Effect of motor imagery and actual practice on learning professional medical skills

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Research article

Keywords: motor imagery, motor learning, professional medical skills

Posted Date: April 16th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-22437/v1

Version of Record: A version of this preprint was published on January 18th, 2021. See the published version at https://doi.org/10.1186/s12909-020-02424-7.

Abstract

Background The peripheral venous catheter (PVC) is the most frequently used medical device in hospital care to administer intravenous treatment or to take blood samples by introducing a catheter into a vein. The aim of this study was to examine the effect of motor imagery (MI) associated with actual training on the learning of PVC insertion into a simulated venous system.

Method: This is a prospective monocentre study in 3rd year medical students. Forty medical students were randomly assigned to the experimental group (n = 20) performing both real practice and MI of PVC insertion or to the control group (n = 20) trained through real practice only. We also recruited a reference group of 20 professional nurses defining the benchmark for a target performance.

Results The experimental group learned the PVC insertion faster than the control group in the first learning phase ($p < 0.001$), reaching the expected reference level after 4 sessions ($p = .87$) whereas the control group needed 5 sessions to reach the same level ($p = .88$). Both groups were at the same level at the end of the scheduled training.

Conclusions MI may thus improve professional motor skills learning, and therefore limit the time needed to reach the expected level. Therefore, MI may strengthen technical medical skill learning.

Background

The insertion of peripheral venous catheter (PVC) is one of the most common medical procedures used by clinicians. It needs inserting a catheter into a vein to administer intravenous therapy or to allow blood collection. There are potential septic risks for the patient, [1] thus, learning how to insert a PVC prevents potential traumatic or infectious lesions and limits the risk of errors. [2–4] Medical techniques are learnt through training procedures. However, due to the short time allocated, and the amount of students involved, the training time is often limited. Mental simulation may provide alternative methods. [5] With respect to the principle: *"never the first time on the patient"*, [6] simulation may offer a reliable framework without any risk (practiced on a manikin). It may also be based on mental representation [7–10], several studies investigating its benefice in learning medical skills. [2, 3, 4, 10, 11, 12] Motor imagery (MI) is a cognitive process of mentally recalling the sensory information generated by the actual execution. [4, 13] through visual or kinesthetic imagery. We represent our own actions through their main visual features (shapes, outlines, colour and movements) or through bodily-evoked sensations. Information is recalled from procedural memory without any movement, whether it comes from static (attitude and position) or dynamic information from body segments, e.g. speed, amplitude, force, pressure. [12, 14]

MI has extensively been used in sports, music or medicine [15] with various goals, in particular learning motor skill and recovering motor ability after injury. [4, 5, 16] MI duration shares similar constraints to those of actual action and took the same time as that needed for actual execution. MI respects spatial constraints, and associating MI with actual practice is more effective than mental or physical practice alone. [12] In addition, MI activates motor/pre-motor regions, the parietal cortex, and subcortical structures (basal ganglia, cerebellum), i.e. a similar activation as that observed during actual execution. [17, 18]

Several studies highlighted the positive effects of MI in surgery and motor rehabilitation. [10, 21–25] MI improved the seizure-grasping abilities of C6-C7 quadriplegic patients through decreased of both movement time and trajectory variability thus revealing brain adaptations. [14] It is particularly effective in cognitively demanding tasks e.g. in surgical techniques. [26, 27] Experienced surgeons view MI as the most effective procedure for preparing for complex and stressful situations [9, 13, 26]. Minimally invasive surgery requires the ability to self-represent the spatial environment in which surgery will take place. [28] MI can adequately plan the needed actions before their execution and complete the usual way to learn medical techniques by memorizing mental references for real practice. [14, 26, 29] Training through mixed practice of actual and MI of suturing a pig's foot led to perform as well as actual practice alone. [25] MI thus provided the same performance as real repetitions, after initial training with actual practice. [30] MI also led surgeons to transfer their abilities to real surgery, unlike another group who read texts about surgery during equivalent time. [25]. Finally, MI improved laparoscopic performance of novice surgeons by reducing the time required for repetitions of the cholecystectomy procedure and providing better quality of movements execution. [3] Eldred-Evans et al. (2013) confirmed that associating MI to real practice favoured surgical skills learning in laparoscopy. [7]

The extent to which MI can substitute and compensate for the effect of actual practice should be better investigated as well as its potential effects on learning medico-surgical techniques under limited practice time. The main objective of this study was to assess whether MI associated with actual training improved PVC insertion.

