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The Effect of Action Observation and Motor Imagery Combinations on Upper Limb Kinematics and EMG during Dart Throwing

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Abstract

Recent research has begun to employ interventions that combine action observation and motor imagery (AOMI) with positive results. However, little is known about the underpinning facilitative effect on performance. Participants (n=50) were randomly allocated to one of five training groups: action observation (AO), motor imagery (MI), simultaneous action observation and motor imagery (S-AOMI), alternate action observation and motor imagery (A-AOMI) and control. The task involved dart-throwing at a concentric circle dartboard at pre- and post-test. Interventions were conducted 3 times per week for 6 weeks. Data were collected from performance outcomes and mean muscle activation of the upper and forearm muscles. Angular velocity and peak angular velocity measurements of the elbow were also collected from the throwing arm. Results showed performance of the A-AOMI group improved to a significantly greater degree than the AO ($p = 0.04$), MI ($p = 0.04$), and control group ($p = 0.02$), and the S-AOMI group improved to a greater degree than the control group ($p = 0.02$). Mean muscle activation of the triceps brachii significantly reduced in the S-AOMI and A-AOMI ($p < 0.01$) groups and participants in the AO (p= 0.04), A-AOMI and S-AOMI ($p < 0.01$) groups significantly reduced activation in the bicep brachii from pre to post-test. Peak angular velocity significant decreased from pre- to post-test in both A-AOMI and S-AOMI ($p < 0.01$) groups. The results reaffirm the benefits of AOMI for facilitating skill learning and provide an insight how these interventions produce favourable changes in EMG and movement kinematics.

Keywords

Motor skill learning, Observational learning, Aiming, Simulation

Introduction

Motor imagery (MI) is characterised as the mental execution of an action without any overt output (1). Action observation (AO) training consists of observing an action conducted by others without any motor output (2). Both MI and AO have been shown to promote motor learning, demonstrating neurophysiological activation of the brain areas corresponding to motor planning and voluntary movement (3). Acute effects of AO and MI interventions filmed from the first-person visual perspective have also been shown to optimise kinetic and kinematic variables and promote motor learning (4–6). For example, Gentili et al.(5) examined the kinematic profiles of participants engaged in MI and physical practice training on a target recognition task using their right arm. Results revealed physical practice and MI training led to decreased movement duration and increased peak acceleration towards the target respectively. The results of this study emphasise the comparable effects of MI to physical practice as previously shown in neuroscience literature (7). Gatti et al. (4) also examined motor learning through assessing movement kinematics (error time, range of motion, mean movement frequency of the wrist and ankles) in response to AO and MI using a hand and foot angular direction task. The authors concluded that movement kinematics showed AO to be more effective than MI in learning a novel, complex motor task. However, as the results were collected after one training session this could apply only to the fast phase of the motor learning process.

More recently, AO combined with MI (AOMI) has been shown to be a more effective intervention than AO or MI performed in isolation for a variety of outcomes such as strength (3,8), skilled movement (9,10), and rehabilitation (11,12). Despite this evidence, little is known about how these combinations are best structured and how they enhance performance. While some research on stroke patients (11) and postsurgical orthopaedic patients (12) has suggested that combining AOMI in a simultaneous manner enhances functional outcomes, a recent study using a sporting task has suggested that the manner in which AO and MI is combined has little bearing on the magnitude of motor learning witnessed. Specifically, Romano-Smith, Wood, Wright, & Wakefield (10) employed a 6-week intervention where one group was instructed to observe whilst simultaneously completing concurrent MI movement (S-AOMI), whilst the other group practiced AOMI by alternating AO and MI components (A-AOMI). Results showed that both AOMI combinations improved significantly more than participants in the AO and MI only groups when learning dart-throwing.

