What we imagine learning from watching others: how motor imagery modulates competency perceptions resulting from the repeated observation of a juggling action

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Abstract

Although motor learning can occur from observing others perform a motor skill (action observation; AO), observers' confidence in their own ability to perform the skill can be falsely increased compared to their actual ability. This illusion of motor competence (i.e., 'over-confidence') may arise because the learner does not gain access to sensory feedback about their own performance – a source of information that can help individuals understand their veridical motor capabilities. Unlike AO, motor imagery (MI; the mental rehearsal of a motor skill) is thought to be linked to an understanding of movement consequences and kinaesthetic information. MI may thus provide the learner with movement-related diagnostic information, leading to greater accuracy in assessing ability. The present study was designed to evaluate the effects of MI when paired with AO in assessments of one's own motor capabilities in an online observation task. Two groups rated their confidence in performing a juggling task following repeated observations of the action without MI (OBS group; n=45) or with MI following observation (OBS+MI; n=39). As predicted, confidence increased with repeated observation for both groups, yet increased to a greater extent in the OBS relative to the OBS+MI group. The addition of MI appeared to reduce confidence that resulted from repeated AO alone. Data support the hypothesis that AO and MI are separable and that MI allows better access to sensory information than AO. However, further research is required to assess changes in confidence that result from MI alone and motor execution.

Keywords: *observational learning, motor imagery, motor competence, motor simulation, self-efficacy*

Action observation (AO) has been defined as a covert form of movement execution that evokes externally-guided motor simulation (Vogt et al., 2013). AO can facilitate motor learning, through repeated observations and activation of cognitive, perceptual, and motor-related processes to varying degrees (Ramsey et al., 2021; Hodges et al., 2007; Hodges, 2017). Although learners may acquire or enhance motor skills through observation, evidence indicates that AO confers inflated judgements of ability, leading to an overestimation of motor competence (i.e., an 'over-confidence' or inflated perception of ability; Jordan et al., 2022; Kardas & O'Brien, 2018; Hodges & Coppola, 2015). For example, repeated observation of a two-ball juggling action led to general increases in confidence across trials, which were higher than those seen in individuals who were allowed to physically practice on some trials (Hodges & Coppola, 2015). Kardas and O'Brien (2018) also showed inflated confidence when videos of complex actions were shown multiple times as opposed to a single time. They suggested that this over-confidence emerges because observers take (motor) information gained at face value, yet lack an understanding of how their personal performance of the action looks and feels. The mechanism underlying this discrepancy between competence perceptions and actual ability is not well understood. However, this over-confidence may be related to a lack of actual motor experience and associated sensory feedback with the action, leading to poor diagnostic capabilities and an overestimation of learning (Kardas & O'Brien, 2018).

Motor imagery (MI), the mental rehearsal of movement thought to involve both visual and kinesthetic internal perceptions, represents a second form of covert movement execution. AO and MI were originally thought to rely on similar processes of motor simulation (termed 'functional equivalence') without the final overt action (Jeannerod, 1995, 2001; Holmes & Calmels, 2008). As such, processes involved in the preparation and execution of actions were also proposed to occur in observed and imagined actions. This equivalence between motor execution, MI, and AO has been indexed through behavioural and neurophysiological measures such as reaction time, eye movements, EEG, and fMRI (see Grosprêtre et al., 2016; Hardwick et al., 2018). However, there is some debate about the relative overlap and conversely, distinctiveness of the processes of AO and MI. One idea is that MI provides better access to sensory effects associated with motor execution than AO alone (Vogt et al., 2013).

In a growing body of work, a separation between the two covert processes of AO and MI has been demonstrated. MI is thought to rely more on executive functions than AO (Glover & Baran, 2017), as well as better access sensory information relating to kinaesthetic experiences (e.g., Kim et al., 2017; Sakamoto et al., 2009; Vogt et al., 2013). While abilities have still been ‘overestimated’ in MI (Dahm & Rieger, 2019), this additional sensory information from MI may lead to a better match than AO between actual and perceived ability. In other words, MI may lead to a deflation of over-confidence that results from repeated AO alone. Thus, rather than considering motor execution, AO, and MI as equivalent, it is suggested that these action states might exist along a continuum (Vogt et al., 2013). Because MI is thought to give better access to kinesthetic experiences associated with execution, it is thought to lie closer to motor execution than AO. In addition, it has been suggested that MI involves feedforward predictive mechanisms that allow for sensory consequences of a movement to be predicted (Dahm & Rieger, 2019; Ingram et al., 2019; Kilteni et al., 2018). Although feedforward mechanisms are thought to be involved in AO too (e.g., Wolpert et al., 2011; Wong et al., 2013), the evidence for this suggestion is less clear, especially in a learning context (e.g., Ong & Hodges, 2010). If MI has access to the sensory consequences of the actions, MI may thus allow for diagnostic information about one’s own capability, beyond that provided by AO. This additional information in MI would permit greater accuracy in judgements of ability relative to AO and, as such, reduce over-confidence when paired with AO.

One complication to the rationale that is provided thus far is that some researchers have argued that MI is an inherent component of AO, especially when there is an intention to actively engage with the stimuli, such as for learning or for ability judgements (Bruton et al., 2020; Eaves et al., 2016). As such, when observing a movement, it may well be that at least some amount of MI is spontaneous (Vogt et al., 2013; Eaves et al., 2022). Although it is difficult to know directly whether MI co-occurs with AO, this assumption can be tested by comparing performance after AO alone or after AO paired with MI. By comparing the similarities and differences in the outcomes of AO-only conditions to situations where AO is paired with MI, assumptions can be tested about the contribution of spontaneous MI during AO, as well as unique effects supporting their independence (Bruton et al., 2020; Tsukazaki et al., 2012; Wright et al., 2014, 2018).

The current study was designed to probe the effects of MI in action observation and to test whether MI might serve to moderate over-confidence that has been shown to result from repeated AO alone. The study was conducted as a conceptual replication of previous work using a single-session observation design to evaluate confidence in skill ability after repeated AO (Hodges & Coppola, 2015; Kardas & O'Brien, 2018, see Exp 6). Expanding on this past work and addressing our main research aim, we assessed confidence in a person's perception of their ability to perform a juggling action when MI was also engaged after AO. In previous work on ability perceptions, videos of the action were always shown in what has been referred to as the third-person or extrinsic perspective (typically a mirrored view). In the current study, we showed videos of a juggling task from both this third-person perspective as well as in the first-person or intrinsic perspective (typically filmed from above and behind as though the observer were actually performing the task). We included this additional first-person video condition in light of evidence that motor cortical excitability is enhanced when watching actions from the first- (rather than the third-) person perspective (e.g., Alaerts et al., 2009). Individuals might be better able to engage their motor systems when watching from the same perspective as when actually performing the task versus a mirrored view. It is unknown if viewing actions from the first-person perspective might also encourage spontaneous MI (Vogt et al., 2013). If true, confidence would not be reduced in the AO+MI condition compared to AO alone when viewed from a first-person perspective.