Methods

Experimental design

The experiment included a pretest (session 1), 4 learning sessions and a post-test (session 6) as summarized in Table I. During the first session, the students watched an instructional video on PVC insertion, then performed the technique twice under the supervision of 2 trainers that were naive in relation to the objectives of the experiment. Each student inserted the PVC on a double skin placed on the forearm of another student. It was an elastomeric venous system into which simulated blood was introduced through a syringe. The experimenters evaluated the quality of the PVC insertion through the respect of each stage using a common rating scale where they indicated whether the participants respected the afordmentioned steps or not. We also recorded the timing of the PVC insertion.

At the end of the first session, we evaluated the students MI ability with the Motor Imagery Questionnaire (MIQ-3), [31] and a mental chronometry test (Figure 1). We used the most recent version of the Movement Imagery Questionnaire (MIQ-3), early proposed by Hall and Pongrac (1983) [32] and later revised by Hall and Martin (1997). [33] This test consists of 12 elements describing real motor situations to be mentally reproduced. The participants assessed each item through a 7-level Likert scale (maximal score = 84 points) and then performed the mental chronometry test on a A4 printed sheet. The test requested to point towards 8 targets placed on two circles in a predetermined order, at free self-pace. The first 4 pointing towards the targets of the small circle were clockwise, and the next four, on the large circle, counterclockwise. The participants started from the center of the circles and went back to this position, after pointing towards each target (Figure 1). Both served as landmarks for each participant to start and stop the timer during MI. We recorded the timing of the 8 pointing during actual execution. Then, each participant mentally performed the same task. The comparison of real and imagined timing was an index of MI quality. The more MI duration matched actual duration (i.e. isochrony), the better the quality of MI, relative to speed preservation. As both the MIQ-3 and pointing towards targets tests addressed different components of MI quality, Williams et al. (2015) advised to use them together for a more comprehensive assessment of motor imagery ability. [34]

***** Please Insert Table 1 around here*****

***** Please Insert Figure 1 around here*****

Patient and public involvement

The participants were forty third-year medical students (23 women, 17 men, mean aged 20.6 ± 1.0) at Claude Bernard University Lyon 1, France. We also requested twenty professional nurses (aged 40.4 ± 4.0) to form the reference group (ref). The experiment did not involve any patient. All participants signed an informed-consent form before starting the study. The management and ethics committee of the Faculty of Medicine (Lyon-Est) approved the experimental design after the experimenters presented the objectives and procedures to the scientific board council. The study also obtained the scientific support of the Center for Education through Simulation in Health (CLESS), hosted by Lyon1 University. We randomly divided the 40 students into two homogeneous groups, the experimental (exp - 13 women and 7 men, mean age = 20.5, ± 1) and the control (ctrl - 10 women and 10 men, mean age = 20.7 ± 0.7), according to their gender, MI abilities and early performance in PVC insertion. We based the exp group training on the association of actual practice (AR) and motor imagery (MI). We requested the ctrl group to perform actual practice with a neutral task (looking at videos about medical care and articles related to ethics and palliative care) for equivalent duration as to the exp group. Although we kept a link with clinical care, the neutral task avoided any relation with MI. Thus, the exp and the ctrl groups trained during 4 successive sessions after the pre-test, performed the post-test and then, the retention test. The overall design was spread over 8 weeks to distribute the learning sequences across time. The ref group only performed the pre-test and the post-test.

We requested the exp group to alternatively perform actual practice and MI according to the experimental design we scheduled, i.e. increasing the rate of MI trials across sessions. The whole workload in the exp group was 36 trials (18 actual and 18 MI).

We read the MI script once for the first MI trial when starting each session as follow: i) Isolate yourself from the environment by closing your eyes and disregard the possible sound environment; ii) Represent all steps of the PVC insertion as an actor, i.e. as if you had to perform the movement yourself; iii) Use sensory information as a support for the construction of MI, mainly tactile (contact with patient's skin and all materials), visual (vein tracking, angle control between the needle and the skin) and proprioceptive (muscle effort, joint position, resistance offered by the skin to the needle insertion ...); iv) Stay motionless during MI, without mimicking the action; v) Start the sequence when spreading and stretching the skin; vi) Stop the action when you place the mandrel into the needle collector.

The MI script clearly described the main steps of the sequence, with the key information for a skilled execution.We thus gave several advices as follow: “When you represent the action, visualize all movements as parts of the action. To do this, close your eyes and try to clearly perceive all the steps of the PVC insertion, as if you were actually performing the movement. You should not move or mimic the movement. Place yourself in relation to the patient, as if you were going to actually make the needle insertion.

