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# THE INFLUENCE OF THE INTERVENTION TIME ON THE MOTOR LEARNING PROCESS INDUCED THROUGH MOVEMENT REPRESENTATION TECHNIQUES: A RANDOMIZED CONTROLLED PILOT TRIAL

Nahia de-la-Hera-Robledo, MSc[1,†]; Miguel Castro-Puerta, MSc[1,†]; Ferran Cuenca-Martínez, MSc[1,2]; Roy La Touche, PhD [1,2]

†Both authors contributed equally

1. Departamento de Fisioterapia, Facultad de Ciencias de la Salud. Centro Superior de Estudios Universitarios La Salle, Universidad Autónoma de Madrid, Madrid, España.

2. Motion in Brains Research Group, Instituto de Neurociencias y Ciencias del Movimiento (INCIMOV), Centro Superior de Estudios Universitarios La Salle, Universidad Autónoma de Madrid, Madrid, España.

**Correspondencia:**

Ferran Cuenca-Martínez, PT, MSc.
Departamento de Fisioterapia. CSEU La Salle. Universidad Autónoma de Madrid.
Calle La Salle, nº 10, 28023 Madrid, España
Teléfono: (+34) 91 740 19 80
Fax: (+34) 91 357 17 30
E-mail: Fecuen2@gmail.com

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## ABSTRACT

**Objective:** The main aim was to assess motor learning process comparing action observation (AO), motor imagery (MI), and double time of MI (2MI) at post- and at 1-week post-intervention through Purdue-Pegboard test. The secondary objectives were to assess if improvements enhanced the ability to imagine and the perceived fatigue.

**Methods:** 20 healthy subjects were randomly assigned to AO group, MI group, 2MI group or placebo observation group.

**Results:** Results in right hand test showed that AO group obtained improvements at post- and at 1-week post-intervention, both with a large effect size ($p$ = .049, $d$ = -1.28 and $p$ = .049, $d$ = -1.4). In left hand test MI group obtained better results than placebo group ($p$ = .016, $d$ = 2.21). In both hand test MI presented differences at the post- and at 1-week post-intervention ($p$ = .006, $d$ = -2.28 and $p$ = .009, $d$ = -1.89). No within- and between-group differences were found in sequence test. With respect to the perceived fatigue, both MI and 2MI showed greater levels of fatigue ($p$ = .003, and $p$ = .045). Finally, no within- and between-group differences were found in the ability to imagine ($p$ > .05).

**Conclusions:** Both movement representation techniques enhanced motor learning, although the results must be considered with caution due to the small sample size. MI seems to cause more fatigue than AO. However, increasing imagery time did not results in greater level of fatigue. The improvements did not lead to an increase in the ability to imagine.

**Keywords:** Action observation; Motor imagery; Motor learning; Time influence; Imagery ability.

## INTRODUCTION

Motor learning is defined as a relatively enduring change in the competence of skill performance, obtained as a result of reiterated practice and interactions with the environment (Willingham, 1998). According to existing literature, physical practice is the most powerful way for acquiring new motor skills. However, action observation (AO) training and motor imagery (MI) have been proven to be effective movement representation techniques in promoting motor learning (Moran et al., 2012).

MI is defined as the mental simulation of a specific movement, in the absence of its actual motor execution (Decety, 1996). AO training is known as the process of learning by observing the ideal model movement (Buccino, 2014). Both movement representation techniques are believed to share common neural mechanisms in the mirror neurons (Jeannerod, 1994). Besides, it has been observed that they produce a neurophysiological activation of the brain areas related to the planning and execution of voluntary movement, that resembles to the real physical movement (Taube et al., 2015).

AO and MI can be useful as adjuncts to physical practice, to facilitate new skill acquisition in several disciplines (Moran et al., 2012). Indeed, they have been widely used for training technical skills in healthy subjects, such as athletes (Feltz and Landers, 1983) and musicians (Pascual-Leone et al., 1995) or in patients, like stroke subjects (Kumar, 2016) or injured athletes (Jones and Stuth, 1997). Even though MI has been shown to be more effective when paired with physical practice (Bovend'eerdt et al., 2012) it is also useful when applying it alone (Zhang et al., 2011). Actually, there is evidence that MI is better than no practice, so it might be beneficial in cases that physical practice is not possible (Zhang et al., 2011).

Even if both movement representation techniques, applied in an isolated way, are helpful for encouraging motor learning, recent studies have shown that AO is more effective than MI in learning new movements (Gatti et al., 2013) at least in the fast phase of motor learning process. In fact, AO training triggers mirror neuron system in a more ecological way (Gatti et al., 2013; Cuenca-Martínez et al., 2020) and is less demanding in terms of cognitive load, because the images are externally provided, while MI requires an internal, autonomous effort to generate the images (Cuenca-Martínez et al., 2020). Consistent with this, it has been shown that MI is less effective in completely inexperienced participants than in subjects that are not absolutely novice (Mulder et al., 2004).