Despite the developing understanding that AOMI provides superior performance effects, it remains unclear precisely *how* AOMI facilitates the motor learning processes through the measurement of upper limb movement kinematics and muscular activity through EMG signals. In an attempt to explain such facilitatory effects, neurophysiological research has indicated that during AOMI there is an increase in neural activity in the cortical areas linked to planning and executing movement, compared to either AO or MI performed alone (13). Recent research extends these findings, demonstrating corticospinal modulations induced by MI have a considerable effect on a wide proportion of the corticospinal pathway corresponding to the targeted muscles, (12,14). Indeed, research shows that motor-related areas (premotor cortex and parietal cortex; 15) are recruited not only when actions are executed, but also when they mentally rehearsed and observed (4,15,16,17). This finding has been broadly interpreted as resonating and/or refining a neural representation for skilled execution (18,19). In addition, the potential kinaesthetic component of MI can aid the prediction of sensory consequences, as it does during the physical execution (20). Thus, by combining the two techniques, may be the best way to improve the motor skill learning by producing greater activity in the motor system than either independent AO or independent MI (13) and stimulating the widest possible range of the corticospinal pathway (12) and refining internal models (18).

Similar findings have also been reported in physical practice intervention studies examining kinematic and kinetic responses to skill learning utilising a target aiming task. The use of physical practice literature is supported by Jeannerod's (21) Simulation Theory. This theory proposes to explain how a functional equivalence exists between AO, MI and action execution (AE) of a motor skill, whereby all three states activate similar neural pathway. Lohse, Sherwood, & Healy (22) examined the kinematic and EMG activity of the agonist (biceps brachii) and antagonist (triceps brachii) employing a darts throwing task. The results demonstrated a reduced EMG activity in both the agonist (bicep brachii) and antagonist (triceps brachii) muscles. Mousavi, Shahbazi, Arabameri, & Shirzad (23) also used a dart throwing task to examine the kinematic profiles such (e.g. Critical elbow angular velocity, and movement time) following a virtual reality training of a dart throwing task. The results demonstrated a reduction in movement time, significant increases in critical elbow angular velocity and significant increase in follow through time (point of release time to full extension).

The aim of this study was to investigate performance results, EMG activity and movement kinematics that may underpin the superior effects of AOMI demonstrated by (10) using a dart throwing task. We hypothesise that AO, MI, A-AOMI, and S-AOMI interventions will produce performance improvements from pre to post test, relative to a control group, and these improvements will be greater in both combined AOMI groups compared to either intervention alone. Further, we hypothesise that owing to the predicted performance improvements in aiming performance, the AOMI groups will consequently evidence a reduction in EMG activity in both the biceps brachii and triceps brachii muscles demonstrated in the study by Lohse et al. (22). Moreover, we expect an increase in movement time, increase in critical elbow angular velocity, and a significant increase in follow through time (point of release time to full extension) from pre to post-test also demonstrated in an aiming based task (23).

Method

Participants

Fifty university students (25 males, 25 females; *Mean age* = 28.80 *years*, *SD* =6.75) were recruited. The number of participants was established to be comparable to that of previous research of a similar nature (9,10,24). All participants reported being right-handed using the Edinburgh Handedness Inventory (25) and reported normal or corrected to normal vision and were novice performers who had limited dart throwing experience. Furthermore, all participants had not previously participated in any MI training. All procedures were carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki and were approved by the University Ethics Committee at the host institution. Written informed consent was obtained from all participants prior to the study, and no payment was provided for participation in this study.

Measures

Movement Imagery Questionnaire-Revised (MIQ-R; Hall & Martin, 1997).

The MIQ-R is an eight-item inventory that assesses an individual’s ability to perform visual and kinaesthetic imagery. In this study, the MIQ-R was employed as a screening tool, also used by previous research (26). The validity and consistency of the MIQ-R has been demonstrated by Gregg, Hall, & Butler (27) and has been used previously in imagery studies investigating aiming tasks (28).