Consistent with previous work examining over-confidence that results from repeated AO (Hodges & Coppola, 2015; Kardas & O'Brien, 2018), confidence was expected to gradually increase as a function of repeated observations in both groups (i.e., AO-only and AO+MI). However, confidence was expected to increase to a greater extent in the AO group than in the group additionally performing MI (i.e., an interaction between Group and Trial). If MI and AO engender different processes, with MI providing better access to sensory information (Vogt et al., 2013), then MI may lead to more realistic perceptions of ability and lower confidence relative to an AO-only group. The study was conducted online during the COVID-19 pandemic and, as a result, in-person juggling ability was not assessed. At the end of the study, participants were asked to attempt the task using house-hold objects and to self-report ratings of their actual ability to allow comparisons with perceived ability. We hypothesized that individuals in the AO+MI group would report more realistic perceptions of ability than individuals in the AO-only group.

METHOD

Participants

A total of 115 participants with normal or corrected-to-normal vision and no upper limb disabilities which would prevent them from juggling or key-pressing, were initially recruited. Participants were excluded if they self-reported engaging in regular juggling practice. Participants were pseudorandomized into one of two groups[1]: OBS+MI or OBS (observation followed by MI or just observation, respectively) and underwent a single online session. Thirty participants were excluded for failing to complete the study (i.e., did not complete the questionnaires and/or did not complete the juggling task), with an additional one participant excluded for identifying as an expert juggler at the close of the experiment. Thus, a total of 84 participants were included in final analyses; with n=45 in the OBS group (*M* age = 25.7 yr, *SD* = 8.2, 35 females, 42 right-handed) and n=39 in the OBS+MI group (*M* age = 26.5 yr, *SD* = 10.3, 28 females, 35 right-handed). Sample size was determined by a power analysis conducted using open-source software (G*Power 3.1), using effect sizes from prior work, while accounting for attrition rates and compliance associated with online studies. We initially selected a moderate effect size of $\eta_p^2 = 0.09$ (alpha = 0.05, power = 0.95), based on previous work examining confidence ratings after AO (Hodges & Coppola, 2015; Kardas & O'Brien, 2018) and conservatively adjusted to $\eta_p^2 = 0.07$ to account for sample sizes reported in this prior work (N = 36 and 150 respectively). This analysis yielded a sample size of N=72, which was further increased to account for expected attrition. All participants provided informed consent in accordance with the Declaration of Helsinki. The University's Research Ethics' Board approved the study.

Before beginning the task, all participants completed the Movement Imagery Questionnaire, version 3 (MIQ3) to characterize MI ability (Williams et al., 2012). The MIQ3 is a self-report instrument, intended to assess three forms of MI: internal visual (i.e., "when you watch yourself performing the movement from an inside point of view or first-person perspective"; Williams et al., 2012), external visual (i.e., "when you watch yourself performing the movement from an outside point of view or third-person perspective"; Williams et al., 2012), and kinaesthetic (i.e., "the feelings and sensations experienced if you were actually producing the movement"; Williams et al., 2012). MIQ3 scores were calculated for each subscale (i.e., form of MI) for each participant. Given the nature of these data (scale-based), density plots conducted for each subscale were used to characterize imagery ability of each group.

Task and Measures

Skill Confidence. Participants watched videos of another person performing a two-ball juggling action (3 sec) and then were asked (forced-choice; yes or no) whether they thought they could perform the action. They then rated their confidence in their ability to perform the action on a visual sliding scale from 0-100% (Hodges & Coppola, 2015).

Assessment of Juggling Ability. Individuals were asked to physically attempt the juggling task three times (using socks rolled into balls, or similar round objects). After each of the three attempts, they reported their ability on a scale of 0-100%. As a manipulation check to confirm compliance, participants were asked to list the objects used to complete the attempts, which included socks, paper rolled up into balls, sport-related balls, and round fruit. Seventy-six participants (of the 84 included in final analyses) reported their items used to complete the attempts. This measure was administered at the close of the study only, rather than before, to mitigate any influence of prior physical practice on confidence ratings.

Procedures

The timeline of experimental procedures is outlined in Figure 1. Participants accessed the study via Qualtrics, a secure online survey tool (qualtrics.com), where they first provided demographic information and completed the MIQ3. After completing this phase, participants were redirected to the Gorilla Experiment Builder (www.gorilla.sc) to enter the online experiment environment.

In Gorilla, participants were shown videos (3 sec clips) of the two-ball juggling action and completed confidence ratings after each viewing. Videos were played according to two conditions: actions performed in the first-person or third-person perspective. All participants completed 20 consecutive trials for each video condition (40 total trials). The order of video conditions was counterbalanced across participants. After each video clip, participants in the OBS+MI group were asked to perform kinaesthetic MI (imagine themselves perform the action from the first-person perspective, focusing on the sensation of the movement) of the just-observed action. Kinaesthetic MI, in particular when performed from the first-person perspective, has been shown to better engage the motor system as assessed through TMS-induced MEPs than visual imagery (Stinear et al., 2006). Participants made a keypress to indicate when they started and stopped their imagined performance, as a manipulation check to capture duration of their MI. After their imagined performance, confidence ratings were provided. For participants in the OBS group, after watching each video clip they were asked to make a keypress of 1-3 sec to help control for the activity and duration of trials across groups. The keypress times were randomized across trials, matching our expected range of imagery durations based upon the duration of the video. The OBS group then made the same confidence ratings. At the close of the experiment, participants physically attempted the action to provide a measure of actual juggling ability.