Furthermore, MI is more susceptible than AO to the influence of some key variables, such as, physical domain, cognitive-evaluator domain and direct modulation domain (Cuenca-Martínez et al., 2020). For instance, concerning the physical domain, it has been proved that athletes with high levels of physical activity had a larger ability to generate motor images than athletes with lower levels of physical activity (Paris-Alemany et al., 2019). It has also been shown that kinesiophobia and the ability to generate both kinesthetic and visual motor images are negatively correlated (La Touche et al., 2018). With respect to cognitive variables, bigger mental efforts made in MI led to larger hemodynamic changes at the cortical level (Wriessnegger et al., 2017). Regarding direct modulation variables, providing visual input before performing MI training makes it easier and leads to a better neurophysiological activity (Taube et al., 2015). In addition, it has been found that individuals who had more vivid imagination had grater results when performing an imagery motor task (Isaac and Marks, 1994). Besides, concerning autonomic nervous system response, it has been observed that the complexity of movement, the effort-intensity, and the levels of physical activity can influence neurovegetative activity when creating motor images. Ultimately, with reference to the synchronization, several studies have demonstrated that unknown, uncommon, and uncomfortable movements can lead to differences in the time invested between the imagined and real execution (Rieger, 2012).

It was hypothesised that doubling MI training time would cause the same effects as AO training on motor learning and would therefore be greater than training with half the duration of MI. Therefore, the main aim of the present pilot study was to assess motor learning improvements comparing AO training, MI and 2MI at post- and at 1-week post-intervention. The secondary objectives were to assess if improvements on motor learning enhanced the ability to generate mental motor images and also to evaluate the impact of each intervention on the perceived fatigue.

## METHODS

### Study design

The present study was a randomized, single-blind controlled pilot trial, organized and conducted in accordance with Consolidated Standards of Reporting Trials requirements (Schulz et al., 2010) **(Figure 1)** and was accepted by ethical committee of the Centro Superior de Estudios Universitarios CSEU La Salle (CSEULS-PI-038/2019). This study was registered in the United States Randomized Trials Registry (trial registry number: NCT04191083). All participants completed the informed consent document before the study.

### Recruitment of participants

A sample of asymptomatic subjects was acquired from CSEU La Salle and Community of Madrid via social networks and emails. The participants were recruited between January and March of 2020. The inclusion criteria included the following: asymptomatic subjects, aged between 18 and 65 years. The exclusion criteria were: (a) subjects who had systemic, cardio-respiratory, central nervous system or rheumatic pathologies, or those who presented any musculoskeletal disease with a source of symptoms at the time of the study; (b) underage subjects; (c) subjects with pain at the time of the study; and (d) participants who were not in full use of their mental capacities and consequently were unable to complete the intervention of the study. Informed written consent was obtained from all participants before the inclusion. Besides, all subjects were given an explanation of the study procedures.

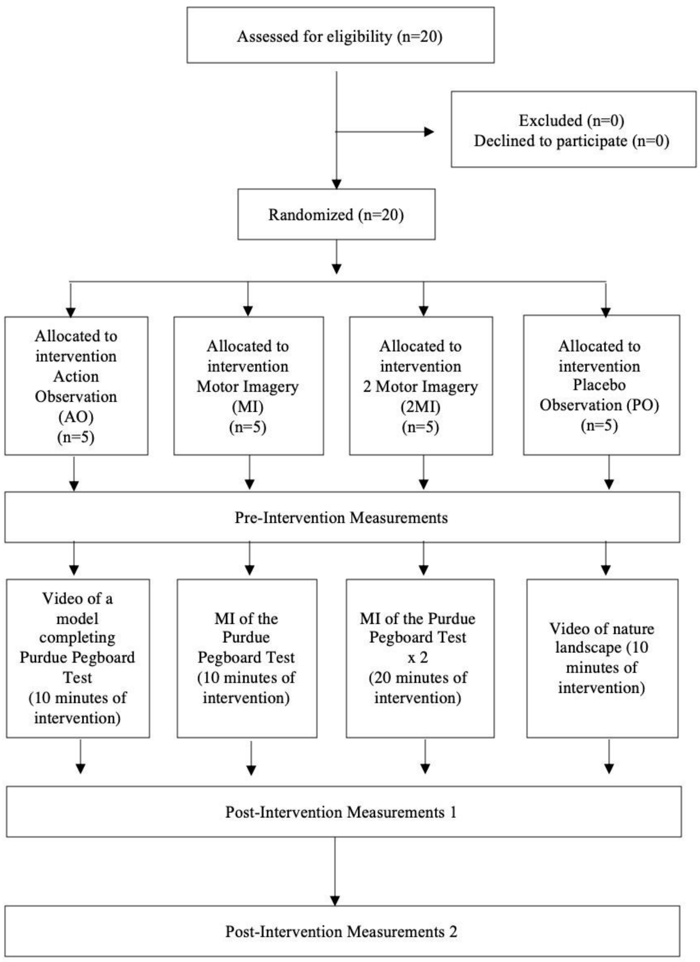
### Randomization

Randomization was accomplished using a computer-generated random sequence table with a balanced 4-block design (GraphPad Software, Inc., CA, USA). The randomization list was created by an independent researcher. Besides, a member of the research group, who was not involved in the assessment or intervention of the subjects, was responsible for the randomization and maintained the list. Thus, participants were randomly assigned to 1 of the 4 groups using the random-sequence list.

### Blinding

The assessments and interventions were executed by different physiotherapist. The evaluator was blinded to the participants assignment. All the intervention procedures were performed by the same therapist, who had more than a year of experience in the field and was blinded to the aim of the study. Subjects were also blinded to their group allocation.

**Figure 1.** Flow chart of the study design.



**Interventions**

- *AO group*

Participants in this group observed a video of a model completing the Purdue Pegboard test in first-person perspective, which lasted 2 minutes and 30 seconds and consisted of 4 different exercises: Right hand test, left hand test, both hands test and a sequence test (*see outcome measures*). The intervention lasted 10 minutes. Thus, the subjects had time to watch the full test 4 times.

