

**Theoretical explanations and the availability of information for learning via combined  
action observation and motor imagery: A commentary on Eaves et al. (2022)**

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1 **Abstract**

2           The recent review by Eaves et al. (Psychological Research/Psychologische Forschung,  
3 2022) outlines the research conducted to-date on combined action-observation and motor  
4 imagery (AOMI), and more specifically, its added benefit to learning. Of interest, these  
5 findings have been primarily attributed to the dual action simulation hypothesis, whereby AO  
6 and MI activate separable representations for action that may be later merged when they are  
7 congruent with one another. The present commentary more closely evaluates this  
8 explanation. What's more, we offer an alternative information-based argument where the  
9 benefit to learning may be served instead by the availability of key information. Along these  
10 lines, we speculate on possible future directions including the need for a transfer design.

1           The review by Eaves et al. (2022) is primarily steered by the added benefit to motor  
2 learning following a combination of action observation (AO) and motor imagery (MI)  
3 compared to each of these modes of simulation on their own. The aims of the current  
4 commentary are twofold: evaluate the dual action simulation hypothesis as it is perhaps the  
5 most dominant theoretical explanation presented to-date (1), and consider the role of  
6 available sources of information (2).

7

### 8 **Dual Action Simulation Hypothesis**

9           According to this framework, there are parallel processing streams stemming from  
10 AO and MI, which manifest from the initiation of independent or separable representations  
11 for action (Eaves et al., 2016; Bruton et al., 2020). Here, the two streams can either merge  
12 together to improve behavioural outcomes in the case of congruent AOMI, or compete  
13 against each other to the detriment of behavioural outcomes in the case of incongruent  
14 AOMI. This logic is heavily adapted from the biased competition framework (Cisek &  
15 Kalaska, 2010), where a single action unfolds as a product of competition between multiple  
16 potential actions at the neuronal level (for a similar concept involving directionally-tuned  
17 neurons, see Georgopoulos et al., 1986).

18           However, when conceiving of this framework based solely on the literary accounts or  
19 wording used to-date, we argue that its explanatory power may require further consideration.  
20 Specifically, the proposed initiation of separable representations for both AO and MI would  
21 imply that there are at least multiple representations for a single category of action (e.g., golf  
22 putt). Alternatively, prevailing views of motor learning would have it that actions are stored  
23 in a more generalizable form, which can then lend itself to the re-parameterization and  
24 transfer of skill for multiple scenarios (e.g., near/far putt) (Schmidt, 1975). In a similar vein  
25 contemporary models of motor control suggest we hold more finite representations; otherwise

1 referred to as internal models (Ghahramani & Wolpert, 2000). These models permit  
2 comparisons between the predicted and actual ‘state’ of the system (e.g., arm position during  
3 the back swing), as well as the sensory consequences (e.g., deltoid stretch during the  
4 backswing), which can facilitate control without having to access multiple stores that are  
5 responsible for seemingly countless motor parameters. In other words, it is not necessary to  
6 store and initiate separable representations for a particular action even if it is deployed in  
7 different ways including AO and MI (for a similar argument, see Frank et al., 2020).

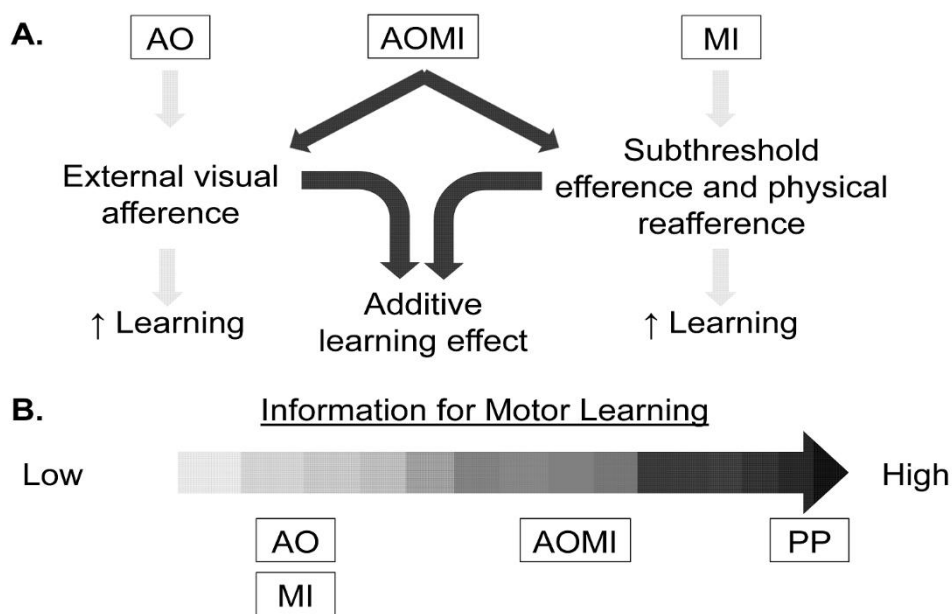
8         That said, it is well noted by Eaves et al. (2022) that there are currently few empirical  
9 studies to have specifically tested this dual action simulation hypothesis with existing  
10 attempts being limited to the measure of corticospinal excitability involving transcranial  
11 magnetic stimulation (TMS) over the primary motor cortex (M1) (e.g., Meers et al., 2020;  
12 Bruton et al., 2020). Hence, they recognise the need to examine the neural processes that  
13 unfold further “upstream” and before these later stages of processing. Along these lines, we  
14 fully concur with their proposed use of multi-voxel pattern analysis (MVPA) to try to shed  
15 light on the possibility for dual action simulation.

