Actualidades en Psicología, *38*(136), january-june, 2024, 77-87
DOI: 10.15517/ap.v38i136.49097

ISSN 2215-3535

Actualidades enPsicología

Universidad de Costa Rica
www.revistas.ucr.ac.cr/index.php/actualidades

Application of a mental imagery protocol for the promotion of implicit learning in university students

Aplicación de un protocolo de imaginería mental para la promoción del aprendizaje implícito en estudiantes universitarios

José M. Mora-Benambourg [1]
https://orcid.org/0000-0002-5557-9385

Bradly Marín-Picado [2]
https://orcid.org/0000-0002-7221-3377

[1,2] Escuela de Psicología, Facultad de Ciencias Sociales, Universidad de Costa Rica, San José, Costa Rica.

[1] ✉ jose.mora_bena@ucr.ac.cr [2] ✉ bradly.marinpicado@ucr.ac.cr

Received: November 15, 2022. Accepted: February 01, 2024.

Abstract. *Objective*. The improvement of cognitive skills has become an issue of particular interest nowadays. It is still being determined if techniques like mental imagery (MI) could generate cognitive enhancement via modulation of neural brain activity. The purpose of this study was to provide information on the impact of mental imagery on implicit motor learning. Method. To test this hypothesis, an MI protocol was applied to an experimental group before performing an implicit learning (IL) task, while a control group received a sham feedback protocol. In addition, to have empirical evidence of cortical activation during MI, we made an electroencephalographic (EEG) record of motor cortex activity during baseline and during the task associated with IL. *Results*. The ANCOVA models all together show how the MI protocol does impact the IL process, but not as clearly as expected.

Keywords. Implicit learning, mental imagery, serial reaction time task, electroencephalography, Mu waves

Resumen. *Objetivo*. La mejora de las habilidades cognitivas es un tema de especial interés en la actualidad. Todavía se está determinando si técnicas como la imaginería mental (IM) podrían generar una mejora cognitiva a través de la modulación de la actividad cerebral. El propósito de este estudio fue aportar información sobre el impacto de la imaginería mental en el aprendizaje motor implícito. *Método*. Se aplicó un protocolo de IM a un grupo experimental antes de realizar una tarea de aprendizaje motor implícito, mientras que un grupo de control recibió realimentación simulada. Además, para tener evidencia empírica de la activación cortical durante la IM, se registró, mediante electroencefalografía, la actividad de la corteza motora durante el inicio y durante la tarea de aprendizaje motor implícito. *Resultados*. Los modelos ANCOVA muestran cómo el protocolo de IM impacta el proceso de aprendizaje motor implícito, pero no tan claramente como se esperaba.

Palabras clave. Aprendizaje implícito, imaginería mental, tarea de tiempo de reacción serial, electroencefalografía, ondas Mu

Introduction

Cognitive enhancement can be defined as "the amplification or extension of core capacities of the mind through improvement or augmentation of internal or external information processing systems" (Bostrom & Sandberg, 2009, p. 311). In certain instances, cognitive enhancement serves as a potential therapeutic intervention, facilitating the improvement of cognitive functions like memory or attention; however, it is not always used in that manner. It could also refer to the use of drugs or devices to improve performance in healthy subjects. Psychological research has been interested in techniques that can facilitate such performance improvements, not only in the clinical population but also in healthy subjects, as a way to improve cognition (Dubljević et al., 2015; Racine et al., 2021).

Recently, a method for cognitive enhancement known as mental imagery (MI) has shown the potential to modify the neural activity of the brain and, in doing so, facilitates human performance improvements (Caligiore et al., 2017; Dahm & Rieger, 2016; Kim et al., 2018; Ladda et al., 2021; Vinicius et al., 2010). MI refers to the dynamic process linked to the internal mental representation, or "simulation," of motor tasks without their physical execution (Caligiore et al., 2017; Vinicius et al., 2010). This process involves and activates numerous brain regions and neural correlates (basic cognitive mechanisms) associated with both observing and executing movements (Hardwick et al., 2018). This suggests that improvements in tasks involving MI may translate into enhanced performance in motor tasks as a result of the neural activity changes occurring in cortical areas shared by both tasks (Hardwick et al., 2018; Kim et al., 2018; Ladda et al., 2021; Lewkowicz et al., 2013; Williams, et al., 2012; Schack et al., 2014).