- *MI group*

Subjects in this intervention group performed a MI protocol of the same 4 exercises as the AO group. They were instructed on the movements they were to imagine by giving precise instructions for each movement. To fulfil this intervention participants had to remain seated, with their eyes closed and as still as possible. Then, they were told to imagine the 4 tasks in first-person perspective. The intervention lasted 10 minutes, as they were asked to imagine the whole test 4 times. It has to be mentioned that they were given a minute of rest in the middle of the intervention.

- 2*MI group*

Participants in this group performed the same protocol as the MI group. The only difference was that they doubled the time of the intervention.

- *Placebo observation (PO) group*

Subjects in the PO group experienced a placebo AO protocol. Participants watched a video clip of nature landscape, without sound and with no human agents or motor gestures, during the same intervention time as the first two groups (AO and MI). This placebo AO protocol has been previously used in other studies (Buccino et al., 2012).

**Outcomes**

*Primary outcomes*

- *Purdue Pegboard test scores*. The Purdue Pegboard is a test of manipulative dexterity. It provides different measurements of the right hand, left hand, and both hands together, and measures dexterity for two types of activity. On the one hand, it evaluates gross movements of hand, fingers, and arms, and on the other, it measures the "tip of the finger", which refers to the dexterity required in small assembly work (Tiffin and Asher, 1948) **(Figure 2)**.

The Pegboard is provided with pins, collars, and washers placed in the proper cups. The extreme right and extreme left-hand pockets should each contain 25 pins. The cup immediately to the right of the centre must contain 20 collars, and the pocket to the left of the centre 40 washers. The subject should be seated at a table and the Pegboard must be directly in front of the operator (Tiffin and Asher, 1948). Four different test scores were obtained with the Purdue Pegboard: Right Hand, Left Hand, Both Hans and Sequence (Tiffin and Asher, 1948).

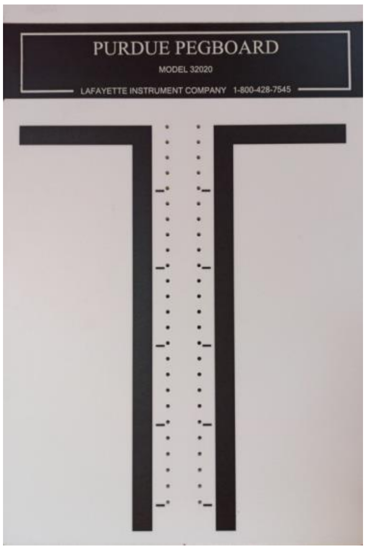
Right-Hand Test.

The participant was asked to pick up one pin at a time with the right hand from the right-hand pocket and to put these pins in the right-hand row, beginning from the top hole. The subject was allowed to put in three or four pins for practice prior to start the test. Then the pins were removed and the tested was instructed to put in as many pins as possible with the right hand for 30 seconds. The right-hand score was the total amount of pins the participant had placed with the right hand.

Left Hand Test.

The procedure described above was followed for the left hand.

**Figure 2.** Purdue pegboard test



Both Hand Test.

In this part the participant simultaneously took a pin from the right hand cup with the right hand and a pin from the left hand cup with the left hand, and placed both pins at the same time in the two rows of holes, starting with the top holes. The both hands score was the number of pairs of pins that the subject had placed in 30 seconds.

Sequence Test.

This part consisted of assembling the pins, collars, and washers. The subject was instructed to pick up a pin from the right hand cup with the right hand and while put in it in the top hole in the right hand row, he/she had to take a washer with the left hand. Just at the moment that the pin had been placed, the subject had to drop the washer over the pin. Then, the subject had to take a collar with the right hand and placed it over the washer. Last, the tested had to pick up another washer with the left hand and drop it over the collar. This completed the first "sequence"' consisting of four parts: a pin, a washer, a collar, and a washer. The score in the sequence test was obtained counting the number of parts assembled during one minute of testing time.

*Secondary outcomes*

- *Ability to imagine*. The movement imagery questionnaire-revised (MIQ-R) is an 8-item self-report inventory. It was employed to evaluate kinesthetic and visual motor imagery ability. Four different movements are involved in the MIQ-R, which consist of four visual and four kinesthetic items. First, subjects were asked to read an explanation of the movement for each item. Then, they physically performed the movement and were instructed to reassume the starting position after finishing it. Afterwards, they were told to perform the mental task, imagining the movement kinaesthetically or visually. Each participant then scored the difficulty or ease of mentally generating that image on a 7-point scale, in which 1 indicates ‘‘very difficult to see/feel’’ and 7 ‘‘very easy to see/feel’’. The internal consistencies of the MIQ-R have been consistently adequate, with Cronbach's α coefficients ranging above 0.84 for the total scale, 0.80 for the visual subscale and 0.84 for the kinesthetic subscale (Campos et al., 2010).

- *Mental chronometry*. Mental chronometry (MC) is a reliable measure that has been generally employed to record objective measurements of the ability to imagine (Williams et al., 2015). First, the subjects were instructed to perform the real movement execution of the task, and the time invested in performing each task was recorded using a stopwatch. Afterwards, it was registered the time participants dedicated to imagining each task. The time between the interval command to start the task (given by the evaluator) and the verbal response at the end of the task (given by the participant) (Malouin et al., 2008).

