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

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28   **Abstract**

29   Recent research has begun to employ interventions that combine action observation and

30   motor imagery (AOMI) with positive results. However, little is known about the

31   underpinning facilitative effect on performance. Participants (n=50) were randomly allocated

32   to one of five training groups: action observation (AO), motor imagery (MI), simultaneous

33   action observation and motor imagery (S-AOMI), alternate action observation and motor

34   imagery (A-AOMI) and control. The task involved dart-throwing at a concentric circle

35   dartboard at pre- and post-test. Interventions were conducted 3 times per week for 6 weeks.

36   Data were collected from performance outcomes and mean muscle activation of the upper

37   and forearm muscles. Angular velocity and peak angular velocity measurements of the elbow

38   were also collected from the throwing arm. Results showed performance of the A-AOMI

39   group improved to a significantly greater degree than the AO ($p = 0.04$), MI ($p = 0.04$), and

40   control group ($p = 0.02$), and the S-AOMI group improved to a greater degree than the

41   control group ($p = 0.02$). Mean muscle activation of the triceps brachii significantly reduced

42   in the S-AOMI and A-AOMI ($p < 0.01$) groups and participants in the AO (p= 0.04), A-

43   AOMI and S-AOMI ($p < 0.01$) groups significantly reduced activation in the bicep brachii

44   from pre to post-test. Peak angular velocity significant decreased from pre- to post-test in

45   both A-AOMI and S-AOMI ($p < 0.01$) groups. The results reaffirm the benefits of AOMI for

46   facilitating skill learning and provide an insight how these interventions produce favourable

47   changes in EMG and movement kinematics.

48   Keywords

49   Motor skill learning, Observational learning, Aiming, Simulation

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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

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77 recent study using a sporting task has suggested that the manner in which AO and MI is

78 combined has little bearing on the magnitude of motor learning witnessed. Specifically,

79 Romano-Smith, Wood, Wright, & Wakefield (10) employed a 6-week intervention where one

80 group was instructed to observe whilst simultaneously completing concurrent MI movement

81 (S-AOMI), whilst the other group practiced AOMI by alternating AO and MI components

82 (A-AOMI). Results showed that both AOMI combinations improved significantly more than

83 participants in the AO and MI only groups when learning dart-throwing.

84 Despite the developing understanding that AOMI provides superior performance effects, it

85 remains unclear precisely *how* AOMI facilitates the motor learning processes through the

86 measurement of upper limb movement kinematics and muscular activity through EMG

87 signals. In an attempt to explain such facilitatory effects, neurophysiological research has

88 indicated that during AOMI there is an increase in neural activity in the cortical areas linked

89 to planning and executing movement, compared to either AO or MI performed alone (13).

90 Recent research extends these findings, demonstrating corticospinal modulations induced by

91 MI have a considerable effect on a wide proportion of the corticospinal pathway

92 corresponding to the targeted muscles, (12,14). Indeed, research shows that motor-related

93 areas (premotor cortex and parietal cortex; 15) are recruited not only when actions are

94 executed, but also when they mentally rehearsed and observed (4,15,16,17). This finding has

95 been broadly interpreted as resonating and/or refining a neural representation for skilled

96 execution (18,19). In addition, the potential kinaesthetic component of MI can aid the

97 prediction of sensory consequences, as it does during the physical execution (20). Thus, by

98 combining the two techniques, may be the best way to improve the motor skill learning by

99 producing greater activity in the motor system than either independent AO or independent MI (13)

100 and stimulating the widest possible range of the corticospinal pathway (12) and refining

101 internal models (18).

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103   Similar findings have also been reported in physical practice intervention studies examining

104   kinematic and kinetic responses to skill learning utilising a target aiming task. The use of

105   physical practice literature is supported by Jeannerod's (21) Simulation Theory. This theory

106   proposes to explain how a functional equivalence exists between AO, MI and action

107   execution (AE) of a motor skill, whereby all three states activate similar neural pathway.

108   Lohse, Sherwood, & Healy (22) examined the kinematic and EMG activity of the agonist

109   (biceps brachii) and antagonist (triceps brachii) employing a darts throwing task. The results

110   demonstrated a reduced EMG activity in both the agonist (bicep brachii) and antagonist

111   (triceps brachii) muscles. Mousavi, Shahbazi, Arabameri, & Shirzad (23) also used a dart

112   throwing task to examine the kinematic profiles such (e.g. Critical elbow angular velocity,

113   and movement time) following a virtual reality training of a dart throwing task. The results

114   demonstrated a reduction in movement time, significant increases in critical elbow angular

115   velocity and significant increase in follow through time (point of release time to full

116   extension).

