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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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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

50

51

52 **Introduction**

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

71 More recently, AO combined with MI (AOMI) has been shown to be a more effective
72 intervention than AO or MI performed in isolation for a variety of outcomes such as strength
73 (3,8), skilled movement (9,10), and rehabilitation (11,12). Despite this evidence, little is
74 known about how these combinations are best structured and how they enhance performance.
75 While some research on stroke patients (11) and postsurgical orthopaedic patients (12) has
76 suggested that combining AOMI in a simultaneous manner enhances functional outcomes, a

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).

102

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 Measures

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).

148 *The Aiming Task*

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

155 *Biomechanical Measures*

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

165 *Electromyography (EMG) recordings*

166 Trigno™ EMG electrodes (Delsys Inc.) with 10 mm diameter and 20mm inter-
167 electrode distance as recommended by Hermens, Freriks, Disselhorst-Klug, & Rau (29) were
168 attached to the prepared skin overlaying the five selected muscles. Muscles were selected based
169 upon research of a similar nature measuring kinematic and electromyography variables during
170 behavioral based darts tasks (22,23,30). To limit cross talk, electrodes were placed parallel to
171 the muscle fibres on the belly of the muscles following accepted anatomical criteria (31,32) for
172 controlling the movement of the wrist, elbow, and shoulder. These muscles included flexor

173 carpi radialis (FCR), extensor carpi radialis (ECR), bicep brachii and triceps brachii and
174 anterior deltoid (see figure 2).

175 *Raw EMG signal processing*

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

185 *Myomotion joint kinematics*

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

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

200 Myomotion joint kinematics – temporal analysis

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

208 **Procedure**

209 Prior to the commencing of the study, all participants gave their informed consent for
210 participation and completed the MIQ-R. All participants were randomly allocated to one of
211 five experimental groups (n =10 per condition): action observation (AO); motor imagery
212 (MI); simultaneous imagery and observation (S-AOMI); and alternate imagery and
213 observation (A-AOMI) and control. All participants, except those in the control group and
214 AO group, received stimulus-response training (35). Participants in the AO and control group
215 were not required to produce a motor image and did not receive LSRT. It was decided that for
216 the nature of this study that LSRT would be used due to the amount of literature that uses the
217 technique, its ability to improve motor imagery ability, to initiate the motor programme for
218 the movement being imaged, and is relatively easy for the participant to understand (36–38).
219 Participants engaging in LSRT based on the bio-informational theory (35) were required to
220 utilise three sources of information within a scenario used to aid their MI For example: (1)

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

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

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

260 *Action observation intervention*

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

268 *Imagery intervention group*

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

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

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

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

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

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

296 *Control group*

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

303 **Data analysis**

304 Based on the previous trial selection process of Lohse et al. (22), throws 2, 3 and 4
305 within blocks 2, 3 and 4, were selected for analysis. Mean EMG activation and kinematic
306 measures across three trials per block were determined for each subject. The decision to
307 select and analyse throws 2, 3 and 4 within blocks 2, 3 and 4, was based upon previous
308 research that suggests to omit on- and off-transient phenomena associated with muscular
309 exertion during the first and last repetitions of each trial, the first and last throw should be
310 discarded (40). Therefore, this ensures that measures are consistent and accurate outcomes
311 (41).

312 A 5 (group) x 2 (time) mixed design analysis of variance (ANOVA) was performed on pre
313 and post-test conditions to observe any changes in performance across treatment groups
314 across all data variables. Where the ANOVA revealed significant effects, post hoc Tukey
315 HSD tests were used to establish where any significant differences existed. Performance was
316 the mean of total throwing accuracy score (out of 300 points) for each group. For the MIQ-V

317 and MIQ-K data, a one-way ANOVA was performed to establish any differences in imagery
318 ability prior to the start of any intervention. Significance was measured at the .05 level. Effect
319 sizes were calculated using partial eta squared (η_p^2) for omnibus comparisons and
320 Cohen's *d* for pairwise comparisons (42).