- *Perceived mental fatigue*. Visual analogue scale of fatigue (VAS-f) was used to quantify the participants perceived mental fatigue after performing the training session. The VAS-f uses a numerical scale of 0–10, with 0 representing minimum fatigue (no fatigue) and 10 representing maximum fatigue. The VAS-f scale is useful, sensitive and easy to apply (Lee et al., 1991).

*Baseline outcomes*

- *Level of physical activity*. The level of physical activity was analysed using the IPAQ questionnaire, which divides participants in 3 groups regarding to their level of activity, which can be high, moderate and low or inactive (Roman-Viñas et al., 2010). This questionnaire has shown acceptable validity and psychometric properties to assess total physical activity. Thus, the psychometric properties of the questionnaire were accepted for use in studies which required the measurement of physical activity; reliability was approximately 0.65 ($r = 0.76$; 95% CI [0.73–0.77]) (Mantilla Toloza and Gómez-Conesa, 2007).

- *Laterality discrimination task*. Accuracy and response time. Recognise Online is an Internet application designed to evaluate the capacity to fulfil laterality discrimination tasks. This app presents diverse right/left images of different parts of the body, and it calculates the speed and precision of making left/right discrimination judgements of each image. The app has been developed and released by the NOI Group, and it gives the option to change the quantity of images and the period of time the participant has to view each image (Linder et al., 2016). Recognise Online was employed to measure both variables, and it was used the 'hand' version. The accuracy of the response is described as the percentage of correct answers of laterality discrimination, which is the ability to identify a body part as being left or right. Response time is defined as the time between the beginning of a stimulus (emergence of the image on the screen) and the observed response (right/left choice). The internal and external validity was established before the application was online. Trials were conducted using a panel of images tested with the letters 'L' for 'left' and 'R' for 'right' and the numbers 1 to 4 to indicate the degree of rotation. The reliability of the Recognise Online application has previously been established in populations with and without pain (Bray and Moseley, 2011). The intraclass correlation coefficient (ICC) response time only was described for 'feet' (ICC 1⁄4 0.63–0.75) and 'trunk' (ICC 1⁄4 0.51–0.91).

**Procedures**

Each participant was given an informed consent document to participate in the study, and also a questionnaire containing data on age, body mass index (BMI), gender, physical activity, educational level and employment level.

Then MIQ-R, mental chronometry and laterality were assessed, to ensure that all the subjects had a similar ability to generate mental motor images. Afterwards, they were taken the pre-intervention measurements of the Purdue Pegboard. Subsequently, in a sitting position, patients performed the AO, MI, 2MI or PO protocol, according to their group. Immediately after the intervention, a blinded evaluator measured the perceived mental fatigue and took the post-intervention measurements of the Purdue Pegboard test. Ultimately, MIQ-R, mental chronometry and Purdue Pegboard test were measured again, by the blinded evaluator, at 1-week post-intervention.

**Statistical analysis**

The statistical analysis was executed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA).

Descriptive statistics were utilised to summarize the data for the continuous variables and are presented as mean ± standard deviation and 95% confidence interval. A two-way repeated measures analysis of variance (ANOVA) was conducted to study the effect of the between-subject factor 'intervention group' with four categories (i.e., AO MI, 2MI and PO) and the within- subject called 'time' with also three categories (i.e., pre-intervention, post-intervention, and 1-week post-intervention) on the dependent variables. Partial eta squared ($\eta_p^2$) was calculated as a measure of effect size (strength of association) for each main effect and interaction in the ANOVAs, with 0.01–0.059 representing a small effect, 0.06–0.139 a medium effect and >0.14 a large effect (Cohen, 1973). A post hoc analysis with Bonferroni correction was performed in the case of significant ANOVA findings for multiple comparisons between variables. Effect sizes (d) were calculated according to Cohen's method, in which the magnitude of the effect was classified as small (0.20–0.49), moderate (0.50–0.79) or large (0.8). The α level was set at .05 for all tests. Moreover, we compared baselines between groups, to explore whether the groups were homogeneous at baseline with a One-way ANOVA.

## RESULTS

A total of 20 asymptomatic participants were included in the present pilot study and were randomly allocated into 4 groups of n = 5 participants per group. No adverse events or loss to follow up were reported in either group. No statistically significant differences in demographic data were present pre-intervention between the groups and the self-report variables, except for the left accuracy ($p = .019$) and the total accuracy ($p = .015$) **(Table 1)**.

**Purdue Pegboard test scores**

Regarding the right-hand test, the ANOVA revealed significant changes during time ($F$ = 10.36, $p$ < .001, $\eta_p^2$ = .393) but not, in the group*time interaction ($F$ = 0.67, $p$ = .672, $\eta_p^2$ = .112). Post hoc analysis showed no significant between-group differences ($p$ > .05). Regarding within-group differences, only AO group showed pre-post and also pre-1-week post-intervention significant differences with a large effect size ($p$ = .049, $d$ = -1.28 and $p$ = .049, $d$ = -1.4). No within-group statistically differences were found in MI, 2MI and PO ($p$ > .05) **(Table 2)**.