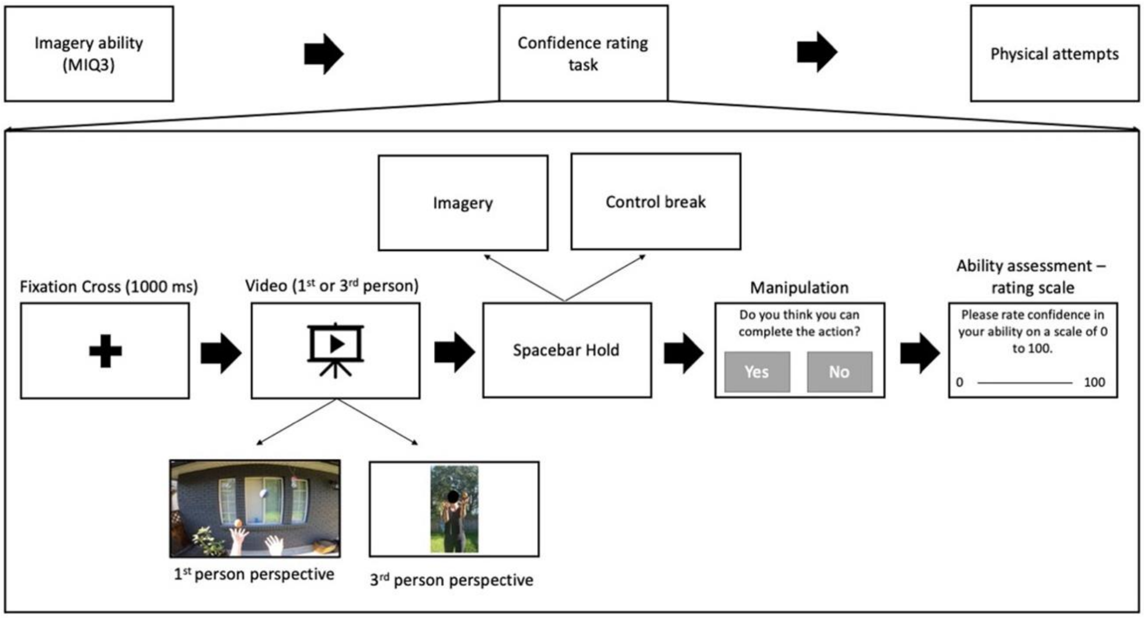

Figure 1. Timeline of the experiment and overview of the confidence rating task.

Data analysis

All statistical analyses were performed using open-source software (R Programming Environment), with an *a priori* alpha of $p < .05$ denoting statistical significance. Before performing parametric tests, data were tested for assumptions (via Shapiro-Wilks and Bartlett tests). Cohen's *d* effect sizes were calculated and reported to quantify effects (or lack thereof) throughout, calculated using pooled *SD*.

Skill confidence. To control for task engagement and as a manipulation check during MI, any trial that exceeded +/-3*SD* of the participant's mean imagery duration, for the OBS+MI group, or keypress duration for the OBS group, was excluded from analyses. The mean proportion of participants who reported 'yes' forced-choice responses were tabulated across participants for each video perspective and group.

The primary outcome measure was perceived confidence, reported on a scale of 0-100%. A linear mixed effects (LME) model conducted using the LME4 package (Bates et al., 2015) was used to assess changes related to confidence rating as a function of Group (between variable; OBS or OBS+MI), and repeated measures variables including Video Perspective (first- or third-person) and Trial (1-20). The LME model accounted for both random and fixed effects, which permitted us to evaluate changes across all trials for all participants, within and between groups (with trial 1 as the reference value). LME contrasts to traditional ANOVAs in that ANOVAs have limited sensitivity to within-subject effects, since they are constrained to have only a single mean intercept, rather than multiple intercepts, to represent each participant in the study (see Baayen et al., 2008; Magezi, 2015; and Nimon, 2012). Group, Trial, and the interaction between Group and Trial were entered as fixed effects to address our primary hypothesis related to the moderating effect of MI on AO. Video Perspective was also entered as a fixed effect, with Participant and Video Perspective entered as nested random effects, to test any moderation of confidence related to perspective.

The LME model we selected was based on a model comparison approach via Chi-square tests to determine whether or not the reduction in the residual sum of squares between different models was statistically significant. A model including a three-way interaction for Group, Video Perspective, and Trial did not significantly improve on our base model, which included only a two-way interaction for Group and Trial. Additional models created with fixed effects for Age and Sex did not improve the base model and so were not included in the final LME model. Results from these model comparisons are reported in Supplementary Materials. To characterize the extent to which confidence was inflated across trials (i.e., accompanying the tested interaction), effect sizes were computed within each group calculated using pooled *SD*s between trials 1 and 2, and trial 1 and 20.

To directly test simple trial related effects, separate linear regression analyses were conducted within each group. Specifically, data were collapsed across Video Perspective and analyses were conducted with Trial as the predictor variable and mean confidence as the dependent variable. Differences between groups were assessed using a *t*-test conducted on the Fisher's z-transformed correlation coefficients.

***Juggling ability*.** To test if exit ability differed between groups and to determine if and by how much confidence was inflated relative to self-reported ability, mean self-report ratings for the three physical attempts at the close of the study ('exit ability') were calculated for each participant. These ratings were compared to individual mean confidence ratings across the last three trials of the confidence task in a two-way ANOVA with Group (OBS vs. OBS+MI; between variable) and Rating Type (after observation or physical attempts; repeated measures variable). To quantify the extent to which confidence was inflated within each group (i.e., alongside the tested interaction), effect sizes were calculated using pooled *SD*s.

RESULTS

Descriptive data pertaining to frequencies and means for self-reported exit-ability and MIQ3 are shown in Table 1. Scores on each MIQ3 subscale overlapped across groups with positive skewness in all data towards the high end of the imagery scale (density plots illustrating these data are included in Supplementary Materials).

Assessments of confidence and ability across repeated observations

Based upon our trial exclusion criteria (i.e., manipulation check), 17 total trials were removed across all 84 participants included in final analyses (0.04% of data removed from the

OBS group and 0.06% of data removed from the OBS+MI group). The mean duration of MI in the OBS+MI group was 3.6 sec (SD = 2.6) and the mean duration of the keypress in the OBS group was 1.3 sec (SD = 0.9).

Figure 2 shows group-level data from the confidence rating task for the first- and third-person perspective videos. Confidence ratings gradually increased across trials and the increase was generally less for the OBS+MI versus OBS group. These descriptive observations were largely confirmed through statistical analysis (see Table 2). There was a significant effect of trial (with effect sizes ranging from $d_{trial\ 1\text{-}2} = .03$ *to* $d_{trial\ 1\text{-}20} = .24$), with confidence of each consecutive trial statistically different from the first trial and generally increasing across the task. Although there was no effect of Group (OBS = 73.8±28.1; OBS+MI =72.4±26.9; d = .04), there were significant interactions between Group and Trial, when comparing the differences between groups at trial 1 compared to differences between the groups at all other trials. With the exception of trial 1, the OBS+MI group had lower confidence across trials, relative to the OBS group. Quantifying the extent to which confidence increased across trials within each group, effect sizes ranged from $d_{trial\ 1\text{-}2} = .06$ to $d_{trial\ 1\text{-}20} = .29$ in the OBS group and from $d_{trial\ 1\text{-}2} = .001$ to $d_{trial\ 1\text{-}20} = .18$ in the OBS+MI group. The effect of video perspective was not significant (d = .02).

There was a positive association between trial and confidence for both groups OBS = 68.80 + 0.47**trial;* OBS+MI = 68.50 + 0.37**trial*. Although the slope of the regression line shallower in the OBS+MI group relative to the OBS group (see Figure 3), there was no statistical difference between the two groups based on the z-transformed correlation coefficients, $t(68.9) < 1$, d = .10.

