Psychological Research (2024) 88:1805–1807
https://doi.org/10.1007/s00426-023-01923-8

RESEARCH

Motor imagery from brain to muscle: a commentary on Bach et al., (2022)

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Received: 15 July 2023 / Accepted: 26 December 2023 / Published online: 29 January 2024

Abstract

In a recent article entitled "Why motor imagery is not really motoric: towards a re-conceptualization in terms of effect-based action control", Bach et al. nicely renewed the concept of motor equivalence between actual movement and motor imagery (MI), i.e. the mental simulation of an action without its corresponding motor output. Their approach is largely based on behavioral studies and, to a lesser extent, on the literature using cerebral imagery. However, the literature on cortico-spinal circuitry modulation during MI can provide further, interesting aspects. Indeed, when it comes to addressing the motor system, one should consider the whole path from brain region to muscle contraction, including sub-cortical structures such as the spinal circuitry. This commentary aims at bridging this gap by providing supplemental evidence and outlining a complementary approach.

In the article of Bach et al. (2022), behavioral-based evidence is put forward regarding the similarity between Motor Imagery (MI) and actual movement, such as movement isochrony or the respect of certain laws of movement. Previous research using cerebral imaging also helped in understanding how far the similarity goes at a brain level. One part of the relevant literature is, however, not fully considered: corticospinal circuitry investigations. These studies mostly used transcranial magnetic stimulation (TMS) over the motor cortex, to elicit muscle Motor Evoked potentials (MEP), or H-reflex paradigms to specifically focus on the spinal circuitry. These techniques help to further investigate modulations of the cortico-spinal pyramidal tract and, in addition, have a high temporal resolution which can inform timing aspects of MI.

Now, a large majority of researchers in this area agreed that MEPs are greater when evoked during MI of the considered limb as compared to rest (Grosprêtre et al., 2015; for review). A study recently compared the evolution of MEP amplitude during the phase that precedes imagined or actual movement, *i.e.* movement preparation and planning (Lebon et al., 2019). The authors showed that whether the task was to imagine or execute the movement, the same modulation of corticospinal excitability was observed, *i.e.,* an inhibition before movement onset and a strong facilitation as execution (or imagination) starts. This is in accordance with Bach *et al.'s* point that MI is not solely about the re-use of execution-related structures, but involves all the preparatory processes, including perceptual and planning ones. Nonetheless, studies focusing on the corticospinal tract, starting at M1 area to the spinal network, still raised an important question: how can the movement not be executed during MI if similar brain motor activations are observed as during actual movement?

In his book entitled "Philosophical investigations", the philosopher Ludwig Wittgenstein asked the following: "What is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?" (Wittgenstein, 1953). This sentence sums up the theory considering MI as motoric and/or the theory that mentally simulating the movement is part of movement preparation. Bach *et al.* refer to a possible effect of MI at the muscle level (Guillot et al., 2007). Recent evidence showed that the brain motor activation induced by MI, although often suggested as weaker than during motor execution (Ehrsson et al., 2003; Fadiga et al., 1999), was still able to generate a subliminal brain output toward the muscle. However, this output may reach only the most sensitive structures of the spinal cord, *i.e.,* the inhibitory interneurons, without activating alpha motoneurons (Grosprêtre et al., 2016; Grosprêtre, Lebon, et al., 2019a, b). These results

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argue in favor of the threshold theory, demonstrating that the cortical activation generated by MI follows the same path as actual movement execution but progressively dissipates from the brain to the muscle. This command seems too weak to activate the muscle effectively, preventing from doing the movement during MI. Nevertheless, in some specific cases, practicing MI can sometimes lead to involuntary release of the movement, as demonstrated by the nice study of Colton and colleagues (Colton et al., 2018). Several mechanisms can explain this phenomenon that most of the people practicing MI may have experienced: 1) an incomplete inhibition of the motor command, 2) a hyper-activation of motor regions during MI which makes the cortical output overpass the activation threshold of spinal motoneurons. This is line with the two current theories to explain how the decoupling between MI and actual movement's activation could work: an inhibition of the motor command during MI at a certain stage of the motor command (Di Rienzo et al., 2014) or a sub-threshold activation of motor process during MI. Both theories can co-exist, as they do not preclude an overlap between MI and actual movement' activations.

However, some intrinsic differences may still exist between neural activation during motor execution and MI. These differences may mainly arise from the lack of peripheral feedback during MI which are normally activated during actual muscle contraction. Indeed, Bach et al. suggested that "feedback from one's own actions—or from such external sources—is missing during imagery" This would explain the different activation observed in some specific brain regions such as the cerebellum or some part of the parietal cortex (Lotze et al., 1999), which are precisely dedicated to integrate peripheral sensory feedbacks in order to build and/or correct the motor command. However, it is important to consider that the motor system can also be sensitive to proprioceptive information during MI. As an example, it was shown that corticospinal excitability was enhanced during MI of an eccentric contraction as compared to rest only when the considered joint was passively stretched in a congruent way during MI (Grosprêtre, Papaxanthis, et al., 2019b). Without the sensory information arising from muscle stretch, it was argued that eccentric contraction may be difficult to mentally represent, as it reflects a form of contradictory action for the motor system: contracting the muscle, while this latter is stretched. Then, previous TMS experiments showed that in some cases, MI is not a unique engagement of the forward model, based on the efferent copy, since the central nervous system is still able to integrate sensory feedbacks while performing MI.

Finally, the point raised by Bach *et al.* really helped going beyond the classical representation of MI processes and the popular "motor equivalence theory". One should not ignore the fact that this motor equivalence also depends upon many factors, such as participants' MI ability (Williams et al., 2012), or participants' expertise (Guillot et al., 2012). As an example, it was shown that MI of high jumps lead to an activation of brain motor regions for professional high jumpers, but not for novices for whom an activation of visual cortices was mainly noticed (Olsson et al., 2008).

To conclude, when addressing motor system adaptations, one should not forget to consider the whole pathway from the brain to the muscle, and particularly the cortico-spinal network which plays a major role in motor execution. Previous research based on TMS and neuro-stimulation techniques would argue in favor of a motoric aspect of MI. However, the point addressed by Bach et al. is also a way to understand this overlap between MI and actual movement. According to Bach et al., Wittgenstein's sentence could also be rephrased to "What's left of the fact that I'm raising my arm if you subtract the fact that I imagine my arm rising?". Therefore, whether MI is motoric, or the actual action involves mental representation of an action appears as an infinite debate like which came first between egg or chicken. What if it was not a "black or white" situation? Previous literature showed that depending on the context (presence of feedback, participant's expertise, etc.), MI and actual action do not provide similar results. In any case, the vast majority of authors who worked on the topic undoubtedly seems to agree on one point: MI and actual action do share similar activations, and that motor/mental representations are integral part of motor control. Overall, this still reminds us how little we know about the fantastic machinery that is our motor system.

Author contributions SG wrote the commentary.

Funding No funding received.

Data availability Not applicable.

Declarations

Conflict of interest The author declares that he has no competing interest for the present article.

Ethical approval Not applicable.

Human ethics decision Not applicable.

Consent to participate Not applicable.

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