With respect to the left hand test, the ANOVA

**Table 1**. Descriptive statistics of socio-demographic data.

| Measures | AO Group (n = 5) | MI Group (n = 5) | 2MI Group (n = 5) | PO group (n = 5) | *p* value |
|---|---|---|---|---|---|
| Age | 45.00 ± 13.7 | 31.8 ± 13.7 | 33.0 ± 15.1 | 39.2 ± 20.0 | .543 |
| BMI | 24.2 ± 2.5 | 23.7 ± 4.2 | 21.9 ± 4.6 | 23.6 ± 2.8 | .779 |
| MIQ- Total | 51.0 ± 5.8 | 45.0 ± 6.6 | 47.8 ± 6.5 | 48.8 ± 5.6 | .501 |
| Time R- Total | 17.9 ± 3.2 | 14.6 ± 1.5 | 15.0 ± 3.0 | 14.5 ± 2.7 | .180 |
| Time I- Total | 20.5 ± 6.9 | 17.1 ± 5.9 | 18.5 ± 5.5 | 15.1 ± .6 | .450 |
| MIQR_K | 25.2 ± 3.0 | 21.0 ± 5.3 | 21.2 ± 5.3 | 24.2 ± 4.1 | .380 |
| Time_KR | 9.0 ± 1.7 | 7.3 ± .9 | 7.8 ± 1.5 | 7.4 ± 1.6 | .261 |
| Time_KI | 10.8 ± 3.5 | 9.6 ± 3.6 | 10.2 ± 3.6 | 7.3 ± .4 | .328 |
| MIQR_V | 25.8 ± 2.9 | 24.0 ± 3.7 | 26.6 ± 1.9 | 24.6 ± 2.9 | .524 |
| Time_VR | 8.9 ± 1.7 | 7.3 ± .6 | 7.2 ± 1.6 | 7.1 ± 1.6 | .140 |
| Time_VI | 9.7 ± 3.7 | 7.5 ± 3.4 | 8.3 ± 2.4 | 7.8 ± .5 | .596 |
| IPAQ_T | 4722.5 ± 2982.9 | 2802.7 ± 1280.8 | 3835.3 ± 2188.6 | 7322.4 ± 4677.0 | .153 |
| Lat-R % accuracy | 74.0 ± 15.2 | 90.0 ± .0 | 84.0 ± 15.2 | 68.0 ± 13.0 | .057 |
| Lat-L % accuracy | 70.0 ± 12.2 | 96.0 ± 5.5 | 90.0 ± 7.1 | 76.0 ± 20,7 | .019* |
| Lat-T % accuracy | 72.0 ± 12.6 | 93.0 ± 2.7 | 87.0 ± 7.6 | 72.0 ± 16.0 | .015* |
| Time R-Lat | 3.8 ± 1.3 | 2.9 ± 1.1 | 2,7 ± 1.3 | 2.5 ± 2.1 | .547 |
| Time L-Lat | 3.2 ± .9 | 3.9 ± 1.1 | 3.6 ± 1.5 | 2.9 ± 1,7 | .696 |
| Time Lat Total | 3.5 ± 1.0 | 3.4 ± .9 | 3.2 ± 1.2 | 2.7 ± 1.8 | .787 |
| **Gender** | | | | | .11 |
| Male | 2 (40.0) | 0 (0.0) | 1 (20.0) | 2 (40.0) | |
| Female | 3 (60.0) | 5 (100.0) | 4 (80.0) | 3 (60.0) | |
| **Educational Level** | | | | | 1.0 |
| Primary education | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |
| Secondary education | 2 (40.0) | 2 (40.0) | 2 (40.0) | 2 (40.0) | |
| College education | 3 (60.0) | 3 (60.0) | 3 (60.0) | 3 (60.0) | |
| **Employment Level** | | | | | .456 |
| Student | 0 (0.0) | 2 (40.0) | 3 (60.0) | 2 (40.0) | |
| Employed | 4 (80.0) | 3 (60.0) | 1 (20.0) | 2 (40.0) | |
| Unemployed | 1 (20.0) | 0 (0.0) | 1 (20.0) | 1 (20.0) | |
| **Dominant Hand** | | | | | .368 |
| Right | 4 (80.0) | 5 (100.0) | 5 (100.0) | 5 (100.0) | |
| Left | 1 (20.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |

Values are presented as mean ± standard deviation or number (%); AO: Action observation MI: Motor Imagery; 2MI: Double-time Motor Imagery; PO: Placebo Observation; BMI: Body Mass Index revealed significant change during time ($F$ = 5.03, $p$ = .013, $\eta_p^2$ = .239) but not in the group*time interaction ($F$ = .78, $p$ = .595, $\eta_p^2$ = .127). Post hoc analysis showed significant between-group differences in the comparison of MI with PO group in the post-intervention with a large effect size ($p$ = .016, $d$ = 2.21). No within-group statistically differences were found in any group ($p$ > .05) **(Table 3)**.

With regard to the both hands, the ANOVA revealed significant changes during time ($F$ = 6.61, $p$ = .004, $\eta_p^2$ = .292) but not, in the group*time interaction ($F$ = 1.79, $p$ = .134, $\eta_p^2$ = .251). Post hoc analysis showed no significant between-group differences ($p$ > .05). Regarding within-group differences, only MI group showed pre-post and also pre-1-week post-intervention significant differences with a large effect size ($p$ = .006, $d$ = -2.28 and $p$ = .009, $d$ = -1.89). No within-group statistically differences were found in OA, 2MI and PO ($p$ > .05) **(Table 4)**.

Regarding the sequence test, the ANOVA revealed significant changes during time ($F$ = 6.04, $p$ = .006, $\eta_p^2$ = .274) but not in the group*time interaction ($F$ = .49, $p$ = .811, $\eta_p^2$ = .084). However, post hoc analysis showed no significant between-groups differences ($p$ > .05). No within-group statistically differences were found un any group ($p$ > .05).