However, the efficacy of methods like MI still needs to be determined. Studies such as the one proposed by Ros et al. (2014) show that MI can improve performance in the serial reaction time task (SRTT, a test used to measure implicit learning), which is consistent with the idea that MI recruits neural correlates involved in the observation and execution of movements. However, their work has some limitations such as data loss and reduced number of participants in each group. This work aims to bring up new data about the impact of MI on implicit learning (IL), the same cognitive process that Ros et al. (2014) investigated.

IL refers to the cognitive process engaged in acquiring and transferring patterns without introspective awareness, encompassing both the acquisition phase of this learning and the retrieval process (López-Ramón et al., 2009). This process is associated with the activation of various cortical zones: the primary motor cortex, supplementary motor area, premotor cortex, and dorsolateral prefrontal cortex (Poldrack et al., 2005; Wilkinson et al., 2010; Wiestler & Diedrichsen, 2013). IL is relevant due to its association with the learning of skills, relationships, structures, and sequences that can be very complex and long, which may require a lot of practice and repetition to learn and/or master (for example, passwords or expertise in chess; Reber et al., 2019). Those skills are hypothesized to be improved through mental repetition, i.e., MI, therefore, through an experimental study, we want to test if an MI protocol could improve a test (SRTT) that requires a similar process of practice and repetition to get better; if results are as hypothesized, this could mean MI could be used as a new method to facilitate IL.

This research utilized a novel iteration of the SRTT, called the Virtual Serial Reaction Time Task (VSRTT), which was developed and validated specifically for this study. Unlike the original task, this new version records not only the same information but also captures the finger positions during task execution (data not utilized in the present paper). Furthermore, to obtain empirical evidence of cortical activation during Motor Imagery (MI), we conducted electroencephalographic (EEG) recordings of motor cortex activity both at baseline and during the IL-associated task. This approach enables us to draw more robust conclusions regarding the impact of MI on cortical activity in one of the structures purportedly influenced by the task and involved in IL task performance.

Experimental Procedure

Participants

The sample size was calculated using G-Power software (with an effect size of .50, 2 groups, and two measures). A total of 65 women, all students from the University of Costa Rica (UCR), were recruited. However, only 53 completed both pre- and post-treatment sessions. Their ages ranged from 18 to 30 years (*M* = 19.96, *SD* = 2.11), and 51 of them were right-handed. None reported a history of injuries that caused unconsciousness (10 minutes or longer) or concussions, nor were mental health diagnoses or histories of electroconvulsive therapy reported. All participants were free of drugs or any kind of psychoactive substance that could affect central nervous system (we asked the participants to not drink coffee 8 hours before any session). Preliminary analyses were conducted on the reaction times for each block of the task, revealing that 7 participants exhibited results exceeding 1.5 standard deviations from the group average. These cases were excluded from subsequent analyses, resulting in a final sample size of 46 participants.

Control group

Each participant was required to make two visits to the laboratory. During the first session, they completed the VSRTT. In the subsequent session, which took place no more than 8 days after the first, they underwent the sham feedback protocol. Following the recommendations of Aliño et al. (2016), participants watched a video of a neurofeedback session displaying pseudorandom data generated by the EEG recording software. This occurred while they were connected to the EEG equipment and attempted to complete the tasks outlined in Table 1. Immediately afterward, they proceeded to complete the VSRTT.

Table 1. Sham feedback protocol

Task	Instruction
X-Wing	A line appears in the middle of the screen alongside an aircraft. The participant is asked to focus his attention to that line.
Lights game	The participant is requested to pay attention to the lights that will illuminate along the screen and to follow them with his eyes.
Thermos	A thermometer is presented to the participants on the screen and they are asked to follow the thermometer level with his gaze, keeping his attention on the constant change of the level (leveling up or down).
Stars game	The participant is requested to pay attention to the stars that will illuminate along the screen, and to follow them with his eyes.
X-Wing	A line appears in the middle of the screen alongside an aircraft. The participant is asked to focus his attention to that line.

Note. Brief description of the task that were given to the participant through the segments of the sham feedback protocol.

Experimental group

Each participant was required to make two visits to the laboratory. In the first session, they completed the VSRTT. In the subsequent session, occurring no more than 8 days after the first visit, they underwent the MI protocol. During this protocol, they were connected to the EEG and attempted to complete the tasks described in Table 2 while receiving actual neurofeedback. Immediately afterward, they proceed to completed the VSRTT.