117   The aim of this study was to investigate performance results, EMG activity and movement

118   kinematics that may underpin the superior effects of AOMI demonstrated by (10) using a

119   dart throwing task. We hypothesise that AO, MI, A-AOMI, and S-AOMI interventions will

120   produce performance improvements from pre to post test, relative to a control group, and

121   these improvements will be greater in both combined AOMI groups compared to either

122   intervention alone. Further, we hypothesise that owing to the predicted performance

123   improvements in aiming performance, the AOMI groups will consequently evidence a

124   reduction in EMG activity in both the biceps brachii and triceps brachii muscles

125   demonstrated in the study by Lohse et al. (22). Moreover, we expect an increase in movement

126   time, increase in critical elbow angular velocity, and a significant increase in follow through

127 time (point of release time to full extension) from pre to post-test also demonstrated in an

128 aiming based task (23).

129 **Method**

130 Participants

131   Fifty university students (25 males, 25 females; *Mean age* = 28.80 *years*, *SD* =6.75)

132 were recruited. The number of participants was established to be comparable to that of

133 previous research of a similar nature (9,10,24). All participants reported being right-handed

134 using the Edinburgh Handedness Inventory (25) and reported normal or corrected to normal

135 vision and were novice performers who had limited dart throwing experience. Furthermore,

136 all participants had not previously participated in any MI training. All procedures were

137 carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki and

138 were approved by the University Ethics Committee at the host institution. Written informed

139 consent was obtained from all participants prior to the study, and no payment was provided

140 for participation in this study.

141 Measure**s**

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

143   The MIQ-R is an eight-item inventory that assesses an individual's ability to perform

144 visual and kinaesthetic imagery. In this study, the MIQ-R was employed as a screening tool,

145 also used by previous research (26). The validity and consistency of the MIQ-R has been

146 demonstrated by Gregg, Hall, & Butler (27) and has been used previously in imagery studies

147 investigating aiming tasks (28).

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149 *The Aiming Task*

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150 A concentric circle dartboard was used to collect performance data. The dartboard

151 was positioned at the centre fixed point, 1.73m from the floor and 2.37m horizontally from

152 the throwing line, as per standard darts rules. Performance (throwing accuracy score) was

153 measured in 10 concentric circles (2cm wide), with the centre scoring 10 points and the outer

154 circle scoring 1 point. Darts that landed outside the circumference of the dartboard were

155 awarded a score of zero (see figure 1)

156 *Biomechanical Measures*

157 Upper limb, 3D joint kinematics, muscle activation patterns, and digital video of the

158 throwing action were captured synchronously via the Noraxon MR3.10 analysis software

159 (Scottsdale, AZ, USA). Phases of movement and temporal characteristics of the throw were

160 determined from a tripod mounted webcam (30 frames per second capture rate), positioned

161 perpendicular to the direction of the throw, and in line with the shoulder joint. Key time

162 points were then extracted from the video and used to define the following phases of

163 movement: (A) flexion to (B) extension and (A) Flexion to (C) point of release for each

164 participant (Figure 2). In conjunction with the video, elbow angle data (flexion-extension)

165 was also used to identify the time point of maximum flexion and maximum extension.

166 *Electromyography (EMG) recordings*

167 Trigno ^{TM} EMG electrodes (Delsys Inc.) with 10 mm diameter and 20mm inter-

168 electrode distance as recommended by Hermens, Freriks, Disselhorst-Klug, & Rau (29) were

169 attached to the prepared skin overlaying the five selected muscles. Muscles were selected based

170 upon research of a similar nature measuring kinematic and electromyography variables during

171 behavioral based darts tasks (22,23,30). To limit cross talk, electrodes were placed parallel to

172 the muscle fibres on the belly of the muscles following accepted anatomical criteria (31,32) for

173 controlling the movement of the wrist, elbow, and shoulder. These muscles included flexor

174 carpi radialis (FCR), extensor carpi radialis (ECR), bicep brachii and triceps brachii and

175 anterior deltoid (see figure 2).