**Perceived fatigue**

With respect to the perceived fatigue, one-way ANOVA showed statistically significant differences ($F$ = 6.6, $p$ = .04). Post hoc analysis showed statistically between-group differences in AO group in comparison with MI ($p$ = .003, 95%CI -9.2 to -1.6), and 2MI ($p$ = .045, 95%CI -7.6 to -.06) showing greater levels of fatigue in both MI groups. Finally, no statistically significant between-group differences were found regarding the comparison between MI and 2MI groups ($p$ > .05) **(Figure 3)**.

**Ability to imagine**

Regarding the total score of MIQ-R, the ANOVA showed no significant differences in time ($F$ = 2.765, $p$ = .116, $\eta_p^2$ = .147) nor in group*time interaction ($F$ = 2.731, $p$ = .078, $\eta_p^2$ = .339).

With regard to the kinesthetic subscale of MIQ-R, the ANOVA showed no significant differences in time ($F$ = 3.96, $p$ = .064, $\eta_p^2$ = .198) nor in

**Table 2.** Comparative analysis of right-hand test.

| Measure | Group | Mean ± SD | | | Mean difference(95%CI); Effect Size (*d*) |
|---|---|---|---|---|---|
| Right hand test | | Pre | Post | 1-week post | a) (Pre) vs. (Post)<br>b) (Pre) vs. (1-week post)<br>c) (Post) vs. (1-week post) |
| | AO | 13.4 ± 2.3 | 15.8 ± 1.3 | 16.6 ± 2.3 | a) -2.4* (-4.8 to -.01) *d*= -1.28<br>b) -3.2* (-6.4 to -.02) *d*= -1.39<br>c) -.8 (-3.4 to 1.8) *d*= -.43 |
| | MI | 15.4 ± .9 | 16.6 ± 1.7 | 18.4 ± 1.7 | a) -1.2 (-3.6 to 1.2); *d*= -.88<br>b) -3.0 (-6.2 to -.2); *d*= -2.2<br>c) -1.8 (-4.4 to .8); *d*= -1.06 |
| | 2MI | 14.8 ± 1.1 | 15.8 ± .8 | 17.0 ± 3.0 | a) -1.0 (-3.4 to 1.4); *d*= -1.04<br>b) -2.2 (-5.4 to .99); *d*= -.97<br>c) -1.2 (-3.8 to 1.4); *d*= -.55 |
| | PO | 15.0 ± 2.1 | 15.0 ± .7 | 16.0 ± 2.6 | a) .00 (-2.4 to 2.4); *d*= 0<br>b) -1.0 (-4.2 to 2.2); *d*= -.42<br>c) -1.0 (-3.6 to 1.6); *d*= -.53 |

*p< .05; AO: Action observation MI: Motor Imagery; 2MI: Double-time Motor Imagery; PO: Placebo Observation

group*time interaction ($F$ = .48, $p$ = .701, $\eta_p^2$ = .082).

Regarding the visual subscale of MIQ-R, the ANOVA showed no significant differences in time ($F$ = .24, $p$ = .633, $\eta_p^2$ = .015) nor in group*time interaction ($F$ = 2.29, $p$ = .117, $\eta_p^2$ = .301).

With reference to the synchronization (I time/R time), the ANOVA showed no significant differences in time ($F$ = 0.671, $p$ = .425, $\eta_p^2$ = .040) nor in group*time interaction ($F$ = 1.46, $p$ = .263, $\eta_p^2$ = .215).

### Sample size calculation

The sample size was estimated with the program G*Power 3.1.7 for Windows (G*Power from University of Dusseldorf, Germany) (Faul et al., 2007). The sample size calculation was considered as a power calculation to detect between-group differences in a primary outcome measures (test 2, left hand). We considered four groups and three measurements for primary outcomes to obtain 80% statistical power (1- $\beta$ error probability) with an α error level probability of 0.05 using analysis of variance (ANOVA) of repeated measures, within-between interaction, and an effect size of $\eta_p^2$ = 0.127 obtained from our results. This generated a sample size of total of 56 participants plus an estimated 15% loss in follow-up, yielding a total of 64 participants (16 per group).

## DISCUSSION

It was hypothesised that doubling MI training time would produce the same effects as AO training on motor learning and would therefore be greater than training with half the duration of MI. The results obtained in the right-hand test showed that only the AO group obtained improvements in the motor