The Aiming Task

A concentric circle dartboard was used to collect performance data. The dartboard was positioned at the centre fixed point, 1.73m from the floor and 2.37m horizontally from the throwing line, as per standard darts rules. Performance (throwing accuracy score) was measured in 10 concentric circles (2cm wide), with the centre scoring 10 points and the outer circle scoring 1 point. Darts that landed outside the circumference of the dartboard were awarded a score of zero (see figure 1)

Biomechanical Measures

Upper limb, 3D joint kinematics, muscle activation patterns, and digital video of the throwing action were captured synchronously via the Noraxon MR3.10 analysis software (Scottsdale, AZ, USA). Phases of movement and temporal characteristics of the throw were determined from a tripod mounted webcam (30 frames per second capture rate), positioned perpendicular to the direction of the throw, and in line with the shoulder joint. Key time points were then extracted from the video and used to define the following phases of movement: (A) flexion to (B) extension and (A) Flexion to (C) point of release for each participant (Figure 2). In conjunction with the video, elbow angle data (flexion-extension) was also used to identify the time point of maximum flexion and maximum extension.

Electromyography (EMG) recordings

Trigno ^{TM} EMG electrodes (Delsys Inc.) with 10 mm diameter and 20mm inter-electrode distance as recommended by Hermens, Freriks, Disselhorst-Klug, & Rau (29) were attached to the prepared skin overlaying the five selected muscles. Muscles were selected based upon research of a similar nature measuring kinematic and electromyography variables during behavioral based darts tasks (22,23,30). To limit cross talk, electrodes were placed parallel to the muscle fibres on the belly of the muscles following accepted anatomical criteria (31,32) for controlling the movement of the wrist, elbow, and shoulder. These muscles included flexor carpi radialis (FCR), extensor carpi radialis (ECR), bicep brachii and triceps brachii and anterior deltoid (see figure 2).

Raw EMG signal processing

Raw EMG were captured synchronously via a Noraxon AIS unit (Analogue Input System) into the Noraxon MR3.10 software, at a sampling frequency of 1500Hz. Signals were band-pass filtered (Hamming 20-350 Hz cut- off), and converted into root mean square (RMS) signals with a window size of (100 ms), which some research suggests that is a more accurate index of physiological changes than measures of raw amplitude (33) and was used in previous studies measuring muscle activation using a dart throwing task (34). Signals were then normalised to the peak activation level for each muscle, recorded during the dart throw movement sequence. Mean activation within the defined phases (flexion to release and flexion to extension) was then calculated for each throw.

Myomotion joint kinematics

The kinematic variables of interest included movement time, follow through time, time to peak angular velocity and angular velocity of the dart throw. These variables were measured at two critical times in the throwing motion: at the moment of retraction (point of maximum elbow flexion) and at the moment of release. To measure these variables, Noraxon MyoMotion (Scottsdale, AZ, USA) motion analysis system was employed to analyse movement kinematic of the throwing arm. MyoMotion inertial measurement units (IMU) were placed according to the rigid-body model defined in the Noraxon MR3 software. Six IMU sensors were placed on the dominant throwing arm and trunk: upper-arm, forearm hand, upper thoracic, pelvis, and lower thoracic segments. The sensors were attached with special fixation straps (for pelvis) and elastic straps. Calibration was carried out using the upright standing position, in order to determine the zero / neutral angle in the measured joints.

Sampling frequency for the inertial sensors was set at 200 Hz. Instantaneous changes in joint angles and angular velocities in the upper limb were recorded during each of the throwing trials. (See Figure 3).

Myomotion joint kinematics – temporal analysis

A temporal analysis of the throw phases outlined in Figure 2 allowed movement time and follow through time and angular velocity to be calculated. Movement time was defined as the time from the moment of full flexion to the point of release (i.e. Release time - Full Flexion time). Follow through time was defined as the time from the point of release to full extension (i.e. Full extension time - Release time). Angular velocity of the throw (in degrees per second) was calculated by subtracting elbow flexion at retraction from flexion at the moment of release and dividing by throwing time.