321 **Results**

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

325 *Self-report data*

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

332 *Performance measures*

333 A 2 x 5 repeated measures ANOVA revealed a significant main effect for time, $F(1,$
334 $45) = 65.65, p < .001, \eta_p^2 = .593$ and a significant time x group interaction, $F(4, 45) = 3.55, p$
335 $= 0.01, \eta_p^2 = .240$. Within group post hoc tests showed that participants in the A-AOMI ($p =$
336 0.01), S-AOMI ($p = 0.03$), AO ($p = 0.04$), group, and MI ($p = 0.04$) group improved
337 significantly from pre-test to post-test, with Cohen's *d* effect sizes of 1.73, 0.96, 0.39 and
338 0.57 respectively. There was however, no significant change for control group from pre to
339 post test ($p = .25$). Between-group post hoc tests showed the S-AOMI group improved to a
340 greater degree than the control group ($p = 0.02$). Participants in the A-AOMI group improved

341 to a greater degree than the AO ($p = 0.04$), MI ($p = 0.04$), and control groups ($p = 0.02$). (See
342 Figure 4).

343 *EMG measures*

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

357 *EMG data*

358 EMG activity was calculated from the point of maximum flexion to point of release. A
359 2 x 5 repeated measures ANOVA revealed no significant time x group interaction for the
360 anterior deltoid $F(4, 44) = .275, p = .89$, triceps brachii $F(4, 44) = .433, p = .78$, flexor carpi
361 radialis $F(4, 43) = .085, p = .98$, and extensor carpi radialis, $F(4, 43) = .085, p = .76$. However,
362 a significant main effect for time, $F(1, 45) = 19.65, (p = .000), \eta_p^2 = .304$ and a significant time
363 x group interaction, $F(4, 45) = 2.76, (p = 0.03), \eta_p^2 = .197$ was found in the bicep brachii. Post
364 hoc tests revealed that EMG mean activity from point of flexion to point of release significantly

365 decreased from pre-test to post-test in the AO ($p= 0.04$), A-AOMI($p= 0.001$), and S-AOMI
366 ($p= 0.005$) groups ($p <.05$), with Cohen's d effect sizes of 1.08, 1.54, 1.43 respectively. EMG
367 mean activity in the control and MI group did not significantly reduce from pre to post-test
368 during the same phase. Between-group post hoc tests revealed that mean EMG activity in the
369 S-AOMI group significantly decreased to a greater degree than the control group ($p=0.02$), and
370 MI group ($p= 0.03$). Participants in the A-AOMI group also decreased to a significantly greater
371 degree than participants in the control group ($p= 0.02$) (See Table 4).

372 *Kinematic measures*

373 *Peak angular velocity*

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

381 *Movement time*

382 For flexion to point of release, there was significant main effect for time, $F(1, 36) = 4.785$, p
383 = 0.03, $\eta_p^2 = .127$ but no significant time x group interaction, $F(4, 36) = .857$, $p=.500$ across
384 movement time during the aiming task. There was no significant main effect for time, $F(1,$
385 $36) = 2.117$, $p = .154$ and no significant time x group interaction, $F(4, 36) = .154$ $p=.960$
386 across the follow through phase movement time during the aiming task. Furthermore, there
387 were no significant main effect for time, $F(1, 34) = .014$, $p = .907$ and no significant time x
388 group interaction, $F(4, 34) = 1.58$, $p=.200$ for time to peak angular velocity amongst groups.

389 **Discussion**

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

404 We propose the following explanations for the improvements shown in performance
405 measures. Firstly, the benefits of motor imagery alone have shown considerable effects on
406 motor performance. Research shows that during MI, motor cortical activation produces a
407 subliminal cortical output that primes spinal networks (14). Additionally, the corticospinal
408 excitability induced by MI shows considerable effects on a wide proportion of the
409 corticospinal pathway, corresponding to the target muscles imaged (12). Similarly, AO can
410 have beneficial effects on performance (e.g., evoking activity in the areas of the brain
411 responsible for movement execution; 43). However, in the current study, these benefits were
412 not as effective in isolation, in comparison to when combined. The added benefits of
413 combining these two techniques were shown in the results. These are two possible