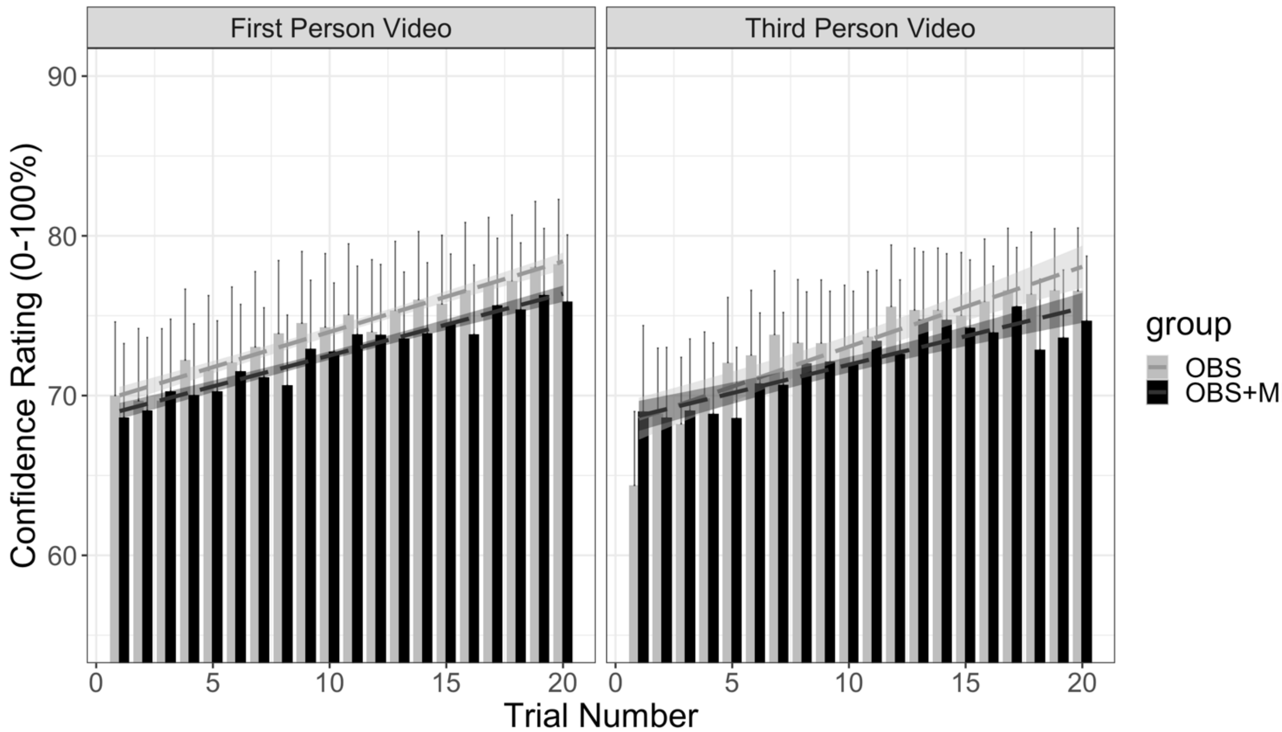

Figure 2. Group-level confidence ratings across trial for videos played from each (first- and third-person) perspective. Error bars represent standard error. The regression line for each group is overlaid, with the shading representing standard error. Linear mixed effects modelling revealed that confidence increased across Trial, yet to a greater extent in the OBS vs. OBS+MI group. No effects of Video Perspective were observed.

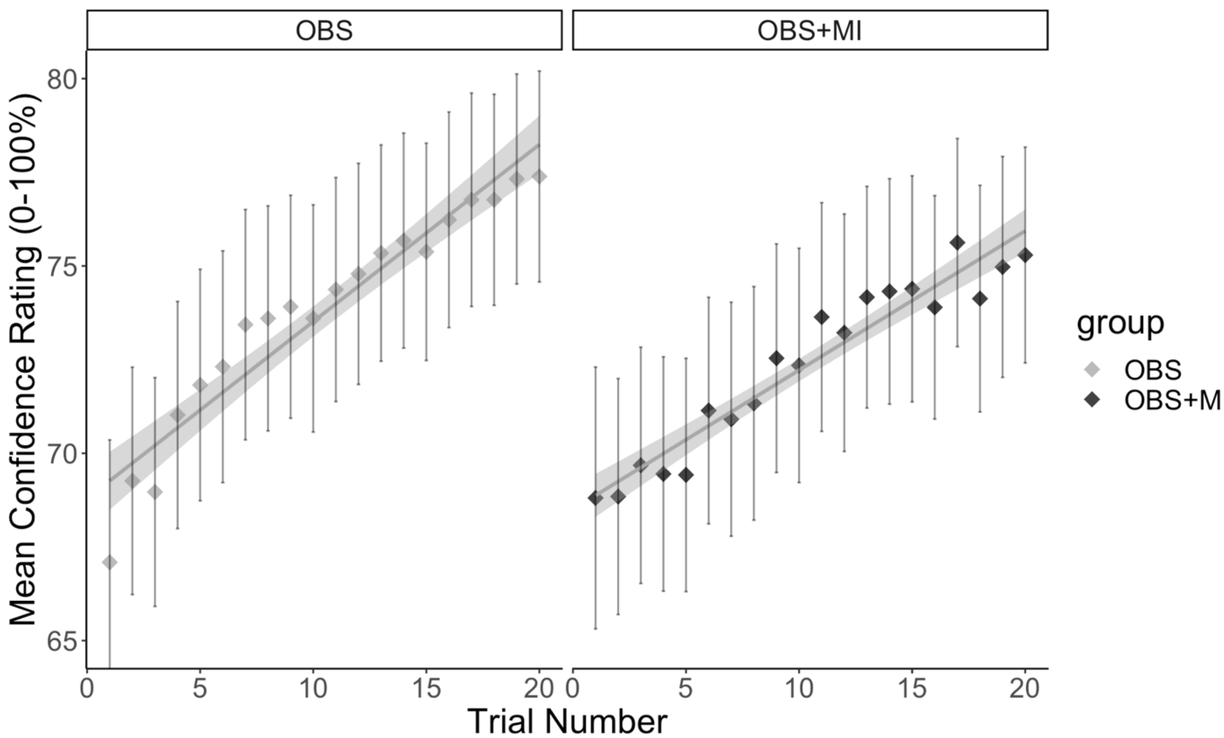

Figure 3. Group-level associations between trial and mean confidence rating. Data were collapsed across video perspective, with error bars depicting standard error and shaded areas showing standard area of the regression line.

The mean proportion of participants who reported 'yes' to the question of whether they could perform the juggling task (i.e., forced-choice) was .91 (OBS group) and .89 (OBS+MI group) for third-person perspective videos and .87 (OBS group) and .90 (OBS+MI group) for first-person perspective videos. Please refer to Supplementary Materials for a figure showing forced-choice data across trials for participants within each group.