Procedure

Prior to the commencing of the study, all participants gave their informed consent for participation and completed the MIQ-R. All participants were randomly allocated to one of five experimental groups (n =10 per condition): action observation (AO); motor imagery (MI); simultaneous imagery and observation (S-AOMI); and alternate imagery and observation (A-AOMI) and control. All participants, except those in the control group and AO group, received stimulus-response training (35). Participants in the AO and control group were not required to produce a motor image and did not receive LSRT. It was decided that for the nature of this study that LSRT would be used due to the amount of literature that uses the technique, its ability to improve motor imagery ability, to initiate the motor programme for the movement being imaged, and is relatively easy for the participant to understand (36–38).

Participants engaging in LSRT based on the bio-informational theory (35) were required to utilise three sources of information within a scenario used to aid their MI For example: (1)

stimulus proposition characteristics of the imagery scenario (e.g., specific details about the pre-test environment), (2) response propositions that describe the physiological response a performer would experience when participating in real life situations (e.g., muscle tension, increased heart rate, postural changes) (3) inferred meaning propositions which explain the relationship between the stimulus and response proposition to the athlete (e.g., it makes me excited to participate). Once participants had identified the information required, they were instructed to engage in MI of the scene (e.g., dart throw). After completing the image, participants were then asked to evaluate their image and reflect on what aspects of their image they found particularly clear to image and which aspects they found more difficult to image. Next, participants were required to re-image the scene by attending to specific details within the imaged scenario they reported to have found easy (e.g., seeing the dart positioned in their hand). Finally, participants were required to evaluate and reflect on the image again. Additional layers in the form of response and meaning proposition that would also be experienced were also added to the script (e.g., feeling their arm raise, the dart leave the hand and make contact with the board). Over the six weeks, participants were instructed to perform imagery in the first person perspective, with their eyes open and build the image up by including additional details and/or by making the details more vivid or life-like. It is important to note however, this process was participant generated and participants were not directed to specific propositions by the researchers.

All participants were given identical brief instructions of the materials as far as showing the participants how to hold the dart, how to throw in one plane, and instructing them that their feet could not cross the throwing line. Participants were also informed about the scoring system and were asked to focus on the centre of the board, ensuring their dart and target were in line. After five practice throws, participants completed their pre-test.

Pre and post-tests consisted of a 40-minute visit to the laboratory, whereby participants were required to physically execute 30 dart throws split into six blocks of five dart throws and performance was measured as the total score. Participants received 2 min of rest between phases, in which they were allowed to sit, and some rest between blocks (while total score was being measured), but remained standing. Based on previous work (26), participants were instructed to perform each intervention session lasting exactly 4 minutes and 12 seconds at home or at their own convenience for three times per week, for a 6-week period. All participants were instructed to separate each intervention session by a minimum of 48 h rest to avoid fatigue and/or boredom. All participants reported being physically-fit and were asked to continue their weekly routine as normal, and refrain from making any adjustments to this in terms of either increasing or reducing their physical workload. Participants imagery or participation diaries (for the control group and AO group) also served as manipulation checks ensuring that participants had correctly performed their intervention, as well as discussing any deviations from normal behaviours, such as sleeping patterns, and physical exertion. Any further issues or comments concerning the intervention video were also noted.

Action observation intervention

Participants in the AO group were provided with a pre-recorded video. The video contained a model executing six blocks of five dart throws, totaling thirty throws. Participants were instructed to observe the pre-recorded video (female hand/male hand) equivalent to their sex. Video recordings provided participants with a view of the models right hand and forearm from a first-person perspective. The video recording consisted of observing an intermediate player executing a total of 30 dart throws while attempting to hit the bullseye, with a total score of 222/300.

Imagery intervention group

Participants begun by generating a simple image of themselves holding a dart with attention being drawn to the aspects of the imaged scenario that they found easy to image. Further details that were relevant scenario were then gradually added (e.g., sensory modalities, physiological sensations, and emotional response). The completed script was then subsequently used by participants to practice during each imagery session. All components of the PETTLEP model of imagery (39) were employed in the interventions that included an imagery component (see table 1details of PETTELP intervention). Additionally, to ensure interventions that incorporated MI were equivalent in time, participants were instructed to perform MI in 'real time', rather than in slow motion or faster than normal. For example, audio feedback of the darts making contact with the board were presented in the intervention videos that contained MI.