414 explanations for this (1) the areas of the brain that AO and MI active demonstrate neural
415 overlap during motor execution and MI as well as during motor execution and AO (21,44),
416 this relates to the motor simulation theory proposed by Jeannerod (21) which suggests that
417 action, either self-intended or observed activates the motor system as part of a broader
418 simulation network. This suggests, the overlapping of brain and neural structures during both
419 AO and MI would provide complementary activation compared to one or the other modality
420 alone (45). (2) Alternatively, this could be owing to neuroplastic alterations previously
421 reported for both AO and MI interventions, which may provoke changes on a cortical level in
422 both the sensory and motor maps of the somatosensory cortex within healthy and clinical
423 populations (12, 43). This, in turn, may promote functional plasticity within the brain leading
424 to a greater dart throwing performance and development of a more efficient motor
425 programme as learning progressed (46). Moreover, the initial architecture of the mental
426 representation held by the novice participants may have been enhanced leading to improved
427 performance in the early motor learning phase (18). This is supported by evidence that
428 suggests that mental representation of novices becomes functionally more organised as
429 performance improves following MI, physical practice and observational learning (17).
430 Therefore, the inclusion of MI alongside AO may have resulted in a task-specific motor
431 representation that produced more effective encoded visuomotor commands, related to the
432 planning and preparation of the executed movement. While this is likely, mental
433 representation structure was not directly measured within this study. Nevertheless, important
434 inferences can be formed from the behavioral outcomes of this study.

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

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

461 Our data showed a significant decrease in peak angular velocity in the AOMI intervention
462 groups. This is surprising as previous research by Mousavi et al. (20) demonstrated a
463 significant increase in critical elbow angular velocity as skill learning progressed. One

464 possible explanation for this discrepancy could be the differences between the specific
465 intervention instructions. Mousavi et al. (20) used virtual reality training which has as a
466 greater visual acuity than observation of a pre-recorded video as used the present study (56).
467 Participants were also able to direct their own movement and gain sensory consequences of
468 the moment executed in the VR environment. However, it must be noted that this link could
469 be considered vague as during VR participants are able to physically perform movements,
470 which would have a greater impact on the brain regions referred to in the
471 psychoneuromuscular theory above. Alternatively, a decrease in angular velocity as shown by
472 participants in the AOMI group could be explained by their desire to execute the throwing
473 skill more accurately (57) such that we suggest that greater velocity and more error prone
474 accuracy could be a demonstration a speed-accuracy. Therefore, we suggest that the faster the
475 participants in the MI, AO, and control group executed to throw the dart throw, the less
476 accurate and consistently they performed (58)

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

487 **Perspective**

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

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686 List of Figures and Tables

687 Figure 1: A still shot of the task performed

688 Figure 2. Kinematic measures of interest: (A) maximum elbow flexion (B) to elbow
689 extension and (A) maximum elbow flexion to (C) point of release

690 Figure 3: An example of the location of electrodes on participants throwing arm

691 Figure 4. Mean (\pm SEM) pre and post-test scores of for each experimental condition
692 ($*p < .05$).

693 Figure 5. Mean (\pm SEM) pre and post angular velocity for each experimental group ($*p < .05$,
694 $** p < .001$).

695

696 Table 1: Summary of the PETLEP motor imagery content for all imagery instructions.
697

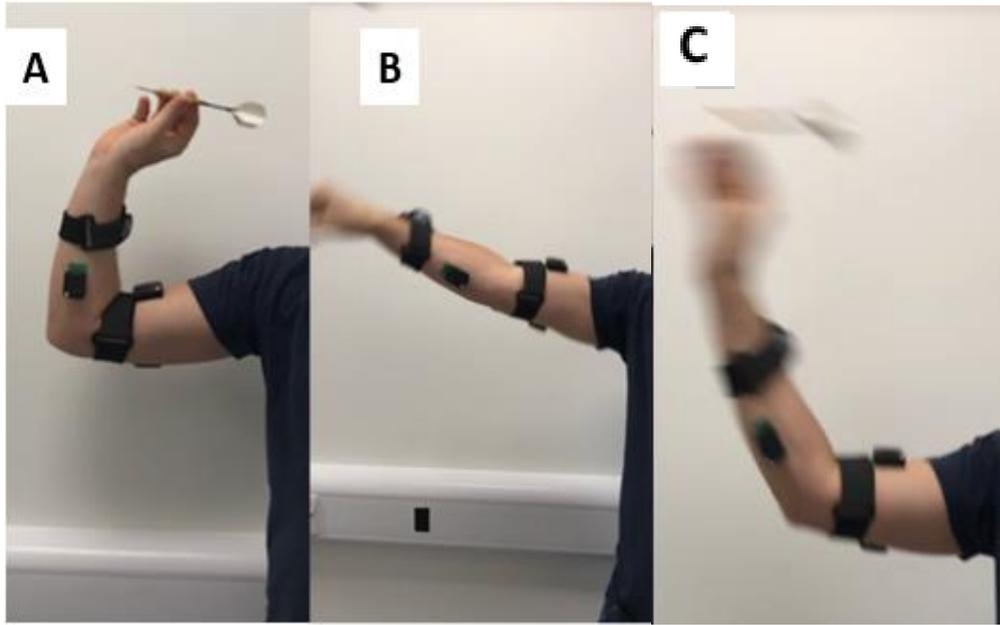
698 Table 2: Baseline characteristics of participants of each variable in each experimental group