Exit juggling ability ratings

Mean self-report exit juggling ability for each group is presented in Table 1 and the relationships between exit confidence and exit ability for individual participants are illustrated in Figure 4. The red line represents a perfect association between ability and confidence. The regression lines for both groups (in addition to most of the individual data points) fall below the red-dashed line, suggesting that confidence was inflated relative to actual ability. A two-way ANOVA did not yield a main effect of group, $F(1,82) < 1$ ($d < .01$), only a main effect of rating type (exit confidence, or exit ability), $F(1,82) = 58.60$, $p < .001$, $d = .74$. Overall exit confidence ratings after observation were inflated relative to exit ability ratings after physical attempts. There was no interaction between Group and Rating Type, $F(1,82) < 1$ (differences between confidence and exit ability within each group resulted in effect sizes of $d = .51$ for the OBS group and $d = .43$ for the OBS+MI group).

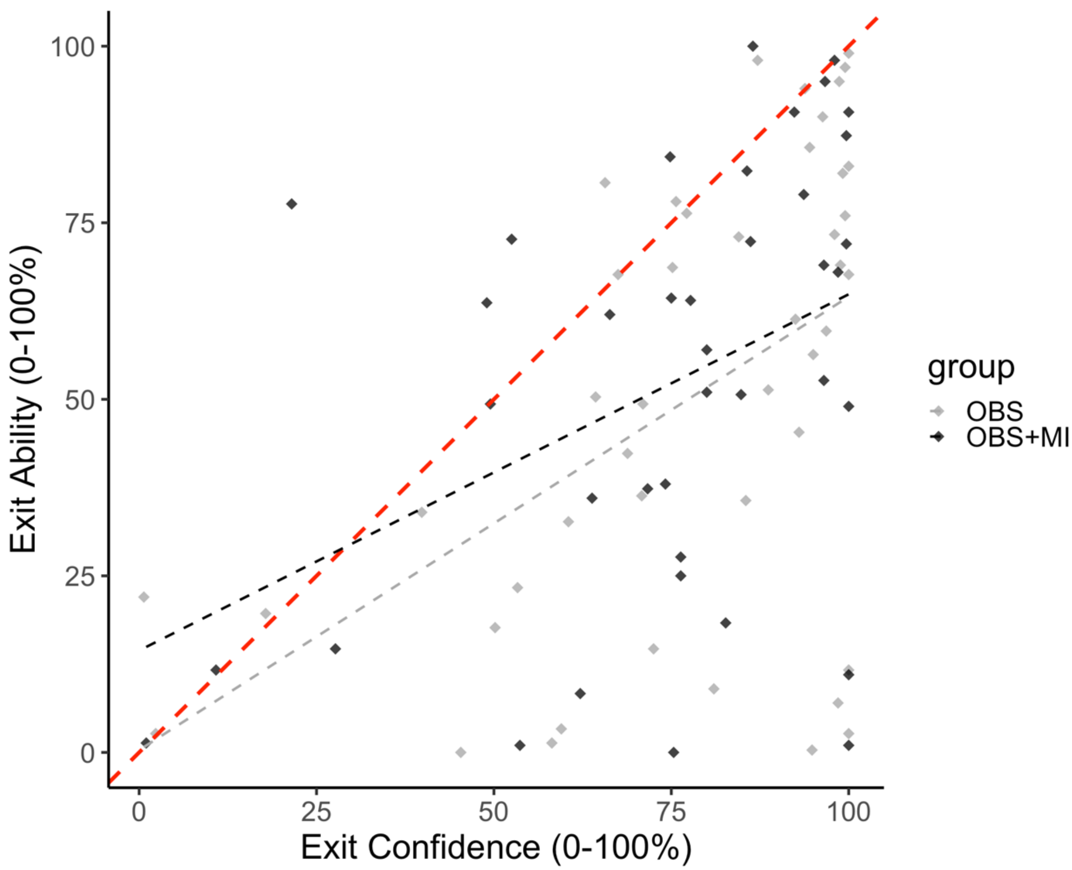

Figure 4. The relationship between exit confidence (averaged across the last three trials) and exit rating (averaged across the three physical attempts) of juggling across all participants, with higher numbers indicative of greater confidence and greater exit ability. The red line represents a perfect association between ability and confidence.

DISCUSSION

The present study was designed to evaluate confidence in skill ability after repeated AO or AO followed by MI of a juggling action. The aim was to determine whether MI moderates the previously demonstrated over-confidence associated with AO alone. Consistent with previous work, confidence increased across repeated AO of the skill. There were no main effects of group, yet there was some evidence, based on the Group X Trial interactions, that confidence ratings were tempered across trials following AO paired with MI. Perceptions of ability for individuals in the OBS+MI versus the OBS group were also better matched to exit ability, based on comparisons of effect sizes, yet the groups did not differ statistically. Both the AO and AO+MI group showed evidence of over-confidence when exit ability ratings were compared to confidence perceptions following observation. The results of this study provide some evidence that MI allows for diagnostic information about capability beyond that of AO, potentially affording better access to actual ability.

There is a growing body of work suggesting that AO and MI are separate action states (Bruton et al., 2020; Tsukazaki et al., 2012; Wright et al., 2014, 2018; Vogt et al., 2013). The data from our study partially concur with this suggestion. Participants were seemingly able to merge a simulated sensory experience engendered through MI with their perceptions gained through AO, impacting their assessment of ability. While both AO and MI are covert forms of action, AO is generally more passive compared to MI, potentially resulting in a more abstract representation than MI, one not so tied to the sensory experiences associated with doing (Vogt et al., 2013). Differences in ratings of confidence across trials between groups, though small, suggest that action simulation is not a “spontaneous” part of AO, or at least not always a spontaneous part of AO (Vogt et al., 2013). It is also possible that spontaneous MI that occurs during AO may be weaker relative to ‘pure’ MI.

There is increasing evidence supporting the idea that MI leads to an internal simulation of sensory consequences through a purported forward model of the simulated action (Dahm & Rieger, 2019; Ingram et al., 2019; Kilteni et al., 2018). Dahm and Rieger (2019) showed that in a dart throwing task performed via motor execution or MI, there were no differences in predicted outcomes after each throw between these conditions. Given that predictions made of the final position of the dart were congruent between the MI condition and a physical performance condition (with visual feedback of their performance occluded), the authors concluded that an internal simulation of sensory consequences was occurring during MI. There were, however, fewer predicted errors during MI than in execution, indicating that abilities were still overestimated (Dahm & Rieger, 2019). If MI allows for relatively accurate predictions of movement success, diagnostic information about capability is thus available to the user.