176 *Raw EMG signal processing*

177 Raw EMG were captured synchronously via a Noraxon AIS unit (Analogue Input System)

178 into the Noraxon MR3.10 software, at a sampling frequency of 1500Hz. Signals were band-

179 pass filtered (Hamming 20-350 Hz cut- off), and converted into root mean square (RMS)

180 signals with a window size of (100 ms), which some research suggests that is a more accurate

181 index of physiological changes than measures of raw amplitude (33) and was used in previous

182 studies measuring muscle activation using a dart throwing task (34). Signals were then

183 normalised to the peak activation level for each muscle, recorded during the dart throw

184 movement sequence. Mean activation within the defined phases (flexion to release and

185 flexion to extension) was then calculated for each throw.

186 *Myomotion joint kinematics*

187 The kinematic variables of interest included movement time, follow through time,

188 time to peak angular velocity and angular velocity of the dart throw. These variables were

189 measured at two critical times in the throwing motion: at the moment of retraction (point of

190 maximum elbow flexion) and at the moment of release. To measure these variables, Noraxon

191 MyoMotion (Scottsdale, AZ, USA) motion analysis system was employed to analyse

192 movement kinematic of the throwing arm. MyoMotion inertial measurement units (IMU)

193 were placed according to the rigid-body model defined in the Noraxon MR3 software. Six

194 IMU sensors were placed on the dominant throwing arm and trunk: upper-arm, forearm hand,

195 upper thoracic, pelvis, and lower thoracic segments. The sensors were attached with special

196 fixation straps (for pelvis) and elastic straps. Calibration was carried out using the upright

197 standing position, in order to determine the zero / neutral angle in the measured joints.

198 Sampling frequency for the inertial sensors was set at 200 Hz. Instantaneous changes in joint

199 angles and angular velocities in the upper limb were recorded during each of the throwing

200 trials. (See Figure 3).

201 Myomotion joint kinematics – temporal analysis

202 A temporal analysis of the throw phases outlined in Figure 2 allowed movement time and

203 follow through time and angular velocity to be calculated. Movement time was defined as the

204 time from the moment of full flexion to the point of release (i.e. Release time - Full Flexion

205 time). Follow through time was defined as the time from the point of release to full extension

206 (i.e. Full extension time - Release time). Angular velocity of the throw (in degrees per

207 second) was calculated by subtracting elbow flexion at retraction from flexion at the moment

208 of release and dividing by throwing time.

209 **Procedure**

210 Prior to the commencing of the study, all participants gave their informed consent for

211 participation and completed the MIQ-R. All participants were randomly allocated to one of

212 five experimental groups (n =10 per condition): action observation (AO); motor imagery

213 (MI); simultaneous imagery and observation (S-AOMI); and alternate imagery and

214 observation (A-AOMI) and control. All participants, except those in the control group and

215 AO group, received stimulus-response training (35). Participants in the AO and control group

216 were not required to produce a motor image and did not receive LSRT. It was decided that for

217 the nature of this study that LSRT would be used due to the amount of literature that uses the

218 technique, its ability to improve motor imagery ability, to initiate the motor programme for

219 the movement being imaged, and is relatively easy for the participant to understand (36–38).

220 Participants engaging in LSRT based on the bio-informational theory (35) were required to

221 utilise three sources of information within a scenario used to aid their MI For example: (1)

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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.

246   Pre and post-tests consisted of a 40-minute visit to the laboratory, whereby participants were

247   required to physically execute 30 dart throws split into six blocks of five dart throws and

248   performance was measured as the total score. Participants received 2 min of rest between

249   phases, in which they were allowed to sit, and some rest between blocks (while total score

250   was being measured), but remained standing. Based on previous work (26), participants were

251   instructed to perform each intervention session lasting exactly 4 minutes and 12 seconds at

252   home or at their own convenience for three times per week, for a 6-week period. All

253   participants were instructed to separate each intervention session by a minimum of 48 h rest

254   to avoid fatigue and/or boredom. All participants reported being physically-fit and were

255   asked to continue their weekly routine as normal, and refrain from making any adjustments to

256   this in terms of either increasing or reducing their physical workload. Participants imagery or

257   participation diaries (for the control group and AO group) also served as manipulation checks

258   ensuring that participants had correctly performed their intervention, as well as discussing

259   any deviations from normal behaviours, such as sleeping patterns, and physical exertion. Any

260   further issues or comments concerning the intervention video were also noted.