**Table 3.** Comparative analysis of left-hand test.

| Measure | Group | Mean ± SD | | | Mean difference(95%CI); Effect Size (*d*) |
|---|---|---|---|---|---|
| Left hand test | | Pre | Post | 1-Week | **a) (Pre) vs. (Post)**<br>**b) (Pre) vs. (1-week post)**<br>**c) (Post) vs. (1-week post)** |
| | AO | 13.6 ± 2.2 | 14.2 ± 1.6 | 14.2 ± 2.6 | a) -.60 (-3.1 to 1.9) *d*= -.31<br>b) -.60 (-2.9 to 1.7) *d*= -.25<br>c) .00 (-2.2 to 2.2) *d*= 0 |
| | MI | 15.0 ± 1.2 | 16.0 ± 2.1 | 15.8 ± 1.9 | a) -1.0 (-3.5 to 1.5); *d*= -.58<br>b) -.80 (-3.1 to 1.5); *d*= -.50<br>c) .20 (-2.0 to 2.4); *d*= 0.1 |
| | 2MI | 13.6 ± 1.3 | 15.2 ± 1.3 | 15.2 ± 1.1 | a) -1.6 (-4.1 to .86); *d*= -1.23<br>b) -1.6 (-3.9 to .72); *d*= -1.33<br>c) .00 (-2.2 to 2.2); *d*= 0 |
| | PO | 12.0 ± 2.3 | 12.6 ± .55 | 14.4 ± 1.3 | a) -.60 (-3.1 to 1.9); *d*= -.36<br>b) -2.4* (-4.7 to -.08); *d*= -1.28<br>c) -1.8 (-4.0 to .43); *d*= -1.80 |
| Mean Difference(95%CI); Effect Size (*d*) | MI vs. PO | 3.0 ± 1.17 (-.51 to 6.5); *d*= 1.64 | 3.4* ± .96 (.52 to 6.3); *d*= 2.21 | 1.4 ± 1.16 (-2.1 to 4.9); *d*= 0.86 | |
| | MI vs AO | 1.4 ± 1.17 (-2.11 to 4.91); *d*= 0.79 | 1.8 ± .96 (-1.09 to 4.69) *d*= 0.96 | 1.6 ± 1.16 (-1.88 to 5.08) *d*= 0.70 | |
| | MI vs 2MI | 1.4 ± 1.17 (-2.11 to 4.91) *d*= 1.12 | .80 ± .96 (-2.09 to 3.69) *d*= 0.46 | .60 ± 1.16 (-2.88 to 4.08) *d*= 0.39 | |

*p< .05; AO: Action observation MI: Motor Imagery; 2MI: Double-time Motor Imagery; PO: Placebo Observation

learning at the end of both post- and also 1-week post-intervention. However, in the left-hand test only MI group obtained greater improvements than the PO group in the post-intervention. In addition, in both hand test, only MI presented differences in both post- and also 1-week post-intervention. No significant within- or between-group differences were found in Sequence Test. Regarding the secondary outcomes, greater levels of perceived fatigue were found in both MI groups. Nonetheless, there was no significant difference between both imagery groups. With regard to the other secondary outcomes, no within- or between-group changes were found.

The results of the present study are unclear, probably due to the low sample size. Although the study does not show statistically significant results in most variables, the statistical power is high, so there is a high probability that we are making a type II (or β error).

Several studies have been conducted on motor learning. Even if there are several current theories on the neurophysiological processes involved on motor learning, all of them agree that when an individual learns a new motor task a neuroplasticity process occurs during the phases of acquisition, consolidation and automation or retention of the task (Dayan and Cohen, 2011). Physical practice is undoubtedly a cardinal aspect in acquiring and consolidating a motor task (Robertson et al., 2004). Besides, the representation practice of motor gestures produces cortical representations and neural substrates similar to those produced by real practice, making MI and AO relevant motor learning strategies (Ehrsson et al., 2003).

The results acquired in the right-hand test suggest that AO promotes motor learning, since subjects achieved improvements at the post-intervention and were maintained at 1-week post-intervention. These findings are consistent with current literature, as there is ample evidence that visual inputs provided through observing the action of others can enhance motor learning (Stefan et al., 2005). Previous studies have shown that AO could result in the acquisition of a neural representation related to appropriate movement kinematics (Stefan et al., 2005), coordination patterns (Hodges et al., 2007) and spatial–temporal goals (Vogt, 1995). These discoveries are also in line with the findings related

**Table 4.** Comparative analysis of both hand test.

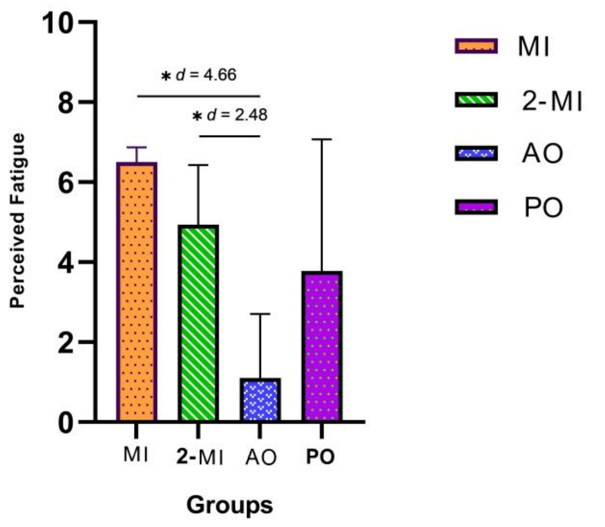
| Measure | Group | Mean ± SD | | | Mean difference(95%CI); Effect Size (*d*) |
|---|---|---|---|---|---|
| Both hand test | | Pre | Post | 1-Week | **a) (Pre) vs. (Post)**<br>**b) (Pre) vs. (1-week post)**<br>**c) (Post) vs. (1-week post)** |
| | AO | 11.2 ± 1.3 | 11.8 ± 1.5 | 12.6 ± 1.9 | a) -.60 (-2.3 to 1.1) *d*= -.43<br>b) -1.4 (-3.99 to 1.2) *d*= -.86<br>c) -.80 (-2.8 to 1.2) *d*= -.47 |
| | MI | 10.6 ± 1.1 | 13.0 ± 1.0 | 14.0 ± 2.3 | a) -2.4* (-4.1 to -.66); *d*= -2.28<br>b) -3.4* (-5.99 to -.82); *d*= -1.89<br>c) -1.0 (-3.04 to 1.04); *d*= -.56 |
| | 2MI | 12.0 ± 1.9 | 11.8± 1.6 | 12.6 ± .55 | a) .20 (-1.5 to 1.9); *d*= .11<br>b) -.60 (-3.2 to 1.99); *d*= -.43<br>c) -.80 (-2.8 to 1.2); *d*= -.67 |
| | PO | 11.0 ± 1.7 | 11.8 ± 2.3 | 11.4 ± 2.1 | a) -.80 (-2.5 to .94); *d*= -.39<br>b) -.40 (-2.99 to 2.2); *d*= -.21<br>c) .40 (-1.6 to 2.44); *d*= .18 |