1. Spread and stretch the skin with your left hand. Locate the exact place where you need to insert the needle.
2. Check the needle-skin angle the before insertion.
3. Insert the needle into the vein by exerting the proper force, try to perceive the resistance feedback of the tissues the needle crosses.
4. When in the vein lumen, stabilize the needle.
5. Insert the catheter, bevel up. Check that the angle is correct, apply the appropriate force, perceive the resistance that the tissues oppose to you.
6. Force the passage of the catheter into the vein lumen.
7. Monitor the arrival of blood in the mandrel.
8. Slowly slide the catheter over the needle to position it in the vein.
9. Loosen the tourniquet with one hand and hold the catheter with the other.
10. Place the mandrel into the needle collector.

Since PVC insertion is a complex procedure, we determined two accurate boundaries separating starting (“spreading and stretching the skin …”) from ending (“placing the mandrel into the needle collector”). We therefore studied a specific part of the whole PVC insertion so that the MI script can be easily understood and memorized, with both accurate timing during actual execution and MI.

Dependent variables

The *duration of actual PVC insertion* was an index of skilled action. We thus timed the last actual trial of each participant, at the end of each session in the exp and ctrl groups. We also timed *MI accuracy* from sessions 2 to 5, by comparing actual duration to that of the imagined action. The exp group triggered the timer when starting the MI sequence and stopped it at the end. We also assessed the *vividness* of MI on a 7-level Likert scale, from very blurred image (level 1) to a ultra-high definition image (level 7), intermediate levels being used for intermediate vividness.

Two expert instructors evaluated the *quality of the PVC insertion* in the exp and the ctrl groups. They were naive with respect to the objectives of the study and uninformed of the participants' home group. They used a specific evaluation grid from the CLESS pedagogical team, made of 5 items that should be considered "reached" or "not reached" and completed at the end of each session. We assessed the quality of the PVC insertion during the last physical trial of each session, and gave a feedback to each participant to help them better memorizing the procedure. This grid served to guide the participants with a formative objective only and was not included into the statistical design. Only the actual duration was the dependent variable in the ref group. We timed a real trial to be compared with that of the exp and ctrl groups.

The participants completed the retention test one month after the post-test. Each participant only performed one real trial and, additionnaly, those of the exp group performed one MI trial. We evaluated the quality of the PVC insertion similarly as during previous tests (actual and MI duration).

Statistical analysis

We processed data of the last real trial of each session with a repeated-measures ANOVA. We then compared performance evolution of the exp group with that of both the ctrl and the ref groups. We also performed a repeated-measures ANOVA comparing the actual duration to that of MI in the exp group. We used Tukey's post-hoc tests for two-by-two comparison, provided that the analysis of variance reached the statistical threshold, set at .05.

Results

During the pretest, the average duration of PVC insertion was 23.8 ± 4.8 s in the exp group and 23.3 ± 5.1 s in the ctrl group. There was no statistical difference between the two. The ANOVA with repeated measures showed a group effect on all the sessions, $F(6, 34) = 97.35$, $p < 0.05$. The exp group significantly outperformed the ctrl group, at the end of the second session (Tukey test, $p < 0.001$), mean durations being 17.6 ± 4.3 s and 21.9 ± 4.7 s in the exp and the ctrl group, respectively. This difference was cleared at the end of the 5th session, duration of actual PVC insertion in both groups being comparable (Fig. 2).

*****Please Insert** Fig. 2 **around here*****

The ANOVA with repeated measures did not show any differences in the quality of PVC insertion between the exp and the ctrl groups during all sessions: F=(6, 34), $p = 0.47$, NS.

We then compared the performance of both the exp and ctrl groups with those of the ref group at the end of the last 3 sessions (the 3rd, 4th and 5th). The ANOVA with repeated measures showed a group effect ($F(2, 58) = 17.46$, $p < 0.001$), only during the third session. The Tukey test evidenced that the ref group performed significantly better than both the exp ($p < 0.01$) and the ctrl ($p < 0.001$) groups. The exp, ref and ctrl group means were 15.5 s (± 3.1), 12.4 s (± 3.4), and 17.9 s (± 2.1) respectively (Fig. 3).

