participants were faster at responding to the finger cues than to the spatial cues (305 ms vs. 369 ms respectively), $F(1,41) = 62.58$, $p < 0.001$, $\eta_\rho^2 = 0.60$. Most importantly, concerning our hypothesis, a 2-way interaction effect for cue × WM load

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[2] Baseline and congruency are analyzed separately for ease of interpretation and the hypothesized different visual properties between stimuli. Analyzing all data together yields similar results.

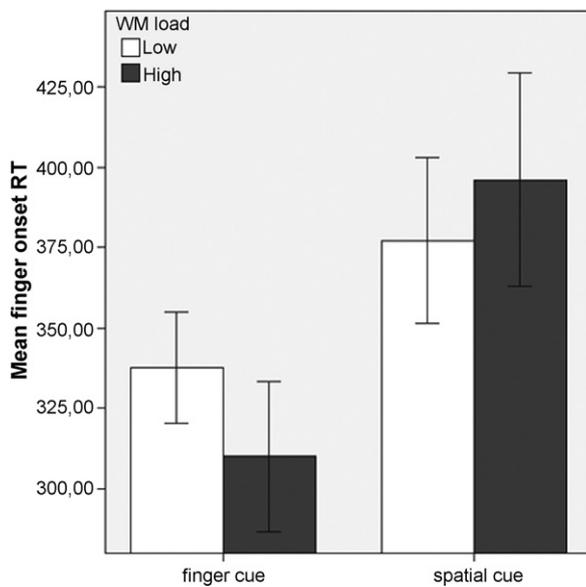[3] Analyses performed with $1/X$ and medians produced similar results.

Fig. 3. Mean finger movement onset times (ms) for baseline conditions as a function of response cue (finger vs. spatial) and working memory (low vs. high). Graph is based on raw means, error bars ± 2SE (note: figure error bars are based on larger error estimates than used for the mean log analysis).
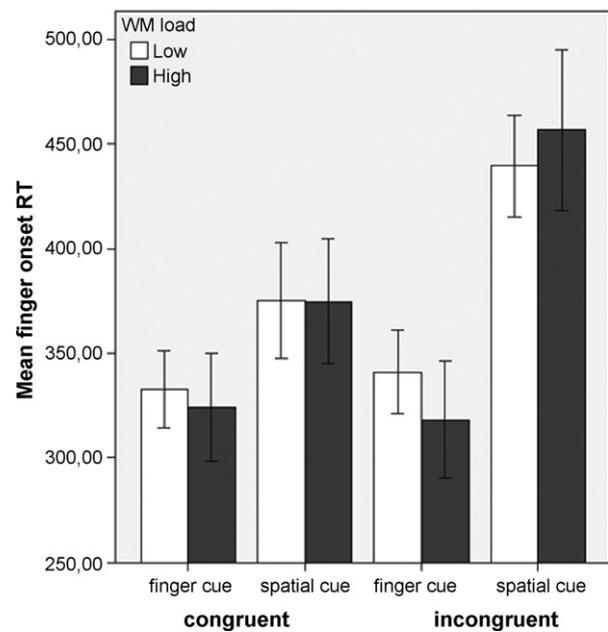

Fig. 4. Mean onset times of finger movement (ms) as a function of congruency (congruent vs. incongruent), response cue (finger vs. spatial) and working memory (low vs. high). Graph is based on raw means, error bars ± 2SE (note: figure error bars are based on larger error estimates than used for the mean log analysis).

revealed that response speed to the finger cues were sped up relatively to spatial cues in high compared with low WM-load conditions, $F(1,41) = 8.70$, $p = 0.005$, $\eta_\rho^2 = 0.18$ (Fig. 3). Further corroborating this was a significant simple effect suggesting that responses to finger cues were faster under high working memory load than low working memory load (286 ms vs. 324 ms respectively), $t(42) = 6.52$, $p = 0.015$, $\eta_\rho^2 = 0.14$ (Fig. 3).

A separate analysis on error rates only demonstrated a larger amount of errors under high working memory load than low working memory load (2.15 errors vs. 0.23 errors respectively), $F(1,41) = 7.61$, $p < 0.01$, $\eta_\rho^2 = 0.15$.

2.2. Congruency analysis

Movement onset of the congruent and incongruent responses were subjected to a 2 (response cue: finger vs. spatial) × 2 (congruency of cue: congruent vs. incongruent) as within subject factors × 2 (WM load: low vs. high) × 2 (block order: respond to finger cue vs. respond to spatial cue) as between subject factors in a repeated measures analysis of variance. Again, all analyses are on log transformed reaction times. For ease of interpretation reaction times in ms will be used for reporting results.

Replicating earlier findings (Brass et al., 2000), participants were faster responding to finger than spatial cues (308 ms vs. 393 ms respectively), $F(1,41) = 161.52$, $p < 0.001$, $\eta_\rho^2 = 0.80$. They were also faster in the congruent compared to the incongruent condition (333 ms vs. 363 ms respectively), $F(1,41) = 60.15$, $p < 0.001$, $\eta_\rho^2 = 0.60$. This effect, however, was qualified by a significant 2-way interaction for cue × congruency, $F(1,41) = 50.88$, $p < 0.001$, $\eta_\rho^2 = 0.55$, and simple effects revealed that responses to the spatial cue in the congruent compared to the incongruent condition were significantly faster (359 ms vs. 430 ms respectively), $F(1,41) = 128.07$, $p < 0.001$, $\eta_\rho^2 = 0.76$. This suggests that participants were worse at ignoring an incongruent finger movement when instructed to respond to spatial cue. When responding to finger cues no interference effects were found for incongruent versus congruent irrelevant spatial cue, $F < 0.5$.