699 Table 3: Manipulation check scores (SD) for each intervention group

700 Table 4. Mean EMG data (\pm SD) pre and post-test from point of flexion to extension as a
701 percentage of peak activity



Figure 1



Throwing phase	Anterior deltoid	Bicep brachii	Triceps brachii	Flexor capri radialis	Extensor carpi radialis
A	Concentric	Concentric	Eccentric	Eccentric	Concentric
B	Eccentric	Eccentric	Concentric	Concentric	Eccentric
C	Eccentric	Eccentric	Concentric	Concentric	Eccentric

Figure 2

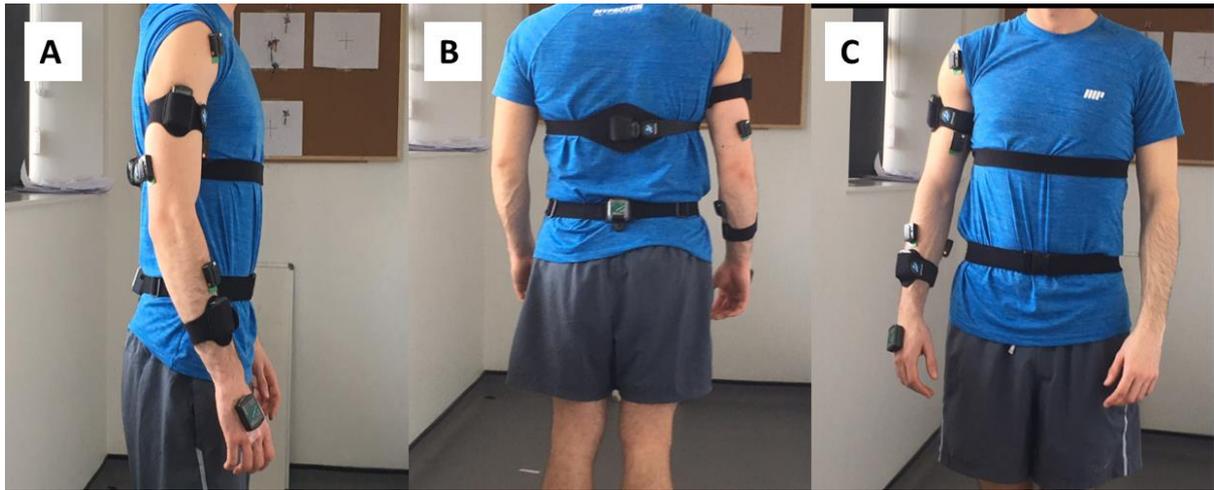


Figure 3

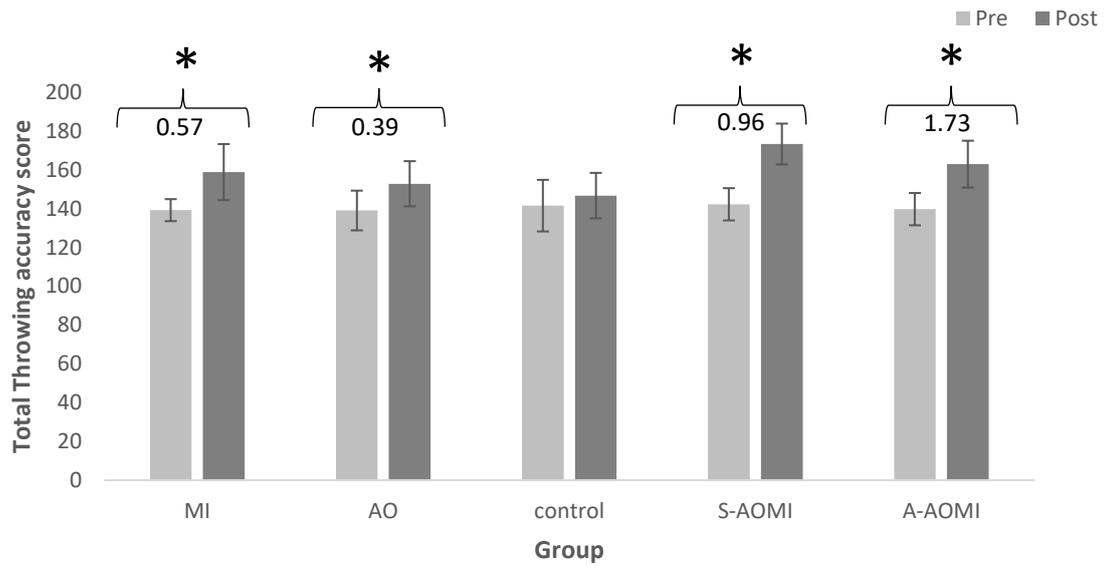


Figure 4

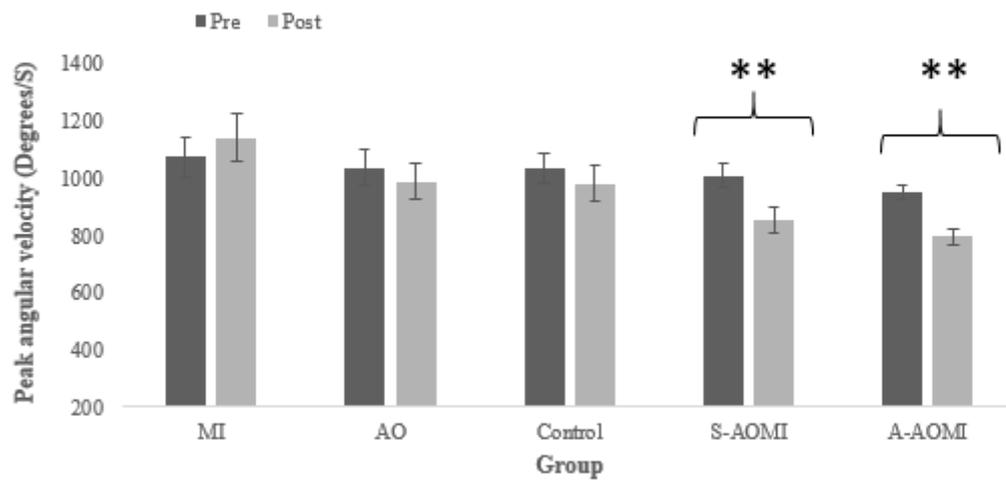


Figure 5

Table 1

PETTLEP category	Description
Physical	Participants were instructed to stand while holding a cylindrical object similar to a dart or pen suggested by Holmes and Collins (2001). Participants were also instructed to adopt the stance recognised in dart throwing performance.
Environment	PETTLEP MI was performed at home. Participants were instructed to watch the video static dartboard within the video from their pre-test
Task	Participants performed a series of dart throws to emulate the performance measure as closely as possible. This included the intricacies associated with their specific skill level on the task.
Timing	Participants were instructed to perform MI in ‘real time’, rather than in slow motion or faster than normal. Auditory cues. For example, audio feedback of the darts making contact with the board during pre-test conditions.
Learning	Participant were instructed to revisit their imagery scripts after every two week period of the intervention and make any necessary adaptations depending on their perceived development of the skill.
Emotion	Scripts were created after the pre-test allowing familiarisation with the dart throwing action. This was based on the results of the stimulus and response training (Lang et al., 1980) that had been undertaken. Participants often identified associations with the physical sensations or of dart throwing.
Perspective	Participants were instructed to image in the first person perspective in order to best reflect the perspective from physical completion of the task.