Alternate imagery and action observation (A-AOMI) group

The A-AOMI group were provided with the pre-recorded observational video. The video consisted of six blocks of five dart throws, equalling 30 throws. Participants were instructed to observe a block of five dart throws and to engage in PETTLEP MI for a further five dart throws in an alternate manner until 30 throws were completed. The PETTLEP MI component of the video was regulated by real time, as the screen during this intervention video exhibited a static dartboard and incorporated audio cues of the darts striking the board to ensure participants were imaging with the equivalent timing to the observational element of their intervention.

Simultaneous imagery and action observation (S-AOMI) group

The S-AOMI group were provided with the pre-recorded video containing six blocks of five dart throws, equalling 30 throws. The video content was equivalent; however, participants were provided with imagery instructions, based on their redeveloped script.

Participants also completed an imagery script. Participants were instructed to observe the dart throws shown in the video whilst simultaneously imaging the physiological feelings and sensations that they would experience when executing performing the dart throw.

Control group

The control group observed a segment of a video interview with a professional darts player three times per week, which took the equivalent amount of time as the interventions presented to the treatment groups. The video did not provide technical advice on dart throw performance. Participants in the control group were informed that the study was designed to investigate the perception of dart throwing participation amongst university students. This procedure is similar to the placebo used research by Smith and Holmes (26).

Data analysis

Based on the previous trial selection process of Lohse et al. (22), throws 2, 3 and 4 within blocks 2, 3 and 4, were selected for analysis. Mean EMG activation and kinematic measures across three trials per block were determined for each subject. The decision to select and analyse throws 2, 3 and 4 within blocks 2, 3 and 4, was based upon previous research that suggests to omit on- and off-transient phenomena associated with muscular exertion during the first and last repetitions of each trial, the first and last throw should be discarded (40). Therefore, this ensures that measures are consistent and accurate outcomes (41).

A 5 (group) x 2 (time) mixed design analysis of variance (ANOVA) was performed on pre and post-test conditions to observe any changes in performance across treatment groups across all data variables. Where the ANOVA revealed significant effects, post hoc Tukey HSD tests were used to establish where any significant differences existed. Performance was the mean of total throwing accuracy score (out of 300 points) for each group. For the MIQ-V and MIQ-K data, a one-way ANOVA was performed to establish any differences in imagery ability prior to the start of any intervention. Significance was measured at the .05 level. Effect sizes were calculated using partial eta squared (η_p^2) for omnibus comparisons and Cohen's *d* for pairwise comparisons (42).

Results

All performance, EMG and Kinematic data did not violate normality of distribution as assessed by Shapiro-Wilk test. Furthermore, a one-way ANOVA revealed no significant difference between groups in any parameter of the baseline characteristics (see Table 2).

Self-report data

Inspection of the imagery diaries and manipulation checks conducted revealed that participants reported performing their imagery as instructed by the researcher. Furthermore, all participants reported completing the pre-designated minimum of 14 sessions and as such all data were included in the study. There were no significant imagery content differences for imaging, ease of visual or kinaesthetic imagery, or imagery vividness (p's > .05). These data are presented in Table 3.

Performance measures

A 2 x 5 repeated measures ANOVA revealed a significant main effect for time, F (1, 45) = 65.65, $p < .001$, $\eta_p^2 = .593$ and a significant time x group interaction, F (4, 45) = 3.55, $p = 0.01$, $\eta_p^2 = .240$. Within group post hoc tests showed that participants in the A-AOMI *(p* = 0.01) , S-AOMI (*p* = 0.03), AO (*p* = 0.04), group, and MI (*p* = 0.04) group improved significantly from pre-test to post-test, with Cohen's d effect sizes of 1.73, 0.96, 0.39 and 0.57 respectively. There was however, no significant change for control group from pre to post test (*p*= .25). Between-group post hoc tests showed the S-AOMI group improved to a greater degree than the control group (*p* = 0.02). Participants in the A-AOMI group improved to a greater degree than the AO (*p* = 0.04), MI (*p* = 0.04), and control groups (*p* = 0.02). (See Figure 4).