261   *Action observation intervention*

262   Participants in the AO group were provided with a pre-recorded video. The video

263   contained a model executing six blocks of five dart throws, totaling thirty throws. Participants

264   were instructed to observe the pre-recorded video (female hand/male hand) equivalent to their

265   sex. Video recordings provided participants with a view of the models right hand and forearm

266   from a first-person perspective. The video recording consisted of observing an intermediate

267   player executing a total of 30 dart throws while attempting to hit the bullseye, with a total

268   score of 222/300.

269   *Imagery intervention group*

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270   Participants begun by generating a simple image of themselves holding a dart with

271   attention being drawn to the aspects of the imaged scenario that they found easy to image.

272   Further details that were relevant scenario were then gradually added (e.g., sensory

273   modalities, physiological sensations, and emotional response). The completed script was then

274   subsequently used by participants to practice during each imagery session. All components of

275   the PETTLEP model of imagery (39) were employed in the interventions that included an

276   imagery component (see table 1details of PETTELP intervention). Additionally, to ensure

277   interventions that incorporated MI were equivalent in time, participants were instructed to

278   perform MI in 'real time', rather than in slow motion or faster than normal. For example,

279   audio feedback of the darts making contact with the board were presented in the intervention

280   videos that contained MI.

281   *Alternate imagery and action observation (A-AOMI) group*

282   The A-AOMI group were provided with the pre-recorded observational video. The

283   video consisted of six blocks of five dart throws, equalling 30 throws. Participants were

284   instructed to observe a block of five dart throws and to engage in PETTLEP MI for a further

285   five dart throws in an alternate manner until 30 throws were completed. The PETTLEP MI

286   component of the video was regulated by real time, as the screen during this intervention

287   video exhibited a static dartboard and incorporated audio cues of the darts striking the board

288   to ensure participants were imaging with the equivalent timing to the observational element

289   of their intervention.

290   *Simultaneous imagery and action observation (S-AOMI) group*

291   The S-AOMI group were provided with the pre-recorded video containing six blocks

292   of five dart throws, equalling 30 throws. The video content was equivalent; however,

293   participants were provided with imagery instructions, based on their redeveloped script.

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294 Participants also completed an imagery script. Participants were instructed to observe the dart

295 throws shown in the video whilst simultaneously imaging the physiological feelings and

296 sensations that they would experience when executing performing the dart throw.

297 *Control group*

298 The control group observed a segment of a video interview with a professional darts

299 player three times per week, which took the equivalent amount of time as the interventions

300 presented to the treatment groups. The video did not provide technical advice on dart throw

301 performance. Participants in the control group were informed that the study was designed to

302 investigate the perception of dart throwing participation amongst university students. This

303 procedure is similar to the placebo used research by Smith and Holmes (26).

304 **Data analysis**

305 Based on the previous trial selection process of Lohse et al. (22), throws 2, 3 and 4

306 within blocks 2, 3 and 4, were selected for analysis. Mean EMG activation and kinematic

307 measures across three trials per block were determined for each subject. The decision to

308 select and analyse throws 2, 3 and 4 within blocks 2, 3 and 4, was based upon previous

309 research that suggests to omit on- and off-transient phenomena associated with muscular

310 exertion during the first and last repetitions of each trial, the first and last throw should be

311 discarded (40). Therefore, this ensures that measures are consistent and accurate outcomes

312 (41).

313 A 5 (group) x 2 (time) mixed design analysis of variance (ANOVA) was performed on pre

314 and post-test conditions to observe any changes in performance across treatment groups

315 across all data variables. Where the ANOVA revealed significant effects, post hoc Tukey

316 HSD tests were used to establish where any significant differences existed. Performance was

317 the mean of total throwing accuracy score (out of 300 points) for each group. For the MIQ-V

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318   and MIQ-K data, a one-way ANOVA was performed to establish any differences in imagery

319   ability prior to the start of any intervention. Significance was measured at the .05 level. Effect

320   sizes were calculated using partial eta squared (η_p^2) for omnibus comparisons and

321   Cohen's *d* for pairwise comparisons (42).

Results

323   All performance, EMG and Kinematic data did not violate normality of distribution as

324   assessed by Shapiro-Wilk test. Furthermore, a one-way ANOVA revealed no significant

325   difference between groups in any parameter of the baseline characteristics (see Table 2).