Specific to our hypothesis we found a 2-way (cue-type × WM load), $F(1,41) = 6.42$, $p = 0.015$, $\eta_\rho^2 = 0.14$, indicating that responses to finger cues were facilitated under high WM load relative to spa-

tial cues. Simple effects seem to suggest that this is driven rather by the faster reaction times to finger cues under high compared to low WM load (294 ms vs. 322 ms respectively), $F(1,41) = 2.77$, $p = 0.104$, $\eta_\rho^2 = 0.06$, than to slower reaction times to spatial cues under high compared to low WM load (395 ms vs. 392 ms respectively), $F(1,41) = 0.008$, $p = 0.93$, $\eta_\rho^2 = 0.01$.

Additionally there was a marginal 3-way interaction (response cue × cue congruency × WM load), $F(1,41) = 2.30$, $p < 0.08$, $\eta_\rho^2 = 0.05$ (Fig. 4). Exploring this tentative result we see it explained by a significant 2-way interaction (response cue × WM load) within the incongruent movement responses; responses to finger cues are facilitated under high working memory while responses to spatial cues are inhibited, $F(1,41) = 8.39$, $p = 0.006$, $\eta_\rho^2 = 0.17$. Moreover, there is a significant simple effect for the finger cue in the incongruent condition, demonstrating that finger-cued responses were faster under high memory load than low working memory load (327 ms vs. 347 ms respectively), $t(41) = 4.43$, $p = 0.041$, $\eta_\rho^2 = 0.10$ (Fig. 4).

A separate analysis on error rates showed that more errors were made under high working memory load than low working memory load (1.99 errors vs. 0.48 errors respectively), $F(1,41) = 6.50$, $p < 0.02$, $\eta_\rho^2 = 0.13$. Additionally, more errors were made when having to respond to a spatial cue than when having to respond to a finger cue (1.60 errors vs. 0.92 errors respectively), $F(1,41) = 13.17$, $p = 0.001$, $\eta_\rho^2 = 0.23$. No other main or interaction effects were found (Fig. 4).

3. Discussion

The findings show that responses to baseline finger cues under high WM load are faster compared to spatial cues. Baseline trials are particularly informative, because there are no simultaneous irrelevant cues when responding, and therefore the cleanest way of detecting any moderating effect of WM load. Moreover, the significant simple effect of increased response speed to finger cues under high load again suggests that occupying resources used to inhibit pre-potent responses will facilitate imitation.

For the congruent versus incongruent cue trials we also see that finger cues overall are facilitated relative to spatial cues under high compared to low working memory load. Looking specifically at the 2-way interaction between cue and WM load, there is a relative decrease in response time when there is an incongruent spatial cue (response cue is finger) compared to incongruent finger cues (response cue is spatial) under high compared to low WM. The significant simple effect for the finger cue in the incongruent condition shows the effect is driven by facilitated imitation under high load. Admittedly, the 3-way interaction necessary to qualify this 2-way and simple effect analysis was only marginal; however, considering our specific a-priori hypothesis, we found it important to explore the underlying effects.

These findings support the existing view of humans having an undeniable tendency to non-consciously mimic the actions of other people. Given that there are costs as well as benefits associated with such imitative behaviours it is important that they are regulated in some way. By demonstrating that increasing working memory load increases response speed to imitative finger cues we provide behavioural evidence of the role executive resources play in the inhibition of imitation. These results in addition with the replication of prior studies demonstrating faster finger reaction times to finger movement cues than to spatial movement cues, add evidence to the suggested fundamental nature of behavioural imitation, as only the most automatic of processes have the property that they are actually facilitated when cognitive control systems are under load.

Interestingly, our results compliment findings from a recent study showing that imitative actions are much less slowed than responses to symbolic cues when simultaneously articulating a word out loud (Kühn & Brass, 2008). Indeed, while the amount of oral responses was kept constant in both N-back conditions, there must have been a higher amount of silent rehearsal in the 2-back task. It is therefore a possibility that this increased silent rehearsal added to the effect of the WM load, vice versa or even fully explains the findings. However, there was still a difference in results between these two experiments; the current paradigm found facilitated reaction times to imitation cues during the 2-back task, whereas Kühn & Brass found that while responses to imitation cues were significantly slowed during simultaneous articulation it was slowed much less than responses to symbolic cues. One cannot however fully exclude the possibility that the effect was driven by an increase in silent rehearsal and in consequence language production areas compared to the 0-back condition. Future research would do well in trying to tease apart the separate influence of executive control and language production on imitative responses. Nonetheless, together with this demonstrated link between speech production and imitative actions we now add to the evidence of the wide range of cognitive functions imitation is related to.

By reducing EF processing capacity in healthy participants, this study also extends on previous studies which show that patients with damage to executive frontal areas have difficulty suppressing unwanted imitative movements (Brass et al., 2003; De Renzi et al., 1996; Luria, 1966; Lhermitte et al., 1986).

Future challenges include understanding where in the perception-action coupling executive functioning influences the imitative process. Does EF preventively inhibit the pre-potent imitative circuitry in situations needed to override the automatic response, or does it come into play only after the imitative actions have been activated, needing to restrict the motor execution at a later stage? This could potentially be explored using EEG measuring the level of action priming while observing movement. By relating ERP patterns to the behavioural data conclusions could possibly be drawn about the interplay between motor pattern activation and the actual motor movement.

Moreover, do these findings translate to real life interactive settings that are prone to social imitation, e.g. will interaction partners' spontaneous imitation of each other increase in situations where their working memory is strained?

In sum, controlling imitative responses is clearly important in scenarios where goal-directed action is desirable and different from the observed behaviour, this we believe is the underlying process explaining the current results. Framed in a response competition scenario, executive functioning plays a role in suppressing the pre-potent but functionally undesirable imitative response.

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