EMG measures

EMG activity was calculated from the point of maximum flexion to maximum extension. A 2 x 5 repeated measures ANOVA revealed no significant time x group interaction for the anterior deltoid *F* (4, 41) = .194, *p* =.94, bicep brachii *F* (4, 41) = .311, *p*=.86, flexor carpi radialis *F* (4, 41) = 1.11, *p*=.36, and extensor carpi radialis *F* (4, 43) = 1.44, *p*=.37, However, a significant main effect for time, *F* (1, 45) = 14.83, (p = .001), η_p^2 = .248 and a significant time x group interaction, *F* (4, 45) = 4.38, *p* = 0.04, η_p^2 = .280 was found for the triceps brachii. Post hoc tests revealed that EMG mean activity from point of flexion to point of extension (whole movement) significantly decreased from pre-test to post test in the S-AOMI (p=0.00) and A-AOMI (p= 0.008) group, with Cohen's d effect sizes of 1.37 and 1.02 respectively. MI and AO groups did not exhibit changes in EMG mean activity during the same phase. Between group post hoc tests revealed that mean EMG activity in the S-AOMI group significantly decreased to a greater degree than MI (p= 0.001) and AO (p= 0.002), but not in the A-AOMI group (*p* =.189) (see Table 4).

EMG data

EMG activity was calculated from the point of maximum flexion to point of release. A 2 x 5 repeated measures ANOVA revealed no significant time x group interaction for the anterior deltoid F(4, 44) = .275, p=.89,triceps brachii *F*(4, 44) = .433, *p*=.78, flexor carpi radialis *F* (4, 43) = .085, *p*=.98, and extensor carpi radialis, *F* (4, 43) = .085, *p*=.76. However, a significant main effect for time, *F* (1, 45) = 19.65, (*p*=.000), η_p^2 = .304 and a significant time x group interaction, *F* (4, 45) = 2.76, (*p* = 0.03), η_p^2 = .197 was found in the bicep brachii. Post hoc tests revealed that EMG mean activity from point of flexion to point of release significantly decreased from pre-test to post-test in the AO (p= 0.04), A-AOMI(p= 0.001), and S-AOMI (p= 0.005) groups ($p <.05$), with Cohen's d effect sizes of 1.08, 1.54, 1.43 respectively. EMG mean activity in the control and MI group did not significantly reduce from pre to post-test during the same phase. Between-group post hoc tests revealed that mean EMG activity in the S-AOMI group significantly decreased to a greater degree than the control group (p=0.02), and MI group (p= 0.03). Participants in the A-AOMI group also decreased to a significantly greater degree than participants in the control group (p= 0.02) (See Table 4).

Kinematic measures

Peak angular velocity

Results showed a significant main effect for time (1, 41) = 5.3, (*p* = .024), $\eta_p^2 = .119$ and a significant time x group interaction, *F* (4, 45) = 2.30, (*p* = 0.07), $\eta_p^2 = .184$. Post hoc tests revealed that peak angular velocity significantly decreased from pre to post test, in the A-AOMI group (p= 0.007) and the S-AOMI group (p= 0.009). Peak angular velocity did not significantly decrease from pre to post test in the MI (p= .251), AO (p= .371), and control groups (*p*= .586). Between group post hoc tests showed that A-AOMI and S-AOMI groups decreased to a significantly greater degree than MI *(ps* = 0.03) and control group (*ps*= 0.02) (see figure 5)

Movement time

For flexion to point of release, there was significant main effect for time, *F* (1, 36) = 4.785, *p* = 0.03, $\eta_p^2 = .127$ but no significant time x group interaction, *F* (4, 36) = .857, *p*=.500 across movement time during the aiming task. There was no significant main effect for time, *F* (1, 36) = 2.117, *p* = .154 and no significant time x group interaction, *F* (4, 36) = .154 *p*=.960 across the follow through phase movement time during the aiming task. Furthermore, there were no significant main effect for time, *F* (1, 34) = .014, *p* = .907 and no significant time x group interaction, *F* (4, 34) = 1.58, *p*=.200 for time to peak angular velocity amongst groups.