***** Please Insert** Fig. 3 **around here*****

The ANOVA with repeated measures showed a group effect during the 4th session, $F(2, 58) = 10.4$, $p < 0.001$. The exp group performed at the level of the ref group (Tukey test, p = .87, NS), whereas the latter still outperformed the ctrl group (Tukey test, $p < 0.001$). No difference emerged when comparing the exp group to the ctrl group. Mean values were respectively 12.8 s (± 2.1), 12.4 s (± 3.4) and 15.9 s (± 3.2) in the exp, ref and ctrl (see Fig. 3).

The ANOVA with repeated measures did not show any group effect during the 5th session, $F(2, 58) = 0.13$, p = .88, mean values being 11.90 (± 2.66), 12.41 (± 3.42), 12.23 (± 2.78) in the exp, ref and ctrl, respectively.

Comparaison of actual duration (AD) to MI duration of (MI_D) in the exp group

The ANOVA with repeated measures comparing actual duration (AD) to MI duration (MI_D) showed a marginally significant difference, $F(5, 35) = 3.54$, p = .07. The Tukey test confirmed that only session 2 exhibited differences between actual and MI duration, mean (SD) being 17.6 (± 4.7) and 13.3 (± 4.3), respectively (see Fig. 4).

*** Please Insert Fig. 4 around here***

Discussion

The main objective of the experiment was to study the effect of Motor imagery (MI) associated with actual practice on the ability to learn how to insert a PVC. We hypothesized that MI should improve learning and make the skills more effective after a six-session training period. [3, 7, 16] We tested the quality and the speed of PVC insertion, two factors attesting that performance reached this goal,. The exp group placed the PVC faster than the ctrl group as early as the second session. The quality of PVC placement was assessed by blind experts and was comparable in both groups during the training sessions and the retention test. Therefore, MI training only improved the speed, but not the quality of the skill. The exp group reached the expected level after 4 sessions, thus faster than the ctrl group. This was due to MI training since we observed isochrony from the third session while the quality of MI remained at the same level. A gain in speed usually causes a decrease in accuracy, as described by Fitts law (1964). [35] We thus could have had an improvement in speed at the expense of execution quality. The speed was improved but not in conjunction with a decrease in accuracy. The participants may have given priority to accuracy as it was not deteriorated by speed improvement during learning. Indeed, the first requirement of the PVC insertion was the accuracy as it is a fine and complex skill. Secondly, the experiment did not include temporal constraints. Time pressure is worthy to be included into the protocol as it is a frequent factor in clinical practice. We did not test this variable as the participants were novice in PVC insertion. In more experienced people, automation would be the response to time pressure, high speed constraints and accuracy requirement as automated skills are highly resistant to any external (distractor) or internal disturbance (emotional load). As previously observed by Decety and Jeannerod (1995), Fitts law also applies in motor imagery. [36] De Witte et al. (2018) observed a positive effect of MI on the quality of suturing and knot tying by novice surgeons. [11] The first stages of motor learning are thus conducive to progress, both in speed and execution accuracy.

Conversely, Jungmann et al. (2011) did not show an effect of MI on learning procedures in surgical novices who completed additional mental practice during the interval between the actual training sessions. [37] In massed learning procedure, training is concentrated over a short period of time and is less effective than when the learning sessions are distributed over time, [11] especially for novice practitioners. The distributed procedure also brings more marked progress when the technique to learn is complex. Neuronal plasticity is better stimulated as this process requires time to operate, especially in novice learners. [38] Thus, the conditions of MI practice strongly influence the progress made.

The exp group performed significantly better than the ctrl group from the second training session showing that MI is quickly effective. During initial learning where a high volume of knowledge was to be learnt, [27] MI better concretized the operations to be carried out and made possible to segment them into several sub-objectives. The association of MI with real practice led to better efficiency than in the ctrl group. Although the two groups achieved comparable final performance, learning was nevertheless facilitated during the early phases, as previously shown by Guillot et al., (2009). [39] Mulla et al. (2012) observed that mental training alone cannot replace conventional training. [40] MI closely involved memory processes, enriched the cognitive phase of learning and thus, may explain that the exp group improved faster than the ctrl group. The association of MI with real practice accelerated motor skills learning as the exp group reached the expected level during the 4th session, whereas 5 sessions were needed in the ctrl group.