An interesting potential consequence of MI associated with the idea that MI allows the individual to better access accurate information about the sensory outcomes of the action, is that they should also be more likely to accurately imagine a failure. This imagination of failure would not be expected in AO, not least because individuals were watching a successful model (cf., Lirgg & Feltz, 1991). The finding that individuals were able to predict errors during MI of a dart-throwing task (Dahm & Rieger, 2019) suggests that MI provides a good indication of one's own capabilities, with non-perfect execution. Taken with our current findings, over-confidence as a result of repeated observation might be expected as a result of both AO and MI, but should be mitigated with the addition of MI. Our data did support these expectations, although not as strongly as might be expected based on past literature. In future work, it will be important to include a physical practice condition to allow comparisons of MI to actual execution to determine whether MI still results in overconfidence in ability, as suggested by our exit-rating data and prior work (Dahm & Rieger, 2019). Such a control condition will also allow us to infer, based on differences in confidence ratings, where MI and AO fall on the action continuum relative to action execution (see Vogt et al., 2013).

Research on the development of movement representations following observational practice also supports the idea that AO leads to relatively abstract mental representations of actions in the absence of physical practice (e.g., Kim et al., 2010, 2017). AO provided information related to the organizational and perceptual aspects of the movement and was shown to be easier to use in initial practice stages as compared to MI (Kim et al., 2017). Visual information provided externally during AO may thus be held in memory as the user gains an understanding of and ultimately learns movement organization and perceptual aspects, yet may bypass any requirement for/reliance on kinesthetic sensory information to facilitate learning (Frank et al., 2016).

It is interesting to consider these data regarding over-confidence following AO and their attenuation with MI in the context of other work where perceptions of fluency have increased following video observation. Both Kardas and O'Brien (2018) and Jordan et al. (2022), have demonstrated over-confidence as a result of short periods of observation from skills as diverse as performing a magic trick, hitting a bulls-eye in darts, or even landing a plane. Jordan et al. suggest that watching a video increases confidence because it helps individuals create more detailed imaginations (in line with ideas about errors in source monitoring; e.g., Lindsay, 2014). Here, we show that this proposed mechanism is either incorrect or needs further qualification. It is not so much that people are better able to imagine when watching a video, but that their imaginations lead to over-confidence because these tertiary imaginations fail to access simulation type processes alerting to actual capabilities. Explicit instructions to engage in MI appears to help give more veridical perceptions of ability than those spontaneously engaged without additional prompts to imagine how the movement would feel to actually perform.

These data raise important considerations for future research. Understanding how such effects translate to skill acquisition (or can be leveraged for skill acquisition) remain unknown, especially when considering how demonstrations are used to bring about learning. We chose the two-ball juggling action based on previous work showing how confidence increased with repeated observations of this task, but was moderated by actual physical practice (Hodges & Coppola, 2015). Using an attainable task permitted an assessment of actual ability, such that we were able to relate confidence ratings (which were high ~70%), with self-reported juggling ability at the end of the study (which was lower at ~50%). A more difficult or unattainable task, such as flying a plane (Jordan et al., 2022), may have resulted in greater attenuation of confidence as a result of combining MI with OBS, compared to OBS alone. As tasks become more difficult or novel, imagining how an action feels may become even more challenging, potentially leading to less confidence in ability from simply watching.

We did not include groups that performed repeated motor execution (as in Hodges & Coppola, 2015), nor ‘pure’ MI (i.e., without AO), and as such, we are precluded from making inferences made about the extent to which one’s ability is overestimated in MI. However, based on differences between exit ability and confidence ratings following OBS+MI in our study and past work showing that ability was overestimated in MI only conditions (Dahm & Rieger, 2019), it is reasonable to suspect that MI, like AO also results in overconfidence. One methodological issue to consider for future work is to control for potential confidence inflation merely as a result of repeated asking. Although there is no reason to predict why the repeated asking for confidence perceptions would be different in an AO+MI group vs. AO only group (as shown here), to more veridically assess how observation or MI changes confidence, control of or manipulations to the frequency of asking this question will be needed. While our OBS group was asked to perform a keypress task to help control for the duration of trials there is also the possibility that mere differences in the duration of the interval between the OBS and OBS+MI group in our study contributed to confidence deflation for this latter group. Although it is difficult to speculate as to why time alone would modulate confidence perceptions, there is a need for better control of timing in future work.

It is also important to consider these data in terms of learning outcomes and whether improved learning, measured in a delayed retention test, would be expected when AO and MI are combined as has been shown in prior work (for reviews see Eaves et al., 2016, 2022). There is quite compelling evidence that combining MI with AO provides additive effects relative to either modality performed on its own (Eaves et al., 2016; Marshall et al., 2020 Scott et al., 2018; Wright et al., 2014; Vogt et al., 2013), although longer-term learning effects have rarely been assessed. In the current design, it may be that we see dissociations between measures of confidence and actual ability assessed at a later retention date, if the addition of MI provides a richer experience for learning, allowing the observer to better acquire and perform the action at a later date, whilst moderating confidence in the short-term.

There was no benefit (or cost) for manipulating the perspective in which videos were displayed and the first-person video perspective did not impact differently on the effects of AO+MI versus AO as predicted. This absence of a difference suggests that spontaneous MI did not occur in AO, even when the perspective was one which would presumably encourage MI (i.e., first-person, see Riach et al., 2018). There is evidence that increased involvement of the motor system is seen when videos are shown from the first-person versus third-person perspective (Alaerts et al., 2009), which may also be mediated by spontaneous MI. However, no evidence supporting this conclusion was seen here, despite the fact that the MI instructions encouraged participants to imagine performing the action themselves (from a first-person perspective), focusing on the feeling of the movement and the timing/ interactions with the juggling balls. However, a measure was not included to assess the extent to which participants were spontaneously performing MI during the AO condition, such that any conclusions about the absence of spontaneous MI during AO is tentative.

Video perspective in our design was included as a repeated measures factor where the order was counterbalanced. As such, any effects of perspective may have been washed out when combined over the first and second half of practice and our study was underpowered to compare only groups who had different video perspectives in the first half (or second half) of practice. An exploratory analysis with video-order as a between factor was, however, conducted (added to Supplementary Materials). A similar pattern of results emerged in terms of Group X Trial interactions, but there was also an effect of video-order. Confidence was lower when first person perspective videos were shown first rather than second. This order effect may suggest, congruent with our predictions, that watching actions from the first-person perspective dilutes inflations of confidence associated with repeated observation, as long as not preceded by an external, third-person view. A first-person view may encourage the spontaneous occurrence of MI or promote more veridical perceptions of ability. In future work it will be important to isolate perspective in an appropriately powered between design.