Discussion

The principal finding of the current study is that six weeks of AOMI training resulted in an improved throwing performance to a greater extent than AO and MI interventions alone. More specifically, our study found that both AOMI combination groups showed a significant reduction in the agonist bicep brachii during the flexion to point of release phase and triceps brachii muscles during the flexion to extension phase of the dart throwing movement. Both AOMI combination groups also showed a significant reduction in peak angular velocity compared to both independent AO, MI and control groups in the darts task. The present study, therefore, provides the first empirical evidence showing differing combination of AOMI interventions across a 6 week home-based intervention period can produce modest, but practically important changes in muscular activation and movement kinematic parameters. The facilitation of aiming performance above and beyond AO and MI alone corroborates with previous research studies that have reported similar improvements in performance after combined AOMI interventions (8,9,11,12,26) and extends the findings of Romano-Smith et al. (11).

We propose the following explanations for the improvements shown in performance measures. Firstly, the benefits of motor imagery alone have shown considerable effects on motor performance. Research shows that during MI, motor cortical activation produces a subliminal cortical output that primes spinal networks (14). Additionally, the corticospinal excitability induced by MI shows considerable effects on a wide proportion of the corticospinal pathway, corresponding to the target muscles imaged (12). Similarly, AO can have beneficial effects on performance (e.g., evoking activity in the areas of the brain responsible for movement execution; 43). However, in the current study, these benefits were not as effective in isolation, in comparison to when combined. The added benefits of combining these two techniques were shown in the results. These are two possible explanations for this (1) the areas of the brain that AO and MI active demonstrate neural overlap during motor execution and MI as well as during motor execution and AO (21,44), this relates to the motor simulation theory proposed by Jeannerod (21) which suggests that action, either self-intended or observed activates the motor system as part of a broader simulation network. This suggests, the overlapping of brain and neural structures during both AO and MI would provide complementary activation compared to one or the other modality alone (45). (2) Alternatively, this could be owing to neuroplastic alterations previously reported for both AO and MI interventions, which may provoke changes on a cortical level in both the sensory and motor maps of the somatosensory cortex within healthy and clinical populations (12, 43). This, in turn, may promote functional plasticity within the brain leading to a greater dart throwing performance and development of a more efficient motor programme as learning progressed (46). Moreover, the initial architecture of the mental representation held by the novice participants may have been enhanced leading to improved performance in the early motor learning phase (18). This is supported by evidence that suggests that mental representation of novices becomes functionally more organised as performance improves following MI, physical practice and observational learning (17). Therefore, the inclusion of MI alongside AO may have resulted in a task-specific motor representation that produced more effective encoded visuomotor commands, related to the planning and preparation of the executed movement. While this is likely, mental representation structure was not directly measured within this study. Nevertheless, important inferences can be formed from the behavioral outcomes of this study.

The introduction of EMG and kinematic dimensions enhance the evolving literature examining AOMI. The results indicate that combining MI alongside AO has a significant effect on motor control as less EMG activation is necessary to carry out the throwing task effectively, regardless of how this combination is structured. The reductions observed in