Mental chronometry also highlighted that the duration of the mental representation slightly underestimated that of real execution, at the beginning of the second session (although this difference did not always reach significance). Underestimation was probably due to task complexity, the mental representation of complex skills being more difficult than that of simple skills. In general, the beginner showed a tendency to omit key points, thus decreasing mental representation duration. [27] During the third session, actual practice duration decreased due to skill execution improvement while that of MI increased, thus attesting that the exp group took into account most elements of the script and that the quality of mental representation improved. This resulted in better congruence between actual and imagined execution times, close to isochrony, thus confirming that both tasks share similar processes. In particular, the programming phase prior to actual execution shares a set of operations with the mental representation of the movement. [17] MI improved the learning of PVC insertion and influenced actual practice. [19, 20] In turn, MI was also modulated by actual practice, both reinforcing each other. Thus, the decrease in the duration of the actual practice led to a decrease in MI duration.

Conclusion

This study showed the main positive effects of MI associated with actual practice on movement duration. Professional practices involving motor skills can be improved through their mental representation, in addition to physical training. Motor imagery provides a complementary procedure that accelerates learning, especially during its early stages. This is a crucial point in the medical professions where the duration of practice is often reduced.

Other objectives could study the role of MI during the automation phase, e.g. by removing stray movements, how MI may help learning under more complex conditions, e.g. in patients with a fragile venous network, or under time pressure and stressful conditions. Defining more precise and operational criteria of PVC insertion through the Objective Skills Assessment Tool (OSAT), could finally complement the evaluation of PVC training. [41]

The major issue from our experiment is that medical techniques should more often integrate MI into the learning and training sessions of medical students. If MI is carried out with respect to its rules of practice, it can have a satisfactory pedagogical effect but also an economical impact by reducing the training costs (number of sessions with time and device gains) while improving the quality of learning. As a result, the quality of care provided to patients should also be improved. The collaboration between medicine/surgery and cognitive neuroscience research thus needs to be strengthened with the aim to improve learning in the field of medico-surgical techniques.

Abbreviations

AD
actual duration
AP
actual practice
CLESS
Center for Education through Simulation in Health
CTRL
control group

EXP
experimental group
MC
mental chronometry
MI
motor imagery
MI_D
motor imagery duration
MIQ-3
Motor Imagery Questionnaire
N
neutral task
PVC
peripheral venous catheter
REF
reference group
*x
number of repetitions of the sequence

Declarations

Ethics approval and consent to participate

The experiment did not involve any patient. All participants signed an informed-consent form before starting the study. The management and ethics committee of the Faculty of Medicine (Lyon-Est) approved the experimental design after the experimenters presented the objectives and procedures to the scientific board council (6.12.2016). The study also obtained the scientific support of the Center for Education through Simulation in Health (CLESS), hosted by Lyon1 University.

Availability of data and materials

The datasets collected, used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

Funding

Professor J.J. Lehot released funds from the Center for Education through Health Simulation (CLESS, Lyon) to reward participants.

The project "Learning Strategies for Healthcare Professions in Immersive Environment" (SAMSEI, 11-IDFI-0034; an IDEFI "Initiatives of excellence in innovative training" grant by the French National Agency for Research), in support and conjunction with Lyon 1 University (member of the University of LYON), allowed foundation and equipped the technical learning platform CLESS.

Authors's contribution

Christian COLLET participated in conceiving the experimental paradigm. He wrote the first draft of the paper and proofread the paper until the final version.

Mahmoud El HAJJ participated in conceiving the experimental paradigm. He leaded the experiment, collected and analyzed the data.

Bernard BUI-XUAN participated in conceiving the experimental paradigm. He proofread the paper.

Jean-Jacques LEHOT participated in conceiving the experimental paradigm. He proofread the paper.

Nady HOYEK coordinated the overall study. He participated in conceiving the experimental paradigm. He proofread and aprooved the final version of the paper.

Acknowledgments

The authors would like to thank:

The medical studies committee of the Faculty of Medicine of Lyon-Est and its Dean, Professor G. Rode, for giving their agreement to carry out the project within the University.

The Nursing trainers for mentoring the experiment and guiding the students in their learning.

The medical students of the Faculty of Medicine (Lyon-Est) for their participation in this protocol.

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Tables

Table 1 : Summary of the experimental design.