16

### 17 **Information Perspective**

18         As stated by Eaves et al. (2022), another possible explanation for the added benefit to  
19 learning following AOMI compared to AO and MI alone involves the different sources of  
20 information that are made available by each of these modes of simulation (*additive effect*). In  
21 this regard, the benefit is not necessarily served by interacting processes (*super-additive*  
22 *effect*),<sup>1</sup> but in line with the motor learning literature, the availability of information that is  
23 specific to the task needing to be learned (e.g., Schmidt, 1975; Guadagnoli & Lee, 2004;  
24 Mackrout & Proteau, 2007). Thus, upon reflection, we recognise that AO can uniquely  
25 provide an external visual referent, while MI can uniquely provide sub-threshold efference

1 and physical reafference (Fig. 1A) (for a similar argument, see Wright et al., 2018; Meers et  
 2 al., 2020; Frank et al., 2020). In combination, these different sources of information can be  
 3 combined to enrich the representation for action, and effectively bring the learner closer to  
 4 the abundance of information that would otherwise be available if they had physically  
 5 practiced (PP) (Deakin & Proteau, 2000; Trempe et al., 2011) (Fig. 1B). Put simply, we may  
 6 conceive of the possible modes of simulation and their related learning outcomes on a  
 7 continuum based on access to information that is specific to motor learning.



8  
 9 **Fig. 1** Conceptual illustration of the different modes of simulation (AO, MI, AOMI), their  
 10 available sources of information and subsequent effects on motor learning (A). In addition,  
 11 there is a motor learning information continuum with AOMI more closely reflecting the high-  
 12 volume of information that is also available in physical practice (PP) (N.B., there are perhaps  
 13 other distinctions along this continuum depending on person-perspective (i.e., first-/third-  
 14 person), although it is not of interest here).

15  
 16 In support of this conjecture, it has been shown that the benefit to learning following  
 17 AOMI is not solely limited to a synchronous form of delivery (simultaneous AO+MI), but

1 also extends to asynchronous (alternate AO  $\rightleftharpoons$  MI) (Romano-Smith et al., 2019, 2022; see  
2 also, Kim et al., 2020). Thus, despite the comparatively disrupted dual action simulation  
3 processes that can be most typically associated with synchronous AOMI, the continued  
4 presence of information for learning during asynchronous AOMI has proved sufficient  
5 enough for there to still be an added benefit to learning (for an alternative argument, see  
6 Azaad & Sebanz, 2023).

7         With this in mind, there are a number of studies identified by Eaves et al. (2022) that  
8 have tried to elucidate the added benefit to learning following AOMI. This interest has  
9 naturally steered researchers toward the level of the independent variable (i.e., mode of  
10 simulation), where they have specifically manipulated the congruency of the AO or MI  
11 component in an attempt to decouple their relative contribution during AOMI. For example,  
12 in a dart-throwing task, individuals that were asked to observe a separately incongruent  
13 shoulder rotation while imagining the required dart throw showed no longer any benefit to  
14 their learning (Romano-Smith et al., 2022; see also, Meers et al., 2020; Bruton et al., 2020).

15         However, it is perhaps also worthwhile considering the value of introducing  
16 additional measures at the dependent level,<sup>2</sup> including a transfer design whereby the learner  
17 would have to adapt any of their learning to an alternative task setting. Perhaps surprisingly,  
18 there have been comparatively few studies involving AOMI that have adopted such a design,  
19 which could arguably limit any conclusions drawn about motor learning per se (e.g., Marshall  
20 et al., 2020) (see Schmidt et al., 2019). Of interest, an additional transfer test can often  
21 highlight the source of information that the learner is most sensitive to, and with it, the very  
22 nature of the representation that they hold. For example, following the learning of a novel  
23 movement pattern (e.g., dart throwing), previous studies have manipulated the physical  
24 response characteristics in transfer (e.g., novel throwing technique or weighted dart) (Shea et  
25 al., 2000; Heyes & Foster, 2002; Bird & Heyes, 2005; Osman et al., 2005; Boutin et al.,

1 2010; Hayes et al., 2012a, b). As a result, if the learner were to find themselves suddenly  
2 unable to transfer, then it stands to reason that they initially developed a motor-specific, as  
3 opposed to -nonspecific, representation. Thus, it is possible that learners could respond better  
4 to this sort of transfer test having undergone AOMI compared to AO and MI alone.

5

## 6 **Conclusion**

7         We concur with many of the points raised by Eaves et al. (2022). However, we raise  
8 at least some questions around the underlying logic surrounding the dual action simulation  
9 hypothesis, while advocating for a potential information-based explanation for the benefits  
10 served by AOMI. In order to learn more about AOMI, Eaves et al. (2022) indicate some  
11 interesting possibilities for future research, although we emphasise the importance of  
12 incorporating an additional transfer.

1 **Footnotes**

2 1) The super-additive effect primarily relates to the potential combination or interaction of  
3 processes that are elicited by AO and MI. At the same time, according to Sternberg's  
4 (1969) logic, it is possible that such processes would assume a statistical interaction as  
5 opposed to sole main effects.

6 2) There have been some minor attempts already to capture eye movements using optical  
7 tracking (Marshall et al., 2020; Bruton et al., 2020), and muscle function using surface  
8 electromyography (EMG) (Romano-Smith et al., 2019, 2022), which have coincided  
9 with performance-related measures following an AOMI intervention.

1 **Author contributions**

2 All authors contributed to the conception of the manuscript. SRS, JR, and AM wrote the  
3 initial draft of the manuscript. CJW reviewed the initial draft of the manuscript. All authors  
4 read and approved the final manuscript.

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7 **Availability of data and materials**

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9 **Declarations Conflict of interest**

10 The authors declare that no competing interests exist.

11 **Ethical approval**

12 Not applicable

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