Self-report data

327   Inspection of the imagery diaries and manipulation checks conducted revealed that

328   participants reported performing their imagery as instructed by the researcher. Furthermore,

329   all participants reported completing the pre-designated minimum of 14 sessions and as such

330   all data were included in the study. There were no significant imagery content differences for

331   imaging, ease of visual or kinaesthetic imagery, or imagery vividness (p's > .05). These data

332   are presented in Table 3.

Performance measures

334   A 2 x 5 repeated measures ANOVA revealed a significant main effect for time, F (1,

335   45) = 65.65, $p < .001$, $\eta_p^2 = .593$ and a significant time x group interaction, F (4, 45) = 3.55, p

336   = 0.01, $\eta_p^2 = .240$. Within group post hoc tests showed that participants in the A-AOMI *(p =*

337   0.01) , S-AOMI (*p* = 0.03), AO (*p* = 0.04), group, and MI (*p* = 0.04) group improved

338   significantly from pre-test to post-test, with Cohen's d effect sizes of 1.73, 0.96, 0.39 and

339   0.57 respectively. There was however, no significant change for control group from pre to

340   post test (*p*= .25). Between-group post hoc tests showed the S-AOMI group improved to a

341   greater degree than the control group (*p* = 0.02). Participants in the A-AOMI group improved

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342 to a greater degree than the AO ($p = 0.04$), MI ($p = 0.04$), and control groups ($p = 0.02$). (See

343 Figure 4).

344 *EMG measures*

345   EMG activity was calculated from the point of maximum flexion to maximum

346 extension. A 2 x 5 repeated measures ANOVA revealed no significant time x group interaction

347 for the anterior deltoid $F_{(4, 41)} = .194$, $p = .94$, bicep brachii $F_{(4, 41)} = .311$, $p = .86$, flexor

348 carpi radialis $F_{(4, 41)} = 1.11$, $p = .36$, and extensor carpi radialis $F_{(4, 43)} = 1.44$, $p = .37$,

349 However, a significant main effect for time, $F_{(1, 45)} = 14.83$, ($p = .001$), $\eta_p^2 = .248$ and a

350 significant time x group interaction, $F_{(4, 45)} = 4.38$, $p = 0.04$, $\eta_p^2 = .280$ was found for the

351 triceps brachii. Post hoc tests revealed that EMG mean activity from point of flexion to point

352 of extension (whole movement) significantly decreased from pre-test to post test in the S-

353 AOMI (p=0.00) and A-AOMI (p= 0.008) group, with Cohen's d effect sizes of 1.37 and 1.02

354 respectively. MI and AO groups did not exhibit changes in EMG mean activity during the same

355 phase. Between group post hoc tests revealed that mean EMG activity in the S-AOMI group

356 significantly decreased to a greater degree than MI (p= 0.001) and AO (p= 0.002), but not in

357 the A-AOMI group ($p = .189$) (see Table 4).

358 *EMG data*

359   EMG activity was calculated from the point of maximum flexion to point of release. A

360 2 x 5 repeated measures ANOVA revealed no significant time x group interaction for the

361 anterior deltoid $F_{(4, 44)} = .275$, p=.89, triceps brachii $F_{(4, 44)} = .433$, $p = .78$, flexor carpi

362 radialis $F_{(4, 43)} = .085$, $p = .98$, and extensor carpi radialis, $F_{(4, 43)} = .085$, $p = .76$. However,

363 a significant main effect for time, $F_{(1, 45)} = 19.65$, ($p = .000$), $\eta_p^2 = .304$ and a significant time

364 x group interaction, $F_{(4, 45)} = 2.76$, ($p = 0.03$), $\eta_p^2 = .197$ was found in the bicep brachii. Post

365 hoc tests revealed that EMG mean activity from point of flexion to point of release significantly

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366 decreased from pre-test to post-test in the AO (p= 0.04), A-AOMI(p= 0.001), and S-AOMI

367 (p= 0.005) groups (p <.05), with Cohen's d effect sizes of 1.08, 1.54, 1.43 respectively. EMG

368 mean activity in the control and MI group did not significantly reduce from pre to post-test

369 during the same phase. Between-group post hoc tests revealed that mean EMG activity in the

370 S-AOMI group significantly decreased to a greater degree than the control group (p=0.02), and

371 MI group (p= 0.03). Participants in the A-AOMI group also decreased to a significantly greater

372 degree than participants in the control group (p= 0.02) (See Table 4).