EMG activity in the agonist muscles producing concentric muscular contractions are indicative of more expert like motor control characterised in maximum efficiency of movement and could be underpinned by the recruitment of fewer motor units recruited (48). Furthermore, the increased efficiency of movement by the combined groups suggests reduced muscle excitation, coordination of muscular fibers and a reduction in the mechanical demand that occurs during the execution of a refined motor programme (49). In the current study there was a significant reduction in EMG activity in the bicep producing a concentric muscular contraction from flexion to point of release, and triceps brachii muscles producing also concentric muscular contraction from flexion to extension within both AOMI groups, corroborating with research showing a reduction in EMG activity with skill development and execution (22,50). Taken as a whole, we believe that reduced muscular activity may be explained by two, well established theoretical notions: psychoneuromuscular theory (51) and the central explanation (21). Observing or imaging an action engages similar neural processes (inferior frontal gyrus (IGF) and, inferior parietal lobe (IPL) as those used in the execution of movement (52), which are consistent with the human mirror neuron system (HMN). MI also modulates muscular activation of the target muscles imaged (53). Expanding on this, the psychoneuromuscular theory (51)suggests that the activation of these areas in imagery has a ‘flowing’ effect on the muscles in question and is able to cause an action potential within the muscles without any motor output. With the addition of AO also shown to have similar impacts on muscular excitability (54), it is plausible that combining the interventions increases the afferent discharge effect, which can modify the motor representation, thus resulting in an increased performance in the two combination groups (55).

Our data showed a significant decrease in peak angular velocity in the AOMI intervention groups. This is surprising as previous research by Mousavi et al. (20) demonstrated a significant increase in critical elbow angular velocity as skill learning progressed. One possible explanation for this discrepancy could be the differences between the specific intervention instructions. Mousavi et al. (20) used virtual reality training which has as a greater visual acuity than observation of a pre-recorded video as used the present study (56). Participants were also able to direct their own movement and gain sensory consequences of the moment executed in the VR environment. However, it must be noted that this link could be considered vague as during VR participants are able to physically perform movements, which would have a greater impact on the brain regions referred to in the psychoneuromuscular theory above. Alternatively, a decrease in angular velocity as shown by participants in the AOMI group could be explained by their desire to execute the throwing skill more accurately (57) such that we suggest that greater velocity and more error prone accuracy could be a demonstration a speed-accuracy. Therefore, we suggest that the faster the participants in the MI, AO, and control group executed to throw the dart throw, the less accurate and consistently they performed (58)

While these results provide a novel contribution to the evolving AOMI literature, some limitations need to be acknowledged. Firstly, it is feasible that if participants have been exposed to a longer training period then greater performance, neuromuscular and movement kinematics may have been revealed. Another limitation is that critical elbow kinematics were only examined which does not encapsulate a comprehensive view of movement while executing a dart throw. Future research could extend beyond critical elbow kinematics and examine movement economy and kinematics of the wrist and hand movements. This may provide alternative explanations of movement economy regarding AOMI interventions, as neither the combined or individual interventions produced significant changes in movement time or angular velocity at the elbow.

Perspective

In conclusion, the study demonstrates the efficacy of combining MI and AO either simultaneously or in an alternate manner, contributing to a superior target aiming performance over and above singular interventions. These findings are supported by a reduction neuromuscular activity of the bicep and triceps muscles, and a decrease in the speed of movement. The findings imply AOMI enhances the formation and adaptation of an internal model of novel movement dynamics. Such a technique may prove beneficial during motor learning of sporting based tasks (8,10,24,59) and motor relearning to counteract age-related functional deterioration (60), post-surgery immobilisation (12) stroke rehabilitation (11), and Parkinson’s disease (61). For example, A-AOMI combination could provide a viable option for rehabilitation treatment for patients with Parkinson’s disease (PD). Those with PD are argued not to lose the functioning needed to complete basic MI instructions (62) therefore the use of such interventions can be delivered in the comfort of the home by utilising simple mobile technologies (61) which will aid in the relearning of movements needed in the recovery and coping process of PD. Due to the extensive instructions that accompany S-AOMI, those patients with PD may struggle to meet the demands upon working memory and those associated with engaging in multiple tasks simultaneously; an issue reported often amongst this population (63). Furthermore, we suggest that S-AOMI combination may prove beneficial for the training of healthy and novice populations to enhance performance skills, which could emulate the concept of learning by imitation particularly for learners during periods of injury or immobilisation.

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Conflicts of interest

None.

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Figure 4. Mean (± s.e.m) pre and post-test scores of for each experimental condition (*$p < .05$).

Figure 5. Mean (± s.e.m) pre and post angular velocity for each experimental group (*$p < .05$, ** $p <.001$).