<table>
<tr><th>Content</th><th>Session Duration</th><th>EXP (MI) Group</th><th>Session Duration</th><th>CTRL Group</th></tr>
<tr><td>Session 1
(Pretest)</td><td>2h</td><td colspan="3">MIQ-3 & mental chronometry – Practical discovery of the clinical technique.
Video instruction - observation + actual repetition of the skill under the same conditions: instructor ans script).
Evaluation: timing of the last AP</td></tr>
<tr><td>Session 2</td><td>1h</td><td>[AP/MI/AP]*3 + [MI/AP/MI]
Evaluations + timing the 2^{nd} and the last AP
MC + Quality of the 5^{th} MI</td><td>1h</td><td>[AP/N/AP]*3 + [N/AP/N]
Evaluations + timing the 2^{nd} and the last AP</td></tr>
<tr><td>Session 3</td><td>1h</td><td>[AP/MI/AP]*2 + [MI/AP/MI]*2
Evaluations + timing the 2^{nd} AP
MC + Quality of the 5^{th} MI
Timing the AP just after last MI</td><td>1h</td><td>[AP/N/AP]*2 + [N/AP/N]*2
Evaluations + timing the 2^{nd} and the last AP</td></tr>
<tr><td>Session 4</td><td>1h</td><td rowspan="3">[AP/MI/AP] + [MI/AP/MI]*3
Evaluations + timing the 2^{nd} AP
MC + Quality of the 6^{th} MI
Timing the AP just after last MI</td><td>1h</td><td rowspan="3">[AP/N/AP] + [N/AP/N]*3
Evaluations + timing the 2^{nd} and the last AP</td></tr>
<tr><td>Session 5</td><td>1h</td><td>1h</td></tr>
<tr><td>Session 6
(Post-test)</td><td>1h</td><td>1h</td></tr>
<tr><td>Retention</td><td>1h</td><td colspan="3">Assessments – timing of actual execution</td></tr>
</table>

MC= mental chronometry AP= actual practice, MI= motor imagery, N=neutral task, *x = Number of repetitions of the sequence.

Figures

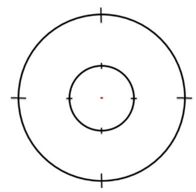

Figure 1

Test of MI imagery quality through mental chronometry

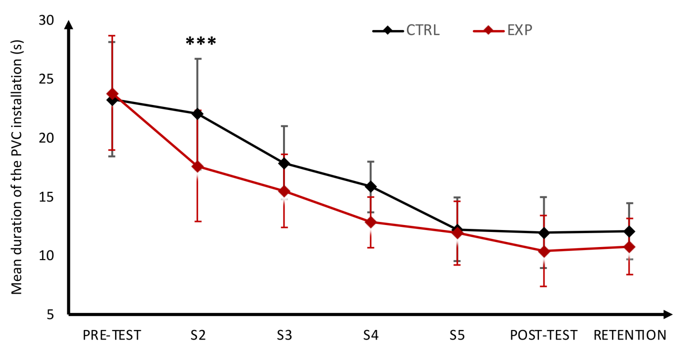

Figure 2

Mean duration (SD) of actual PVC insertion in the exp and the ctrl groups. Timing are from the last trial of sessions 2 to 5, including the pre- and the post-tests, as well as the retention test.

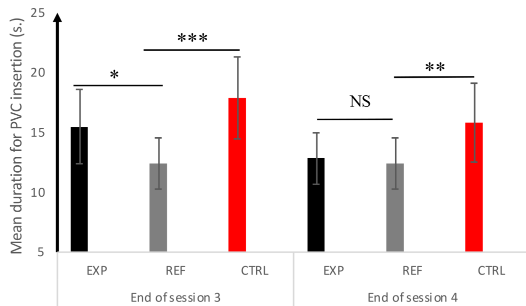

Figure 3

Comparison of the actual mean duration needed to insert the PVC among the 3 groups, exp, ref and ctrl at the end of the third and the fourth training session.

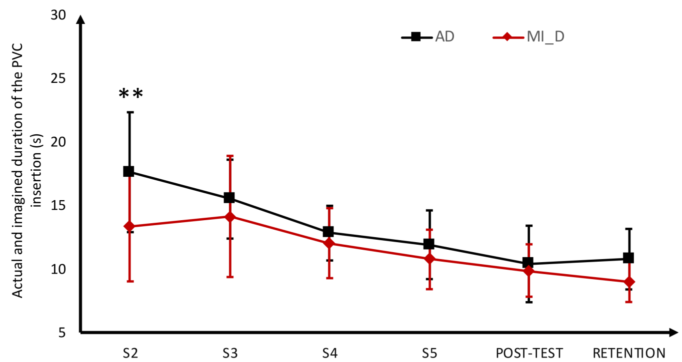

Figure 4

Mean (SD) Comparaison of actual duration (AD) to MI duration (MI_D) needed to perform the insertion of the PVC, in the exp group, during the 4 training sessions (from S2 to S5), the post test and the retention test.