373 *Kinematic measures*

374 *Peak angular velocity*

375 Results showed a significant main effect for time (1, 41) = 5.3, (p = .024), η_P^2 = .119

376 and a significant time x group interaction, F (4, 45) = 2.30, (p = 0.07), η_P^2 = .184. Post hoc tests

377 revealed that peak angular velocity significantly decreased from pre to post test, in the A-AOMI

378 group (p= 0.007) and the S-AOMI group (p= 0.009). Peak angular velocity did not significantly

379 decrease from pre to post test in the MI (p= .251), AO (p= .371), and control groups (p= .586).

380 Between group post hoc tests showed that A-AOMI and S-AOMI groups decreased to a

381 significantly greater degree than MI *(ps* = 0.03) and control group *(ps*= 0.02) (see figure 5)

382 *Movement time*

383 For flexion to point of release, there was significant main effect for time, F (1, 36) = 4.785, p

384 = 0.03, η_p^2 = .127 but no significant time x group interaction, F (4, 36) = .857, p=.500 across

385 movement time during the aiming task. There was no significant main effect for time, F (1,

386 36) = 2.117, p = .154 and no significant time x group interaction, F (4, 36) = .154 p=.960

387 across the follow through phase movement time during the aiming task. Furthermore, there

388 were no significant main effect for time, F (1, 34) = .014, p = .907 and no significant time x

389 group interaction, F (4, 34) = 1.58, p=.200 for time to peak angular velocity amongst groups.

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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

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415 explanations for this (1) the areas of the brain that AO and MI active demonstrate neural

416 overlap during motor execution and MI as well as during motor execution and AO (21,44),

417 this relates to the motor simulation theory proposed by Jeannerod (21) which suggests that

418 action, either self-intended or observed activates the motor system as part of a broader

419 simulation network. This suggests, the overlapping of brain and neural structures during both

420 AO and MI would provide complementary activation compared to one or the other modality

421 alone (45). (2) Alternatively, this could be owing to neuroplastic alterations previously

422 reported for both AO and MI interventions, which may provoke changes on a cortical level in

423 both the sensory and motor maps of the somatosensory cortex within healthy and clinical

424 populations (12, 43). This, in turn, may promote functional plasticity within the brain leading

425 to a greater dart throwing performance and development of a more efficient motor

426 programme as learning progressed (46). Moreover, the initial architecture of the mental

427 representation held by the novice participants may have been enhanced leading to improved

428 performance in the early motor learning phase (18). This is supported by evidence that

429 suggests that mental representation of novices becomes functionally more organised as

430 performance improves following MI, physical practice and observational learning (17).

431 Therefore, the inclusion of MI alongside AO may have resulted in a task-specific motor

432 representation that produced more effective encoded visuomotor commands, related to the

433 planning and preparation of the executed movement. While this is likely, mental

434 representation structure was not directly measured within this study. Nevertheless, important

435 inferences can be formed from the behavioral outcomes of this study.

436 The introduction of EMG and kinematic dimensions enhance the evolving literature

437 examining AOMI. The results indicate that combining MI alongside AO has a significant

438 effect on motor control as less EMG activation is necessary to carry out the throwing task

439 effectively, regardless of how this combination is structured. The reductions observed in

440   EMG activity in the agonist muscles producing concentric muscular contractions are

441   indicative of more expert like motor control characterised in maximum efficiency of

442   movement and could be underpinned by the recruitment of fewer motor units recruited (48).

443   Furthermore, the increased efficiency of movement by the combined groups suggests reduced

444   muscle excitation, coordination of muscular fibers and a reduction in the mechanical demand

445   that occurs during the execution of a refined motor programme (49). In the current study there

446   was a significant reduction in EMG activity in the bicep producing a concentric muscular

447   contraction from flexion to point of release, and triceps brachii muscles producing also

448   concentric muscular contraction from flexion to extension within both AOMI groups,

449   corroborating with research showing a reduction in EMG activity with skill development and

450   execution (22,50). Taken as a whole, we believe that reduced muscular activity may be

451   explained by two, well established theoretical notions: psychoneuromuscular theory (51) and

452   the central explanation (21). Observing or imaging an action engages similar neural processes