Conclusion

The current study adds to a growing body of literature showing that repeated observation of successful actions of others appears to result in inflated perceptions of ability, or ‘over-confidence'. We also show for the first time that encouraging motor imagery after observing novel actions appears to temper this over-confidence which results from repeated observations, but does not eliminate it. Together with previous literature exploring skill acquisition stimulated by MI and AO, we conclude that MI allows access to sensory effects associated with action execution more than AO alone. MI can provide the learner with improved diagnostic information about capability, supporting the idea that AO and MI are separable states. Although more research is required to quantify the contribution of spontaneous MI during AO and obtain objective measures of performance in the short and long term, this work serves to inform on the nature of these covert forms of practice and why perceptions of ability are not well matched to reality.

Table 1.
Group characteristics, including MIQ3 subscale scores and skill ability ratings.

	OBS	OBS+MI
	Mean score *(SD)*	Mean score *(SD)*
Internal visual imagery (/7)	5.5 *(1.2)*	5.2 *(1.0)*
External visual imagery (/7)	5.7 *(1.1)*	5.7 *(1.2)*
Kinaesthetic imagery (/7)	5.5 *(1.1)*	5.2 *(1.2)*
Exit juggling ability (0-100%)	49.9 *(32.3)*	52.2 *(30.8)*

Table 2: *Linear mixed effects model statistics for confidence ratings data comparing across Group (OBS+MI vs OBS), Trial, the interaction of Group and Trial, and the main effect of Video Perspective (comparing Third-person to First-person video perspective).*

	Response (%)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	66.08	58.22 – 73.95	**<.001**
Group [OBS+MI]	3.43	-7.84 – 14.71	.551
Trial [2] –[20] combined	3.30 to 11.65		**all =/<.001**
Video Perspective [Third-Person Video]	-0.69	-4.01 – 2.64	.685
Group [OBS+MI] * Trial [2]	-3.63	-6.57 – -0.69	**.016**
Group [OBS+MI] * Trial [3]	-2.99	-5.92 – -0.06	**.046**
Group [OBS+MI] * Trial [4] – [20]	-5.96 to -3.59		**all =<.017**
Random Effects			
σ^2	45.31		
τ_{00} Video Perspective:participant	118.65		
τ_{00} participant	608.17		
ICC	.94		
N Video Perspective	2		
N participant	84		
Observations	3344		
Marginal R^2 / Conditional R^2	.010 / 0.94		

Note that text in square brackets indicates the comparison group or conditions to the reference group (OBS or First-Person) or reference condition (Trial 1). Summaries are included (i.e., ranges of values) for trial-related effects that are showing the same general outcomes.

DATA ACCESSIBILITY

Data are registered and available on the Open Science Framework: osf.io/gh2n7, DOI: 10.17605/OSF.IO/GH2N7.

REFERENCES

Alaerts, K., Heremans, E., Swinnen, S.P., Wenderoth, N., 2009. How are observed actions mapped to the observer's motor system? Influence of posture and perspective. Neuropsychologia 47, 415–422. https://doi.org/10.1016/j.neuropsychologia.2008.09.012

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59(4), 390-412. https://doi.org/10.1016/j.jml.2007.12.005

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software,* 67(1), 1-48. https://doi.org/10.18637/jss.v067.i01

Bruton, A. M., Holmes, P. S., Eaves, D. L., Franklin, Z. C., & Wright, D. J. (2020). Neurophysiological markers discriminate different forms of motor imagery during action observation. *Cortex, 124*, 119-136. https://doi.org/10.1016/j.cortex.2019.10.016

Callow, N., Hardy, L., 2004. The relationship between the use of kinaesthetic imagery and different visual imagery perspectives. Journal of Sports Sciences 22 (2), 167–177. http://dx.doi.org/10.1080/02640410310001641449

Dahm, S. F., & Rieger, M. (2019). Is imagery better than reality? Performance in imagined dart throwing. *Human Movement Science*, 66, 38-52. https://doi.org/10.1016/j.humov.2019.03.005

Eaves, D., Hodges, N., Buckingham, G., Buccino, G., Vogt, S. (*2022*) Enhancing motor imagery practice using synchronous action observation. *Psychological Research*. https://doi.org/10.1007/s00426-022-01768-7

Eaves, D. L., Riach, M., Holmes, P. S., & Wright, D. J. (2016). Motor imagery during action observation: A brief review of evidence, theory and future research opportunities. *Frontiers in Neuroscience, 10*, 514-514. https://doi.org/10.3389/fnins.2016.00514

Frank, C., Land, W. M., & Schack, T. (2015;2016;). Perceptual-cognitive changes during motor learning: The influence of mental and physical practice on mental representation, gaze behavior, and performance of a complex action. *Frontiers in Psychology, 6*, 1981-1981. https://doi.org/10.3389/fpsyg.2015.01981

Glover, S., & Baran, M. (2017). The motor-cognitive model of motor imagery: Evidence from timing errors in simulated reaching and grasping. *Journal of experimental psychology: human perception and performance*, *43*(7), 1359.

Grosprêtre, S., Ruffino, C., & Lebon, F. (2016). Motor imagery and cortico-spinal excitability: A review. *European Journal of Sport Science, 16*(3), 317-324. https://doi.org/10.1080/17461391.2015.1024756

Hardwick, R. M., Caspers, S., Eickhoff, S. B., & Swinnen, S. P. (2018). Neural correlates of action: Comparing meta-analyses of imagery, observation, and execution. *Neuroscience and Biobehavioral Reviews*, *94*, 31-44. https://doi.org/10.1016/j.neubiorev.2018.08.003

Hodges, N. J. (2017). Observations on action-observation research: An autobiographical retrospective across the past two decades. *Kinesiology Review (Champaign, Ill.), 6*(3), 240-260. https://doi.org/10.1123/kr.2017-0016

Hodges, N. J., & Coppola, T. (2015). What we think we learn from watching others: The moderating role of ability on perceptions of learning from observation. *Psychological Research*, *79*(4), 609-620. https://doi.org/10.1007/s00426-014-0588-y

Hodges, N. J., Williams, A. M., Hayes, S. J., & Breslin, G. (2007). What is modelled during observational learning? *Journal of Sports Sciences, 25*(5), 531-545. https://doi.org/10.1080/02640410600946860

Holmes, P., & Calmels, C. (2008). A neuroscientific review of imagery and observation use in sport. *Journal of Motor Behavior, 40*(5), 433-445. https://doi.org/10.3200/JMBR.40.5.433-445

Holmes, P., Collins, D., 2001. The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists. Journal of Applied Sport Psychology 13 (1), 60–83. http://dx.doi.org/10.1080/10413200109339004

Ingram, T. G. J., Solomon, J. P., Westwood, D. A., & Boe, S. G. (2019;2018;). Movement related sensory feedback is not necessary for learning to execute a motor skill. *Behavioural Brain Research*, *359*, 135-142. https://doi.org/10.1016/j.bbr.2018.10.030