*p< .05; AO: Action observation MI: Motor Imagery; 2MI: Double-time Motor Imagery; PO: Placebo Observation

to the mirror neurons that fire not only when one makes a movement, but also when someone observes another who performs the same movement (Rizzolatti and Craighero, 2004).

Regarding the results obtained in the left-hand test, MI seems to be effective in acquiring a new motor skill, since MI training group obtained better results than PO group. In addition, in both hand test, only MI presented differences in the post- and also at 1-week post-intervention. This results are consistent with existing literature that MI can enhance movement an learning in healthy adults (Malouin et al., 2013). Previous studies have shown that MI duration may impact imagery efficacy (Etnier, J. L., & Landers, 1996). Some authors suggest that the optimal time for MI to provide the greatest benefits is between 10 and 15 mins, which is in line with our findings, as only those who performed MI task for 10 minutes obtained statistically significant better results. According to this finding, doubling MI time may not be sufficient to cause the same effects as AO on motor learning and some other variables, such as, imagery perspective (Callow and Hardy, 2004), imagery type (Nordin and Cumming, 2005), attention focus during imagery (Caliari, 2008), imagery speed (Jenny and Munroe-Chandler, 2016), apart from increasing intervention time should be considered.

**Figure 3.** Representation levels of perceived mental fatigue.




MI: motor imagery; AO: action observation; PO: placebo group

According to previous research, MI seems to be more cognitively demanding in comparison to AO (Buccino, 2014). In fact, previous studies have shown that movements representation through MI can cause mental fatigue. According to some authors, it is possible that intensive movement representation training could induce mental fatigue that would also directly affect the maintenance of attention on the task and the coding of the task information (Boksem et al., 2005). This loss of attention might be more pronounced in MI than in AO training (Guillot et al., 2004). The results obtained in the present study are consistent with previous findings, as both imagery groups, MI and 2MI, showed greater levels of fatigue. However, in contrast to other authors (Talukdar et al., 2019), increasing imagery time did not result in more noticeable fatigue. This result could be interesting, but it should be interpreted with caution because of the low sample size of the study. Probably the subjects within the longest MI group stopped imagining at some point during the intervention.

The scores of both the MIQ-R and the mental chronometry were utilized with the objective of evaluating the ability to generate both kinesthetic and visual motor images of the subjects of study. The results found on the MIQ-R questionnaire were high in all groups, and there were no differences between them, therefore showing that the subjects had a great ability to generate mental motor images. The MIQ-R scores obtained in our study, similar to those found by others (Guillot et al., 2008), indicate that the participants can be considered as “good imagers”. Good imagers usually show higher activity in brain regions that play a critical role in the generation of mental images (Guillot et al., 2008). In addition, although the proven effects of MI practice on motor performance, how inter-individual differences regarding the ability to generate mental motor images influence motor performance improvement by MI practice is still under debate (Lebon et al., 2010). According to some authors, the improvements on motor learning after the mental training do not appear to cause increases in the ability to imagine, findings that are in line with the results obtained in the present study. The results further suggest that the MIQ-R was not sufficient to discriminate imagery ability differences and should be associated with other measures of imagery vividness. The results obtained might be related to a ceiling effect because of the selection of good imagers (Guillot et al., 2010).

Several studies have demonstrated that unknown, uncommon, and uncomfortable movements can lead to differences in the time invested between the imagined and real execution (Rieger, 2012). It is possible that no differences were found in the present study, as subjects were asked to perform very simple and common movements. Another explanation could be that the study was conducted with asymptomatic subjects, who had a good ability to imagine.

### Limitations

This study presents several limitations. First, the sample size is small; thus, the results should be considered with caution. Second, the results have only been assessed in short term; it might be interesting to consider the impact of the intervention in the medium and long term. The difficulty in generating motor images was measured through an instrument of self-report and by a mental chronometry task. Even if we consider that these instruments have a good reliability, it would be interesting for future studies to use neural functional images. In addition, the neurovegetative system could have been evaluated to observe changes during the imagination process. Finally, the study was conducted with healthy participants. It is not possible to extrapolate the results to patients who have pain or functional disorders.

## CONCLUSION

Our results suggest that AO and MI are effective tools for acquiring new motor skills, since both interventions showed improvements at least in one of the Purdue Pegboard tests at both post- and also at 1-week post-intervention. Regarding the perceived fatigue, MI seems to cause more fatigue than AO. However, increasing imagery time did not results in greater level of perceived mental fatigue. In addition, the improvements on motor learning after the mental training do not appear to cause increases in the ability to imagine. Further research is needed to conclude whether motor imagery could somehow match the effects of action observation on motor learning.

### FRASES DESTACADAS

- All results of the present work must be considered with great caution due to the low sample size.
- 2MI (double time) did not result in increased motor learning compared to AO training
- MI presented greater fatigue than AO, however, there were no significant differences between MI and 2MI.

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