453   (inferior frontal gyrus (IGF) and, inferior parietal lobe (IPL) as those used in the execution of

454   movement (52), which are consistent with the human mirror neuron system (HMN). MI also

455   modulates muscular activation of the target muscles imaged (53). Expanding on this, the

456   psychoneuromuscular theory (51)suggests that the activation of these areas in imagery has a

457   'flowing' effect on the muscles in question and is able to cause an action potential within the

458   muscles without any motor output. With the addition of AO also shown to have similar

459   impacts on muscular excitability (54), it is plausible that combining the interventions

460   increases the afferent discharge effect, which can modify the motor representation, thus

461   resulting in an increased performance in the two combination groups (55).

462   Our data showed a significant decrease in peak angular velocity in the AOMI intervention

463   groups. This is surprising as previous research by Mousavi et al. (20) demonstrated a

464   significant increase in critical elbow angular velocity as skill learning progressed. One

19

465   possible explanation for this discrepancy could be the differences between the specific

466   intervention instructions. Mousavi et al. (20) used virtual reality training which has as a

467   greater visual acuity than observation of a pre-recorded video as used the present study (56).

468   Participants were also able to direct their own movement and gain sensory consequences of

469   the moment executed in the VR environment. However, it must be noted that this link could

470   be considered vague as during VR participants are able to physically perform movements,

471   which would have a greater impact on the brain regions referred to in the

472   psychoneuromuscular theory above. Alternatively, a decrease in angular velocity as shown by

473   participants in the AOMI group could be explained by their desire to execute the throwing

474   skill more accurately (57) such that we suggest that greater velocity and more error prone

475   accuracy could be a demonstration a speed-accuracy. Therefore, we suggest that the faster the

476   participants in the MI, AO, and control group executed to throw the dart throw, the less

477   accurate and consistently they performed (58)

478   While these results provide a novel contribution to the evolving AOMI literature, some

479   limitations need to be acknowledged. Firstly, it is feasible that if participants have been

480   exposed to a longer training period then greater performance, neuromuscular and movement

481   kinematics may have been revealed. Another limitation is that critical elbow kinematics were

482   only examined which does not encapsulate a comprehensive view of movement while

483   executing a dart throw. Future research could extend beyond critical elbow kinematics and

484   examine movement economy and kinematics of the wrist and hand movements. This may

485   provide alternative explanations of movement economy regarding AOMI interventions, as

486   neither the combined or individual interventions produced significant changes in movement

487   time or angular velocity at the elbow.

488   **Perspective**

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489   In conclusion, the study demonstrates the efficacy of combining MI and AO either

490   simultaneously or in an alternate manner, contributing to a superior target aiming

491   performance over and above singular interventions. These findings are supported by a

492   reduction neuromuscular activity of the bicep and triceps muscles, and a decrease in the

493   speed of movement. The findings imply AOMI enhances the formation and adaptation of an

494   internal model of novel movement dynamics. Such a technique may prove beneficial during

495   motor learning of sporting based tasks (8,10,24,59) and motor relearning to counteract age-

496   related functional deterioration (60), post-surgery immobilisation (12) stroke rehabilitation

497   (11), and Parkinson's disease (61). For example, A-AOMI combination could provide a

498   viable option for rehabilitation treatment for patients with Parkinson's disease (PD). Those

499   with PD are argued not to lose the functioning needed to complete basic MI instructions (62)

500   therefore the use of such interventions can be delivered in the comfort of the home by

501   utilising simple mobile technologies (61) which will aid in the relearning of movements

502   needed in the recovery and coping process of PD. Due to the extensive instructions that

503   accompany S-AOMI, those patients with PD may struggle to meet the demands upon

504   working memory and those associated with engaging in multiple tasks simultaneously; an

505   issue reported often amongst this population (63). Furthermore, we suggest that S-AOMI

506   combination may prove beneficial for the training of healthy and novice populations to

507   enhance performance skills, which could emulate the concept of learning by imitation

508   particularly for learners during periods of injury or immobilisation.

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512   **Conflicts of interest**

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513   None.

514

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694   Figure 4. Mean (± s.e.m) pre and post-test scores of for each experimental condition

695   (*$p < .05$).

696   Figure 5. Mean (± s.e.m) pre and post angular velocity for each experimental group

697   (*$p < .05$, ** $p < .001$).