Jeannerod, M. (1995). Mental imagery in the motor context. *Neuropsychologia*, *33*(11), 1419-1432. https://doi.org/10.1016/0028-3932(95)00073-C

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage (Orlando, Fla.), 14*(1), S103-S109. https://doi.org/10.1006/nimg.2001.0832

Jordan, K., Zajac, R., Bernstein, D., Joshi, C., & Garry, M. (2022). Trivially informative semantic context inflates people's confidence they can perform a highly complex skill. *Royal Society Open Science, 9*(3), 211977-211977. https://doi.org/10.1098/rsos.211977

Kardas, M., & O'Brien, E. (2018). Easier seen than done: Merely watching others perform can foster an illusion of skill acquisition. *Psychological Science, 29*(4), 521-536. https://doi.org/10.1177/0956797617740646

Kilteni, K., Andersson, B. J., Houborg, C., & Ehrsson, H. H. (2018). Motor imagery involves predicting the sensory consequences of the imagined movement. *Nature Communications, 9*(1), 1617-9. https://doi.org/10.1038/s41467-018-03989-0

Kim, T., Cruz, A., & Ha, J. (2010). Differences in learning facilitatory effect of motor imagery and action observation of golf putting. *Journal of Applied Sciences (Asian Network for Scientific Information), 11*(1), 151-156. https://doi.org/10.3923/jas.2011.151.156

Kim, T., Frank, C., & Schack, T. (2017). A systematic investigation of the effect of action observation training and motor imagery training on the development of mental representation structure and skill performance. *Frontiers in Human Neuroscience*, *11*, 499-499. https://doi.org/10.3389/fnhum.2017.00499

Lindsay, D. S. (2014). Memory source monitoring applied. The SAGE handbook of applied memory, 59-75.

Lirgg, C. D., & Feltz, D. L. (1991). Teacher versus peer models revisited: Effects on motor performance and self-efficacy, *Research Quarterly for Exercise & Sport, 62(2)*, 217-224. https://doi.org/10.1080/02701367.1991.10608713

Magezi, D. A. (2015). Linear mixed-effects models for within-participant psychology experiments: An introductory tutorial and free, graphical user interface (LMMgui*). Frontiers in Psychology, 6*, 2-2. https://doi.org/10.3389/fpsyg.2015.00002

Marshall, B., Wright, D. J., Holmes, P. S., & Wood, G. (2020). Combining action observation and motor imagery improves eye-hand coordination during novel visuomotor task performance. *Journal of Motor Behavior*, *52*(3), 333-341. https://doi.org/10.1080/00222895.2019.1626337

Nimon, K. F. (2012). Statistical assumptions of substantive analyses across the general linear model: A mini-review. *Frontiers in Psychology, 3,* 322-322. https://doi.org/10.3389/fpsyg.2012.00322

Ong, N. T., & Hodges, N. J. (2010). Absence of after-effects for observers after watching a visuomotor adaptation. *Experimental Brain Research, 205*(3), 325-334. https://doi.org/10.1007/s00221-010-2366-4

Ramsey, R., Kaplan, D. M., & Cross, E. S. (2021). Watch and Learn: The Cognitive Neuroscience of Learning from Others' Actions. *Trends in Neurosciences (Regular Ed.), 44*(6), 478-491. https://doi.org/10.1016/j.tins.2021.01.007

Riach, M., Holmes, P. S., Franklin, Z. C., & Wright, D. J. (2018). Observation of an action with a congruent contextual background facilitates corticospinal excitability: A combined TMS and eye-tracking experiment. *Neuropsychologia*, *119*, 157–164. https://doi.org/10.1016/j.neuropsychologia.2018.08.002

Sakamoto, M., Muraoka, T., Mizuguchi, N., & Kanosue, K. (2009). Combining observation and imagery of an action enhances human corticospinal excitability. *Neuroscience Research, 65*(1), 23-27. https://doi.org/10.1016/j.neures.2009.05.003

Scott, M., Taylor, S., Chesterton, P., Vogt, S., & Eaves, D. L. (2018). Motor imagery during action observation increases eccentric hamstring force: An acute non-physical intervention. *Disability and Rehabilitation, 40*(12), 1443-1451. https://doi.org/10.1080/09638288.2017.1300333

Stinear, C., Byblow, W., Steyvers, M., Levin, O., Swinnen, S., 2006. Kinesthetic, but not visual, motor imagery modulates corticomotor excitability. Experimental Brain Research 168 (1–2), 157–164. http://dx.doi.org/10.1007/s00221-005-0078-y

Tsukazaki, I., Uehara, K., Morishita, T., Ninomiya, M., & Funase, K. (2012). Effect of observation combined with motor imagery of a skilled hand-motor task on motor cortical excitability: Difference between novice and expert. *Neuroscience Letters, 518*(2), 96-100. https://doi.org/10.1016/j.neulet.2012.04.061

Vogt, S., Di Rienzo, F., Collet, C., Collins, A., & Guillot, A. (2013). Multiple roles of motor imagery during action observation. *Frontiers in Human Neuroscience, 7*, 807-807. https://doi.org/10.3389/fnhum.2013.00807

Williams, S. E., Cumming, J., Ntoumanis, N., Nordin-Bates, S. M., Ramsey, R., & Hall, C. (2012). Further validation and development of the movement imagery questionnaire. *Journal of Sport & Exercise Psychology, 24*(5), 621-646.

Wolpert, D. M., Diedrichsen, J., & Flanagan, J. R. (2011). Principles of sensorimotor learning. *Nature Reviews. Neuroscience, 12*(12), 739-751. https://doi.org/10.1038/nrn3112

Wong, L., Manson, G. A., Tremblay, L., & Welsh, T. N. (2013). On the relationship between the execution, perception, and imagination of action. *Behavioural Brain Research, 257*, 242-252. https://doi.org/10.1016/j.bbr.2013.09.045

Wright, D. J., Williams, J., & Holmes, P. S. (2014). Combined action observation and imagery facilitates corticospinal excitability. *Frontiers in Human Neuroscience, 8*, 951-951. https://doi.org/10.3389/fnhum.2014.00951

Wright, D. J., Wood, G., Eaves, D. L., Bruton, A. M., Frank, C., & Franklin, Z. C. (2018). Corticospinal excitability is facilitated by combined action observation and motor imagery of a basketball free throw. *Psychology of Sport and Exercise, 39*, 114-121. https://doi.org/10.1016/j.psychsport.2018.08.006

Footnotes

[1]AO+MI is a term frequently used to describe the *simultaneous* performance of MI and AO (e.gs., Bruton et al., 2020; Eaves et al., 2016). Because in our study MI is completed independently from AO, we opted to name our Groups OBS+MI and OBS to distinguish it from this alternative method.