Table 2

	MI (N=10)	A-AOMI (N=10)	S-AOMI (N=10)	AO (N=10)	Control (N=10)	P value
Gender (Male)	5	5	5	4	6	
Gender (Female)	5	5	5	6	4	
Age (y)	29.0 ± (6.39)	26.0 ± (4.66)	26.7 ± (4.91)	30.0 ± (7.57)	29.0 ± (8.24)	0.785
Height (cm)	170 ± (7.40)	173.40 ± (8.10)	176.80 ± (9.2)	173.63 ± (7.76)	172.58 ± (7.87)	0.846
performance score	139.30 ± (17.94)	139.80 ± (26.31)	142.30 ± (3.0)	139.10 ± (32.39)	141.60 ± (42.09)	0.999
MIQ- R visual	6.62 ± (0.50)	6.65 ± (0.55)	6.79 ± (0.37)	6.36 ± (0.78)	6.55 ± (0.61)	0.335
MIQ-R kinaesthetic	6.63 ± (0.50)	6.57 ± (0.57)	6.77 ± (0.37)	6.36 ± (0.76)	6.44 ± (0.42)	0.489
EMG – flexion to extension						
Anterior deltoid	73.51 ± (14.52)	64.62 ± (12.30)	71.30 ± (10.22)	70.97 ± (15.16)	66.41 ± (15.05)	0.513
Biceps brachii	43.15 ± (9.56)	50.57 ± (16.39)	65.28 ± (16.58)	58.09 ± (26.06)	51.89 ± (16.60)	0.117
Triceps brachii	67.28 ± (11.58)	65.55 ± (17.90)	61.25 ± (14.59)	57.36 ± (8.08)	59.66 ± (14.92)	0.479
Flexor Capri Radials	47.95 ± (21.48)	42.56 ± (22.87)	45.25 ± (29.01)	39.78 ± (24.72)	42.32 ± (22.87)	0.976
Extensor Capri Radialis	51.46 ± (29.15)	44.56 ± (20.46)	49.84 ± (20.26)	44.56 ± (20.26)	52.16 ± (29.67)	0.699
EMG – flexion to point of release						
Anterior deltoid	73.51 ± (23.73)	64.62 ± (12.30)	74.94 ± (15.36)	70.97 ± (9.09)	66.41 ± (14.52)	0.680
Biceps brachii	47.95 ± (15.85)	51.75 ± (16.70)	53.63 ± (25.75)	56.64 ± (22.68)	46.69 ± (18.78)	0.220
Triceps brachii	44.73 ± (28.90)	62.93 ± (28.71)	45.75 ± (29.45)	58.38 ± (20.82)	60.15 ± (19.32)	0.369
Flexor Capri Radials	47.92 ± (21.48)	42.56 ± (25.25)	45.25 ± (29.01)	39.78 ± (24.72)	41.23 ± (31.08)	0.959
Extensor Capri Radialis	51.46 ± (29.15)	44.56 ± (20.26)	49.84 ± (15.89)	53.39 ± (28.85)	52.16 ± 29.67	0.947
Movement kinematics						
Movement time	0.18 ± (0.02)	0.19 ± (0.08)	0.16 ± (0.02)	0.16 ± (0.05)	0.20 ± (0.04)	0.355
Follow thorough time	0.05 ± (0.02)	0.04 ± (0.02)	0.05 ± (0.01)	0.05 ± (0.02)	0.05 ± (0.03)	0.586
Time to peak angular velocity	0.15 ± (0.42)	0.18 ± (0.86)	0.14 ± (0.31)	0.15 ± (0.25)	0.16 ± (0.51)	0.635
Angular velocity	1074.0 ± (220.60)	963.20 ± (87.32)	1009.70 ± (127.64)	1038.0 ± (200.09)	1037.33 ± (164.13)	0.651

Table 3

	A-AOMI	S-AOMI	MI
Frequency of imaging	17.1 ± (1.66)	15.7 ± (1.41)	15.4 ± (3.27)
Ease of imagery (see)	6.1 ± (0.87)	6.0 ± (1.0)	6.1 ± (0.87)
Ease of imagery (feel)	6.5 ± (0.69)	6.4 ± (0.67)	6.2 ± (0.78)
Vividness of imagery	6.6 ± (0.51)	6.8 ± (0.42)	6.7 ± (0.48)

Table 4

Component	Group	Maximum flexion to extension		Maximum flexion to point of release	
		Mean pre \pm (SD)	Mean post \pm (SD)	Mean pre \pm (SD)	Mean post \pm (SD)
Anterior deltoid	S-AOMI	71.30 \pm (10.22)	70.41 \pm (6.04)	74.94 \pm (15.36)	70.41 \pm (6.04)
	A-AOMI	64.62 \pm (12.30)	62.18 \pm (27.15)	64.62 \pm (12.30)	62.18 \pm (27.15)
	AO	70.97 \pm (15.16)	67.27 \pm (15.59)	70.97 \pm (9.09)	71.13 \pm (34.38)
	MI	73.51 \pm (14.52)	67.18 \pm (11.75)	73.51 \pm (23.73)	62.65 \pm (17.84)
	Control	66.41 \pm (15.05)	67.91 \pm (17.83)	66.41 \pm (14.52)	67.91 \pm (17.88)
Bicep brachii	S-AOMI	65.28 \pm (16.58)	61.14 \pm (16.14)	53.63 \pm (25.75)**	34.61 \pm (14.45)**b
	A-AOMI	50.57 \pm (16.39)	42.00 \pm (20.28)	51.75 \pm (16.70)**	22.94 \pm (14.95)**c
	AO	58.09 \pm (26.06)	44.24 \pm (19.30)	56.64 \pm (22.68)*	33.65 \pm (19.57)*
	MI	43.15 \pm (9.56)	41.82 \pm (20.07)	47.95 \pm (15.85)	29.17 \pm (21.08)
	Control	51.89 \pm (16.60)	47.45 \pm (16.50)	46.69 \pm (18.78)	45.99 \pm (15.29)
Triceps brachii	S-AOMI	61.25 \pm (14.59)**	24.13 \pm (10.09)**a	45.75 \pm (29.45)	55.97 \pm (20.26)
	A-AOMI	65.55 \pm (17.90)**	44.05 \pm (23.63)**	62.93 \pm (28.71)	55.85 \pm (30.27)
	AO	57.36 \pm (8.08)	60.64 \pm (13.52)	58.38 \pm (20.82)	55.28 \pm (23.97)
	MI	67.28 \pm (11.58)	62.63 \pm (22.63)	44.73 \pm (28.90)	42.00 \pm (29.48)
	Control	59.66 \pm (14.92)	53.45 \pm (25.42)	60.15 \pm (19.32)	49.08 \pm (27.13)
Flexor Capri radialis	S-AOMI	45.25 \pm (29.01)	38.81 \pm (21.67)	45.25 \pm (29.01)	38.81 \pm (21.67)
	A-AOMI	42.56 \pm (22.87)	34.13 \pm (30.52)	42.56 \pm (25.25)	34.13 \pm (30.52)
	AO	39.78 \pm (24.72)	32.95 \pm (25.84)	39.78 \pm (24.72)	41.23 \pm (31.84)
	MI	47.95 \pm (21.48)	37.62 \pm (30.54)	47.92 \pm (21.48)	37.62 \pm (30.54)
	Control	42.32 \pm (22.87)	41.23 \pm (31.84)	41.23 \pm (31.08)	42.32 \pm (31.84)
Extensor Capri radialis	S-AOMI	49.84 \pm (20.26)	50.79 \pm (22.37)	49.84 \pm (15.89)	50.79 \pm (12.26)
	A-AOMI	44.56 \pm (20.46)	41.19 \pm (20.46)	44.56 \pm (20.26)	41.19 \pm (20.46)
	AO	44.56 \pm (20.26)	44.76 \pm (22.37)	53.39 \pm (28.85)	44.76 \pm (22.37)
	MI	51.46 \pm (29.15)	43.77 \pm (19.76)	51.46 \pm (29.15)	43.77 \pm (30.96)
	Control	52.16 \pm (29.67)	54.36 \pm (19.76)	52.16 \pm 29.67	54.36 \pm (19.76)

* $p < 0.05$ significant difference from pre to post-test ** $P < 0.01$ significant difference from pre to post-test.

a- significant difference between S-AOMI and MI, AO and control groups, b- significant difference between S-AOMI, MI and control group, c- significant difference between A-AOMI and control group