Instruments

Virtual Serial Reaction Time Task (VSRTT)

This task leverages the Leap Motion Hardware (Leap Motion Developer, 2016) and mirrors both the functional and structural characteristics of the SRTT developed by Nissen and Bullmer (1987). Additionally, it allows for the recording of hand and finger positions during task execution, thus enabling the collection of data concerning the motor responses demanded by the task (data not utilized in the present paper).

In the original version of the SRTT, participants respond to a light appearing in one of four predetermined positions on the screen by pressing the corresponding button located directly beneath the light using their fingers. In this update version, the VSRTT, participants are tasked with touching a tablet where a circle lights up in one of four default positions. They must then lift their finger off the screen until the next trial begins, mimicking the SRTT's action sequence. Positioned in front of the participant, the Leap Motion device records hand movements throughout this process (refer to Figure 1 for details)

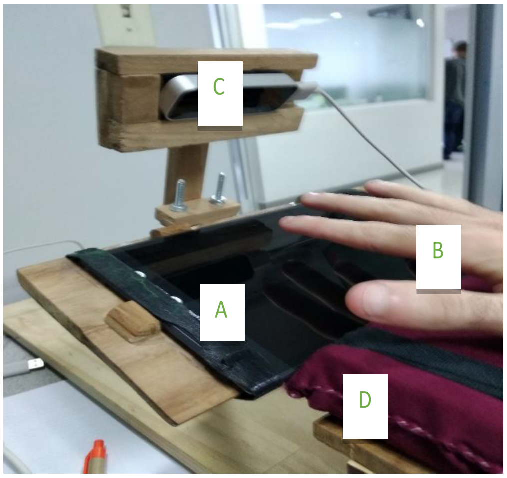
The VSRTT is structured into 8 blocks, with each block comprising a sequence of 12 trials that is repeated 10 times within the block. Blocks 1 and 6 feature sequences that are randomly generated, earning them the designation of random blocks; the remaining blocks contain predefined sequences and are thus referred to as sequential blocks. In order to control any possible practice or plasticity effects, considering the ideas of Ros et al. (2014),

Table 2. Motor mental imagery protocol

Task	Instruction
X-Wing	The participant is asked to try to imagine that he moves to the middle of the screen an aircraft that appears on the screen using his hand.
Fingers Imagery	The participant is asked to imagine a hand in front of him. Next, he must calculate the distance/space between the fingers of the imaginary hand and keep doing that exercise during all the segment. Also, periodically, he must adjust the imaginary hand position and repeat the task.
Thermos	A thermometer is displayed on the screen for participants, who are then prompted to maintain their level as high as possible by mentally visualizing themselves moving it with their hand.
Hand movement mental imagery	The participant is asked to try to imagine that he has his hand in front of him and that he moves it randomly and constantly.
X-Wing (again)	The participant is asked to try to imagine that he moves to the middle of the screen an aircraft that appears on the screen using his hand.

Note. Brief description of the task that were given to the participant through the segments of the motor mental imagery protocol.

Figure 1. Virtual Serial Reaction Time Task.



Note. (A) Tablet where the stimulus of the VSRTT are presented. (B) Hand of the participant during the execution of the task. (C) Leap motion recording hand movements. (D) Rest hands.

two different sequences were designed for each session. The sequence of button presses, determined by the order in which the lights appear according to their position numbers, follows the pattern 121342314324 for the first session and 121423413243 for the second session.

From the measurements obtained in the VSRTT regarding reaction time (RT), two key components can be derived to assess IL: the learning rate and the learning degree. The learning rate signifies a gradual decrease in the mean RT across sequential blocks within the VSRTT. This reduction is manifested by comparing the mean RT of the initial sequential block to that of the final sequential block. Conversely, the learning degree denotes the difference observed in the mean RTs when transitioning from a sequential block to a random one, specifically during the shift from block 5 (sequential) to block 6 (random) (Robertson, 2007; Unsworth & Engle, 2005).

Concerning the test's validity, the VSRTT demonstrates convergent validity with the SRTT. Additionally, although Gallant et al. (2016) note the absence of formally reported psychometric properties for the SRTT, various studies have established convergent, divergent, and conceptual validity between the task and several constructs associated with IL. Consequently, it is inferred that the VSRTT possesses psychometric properties comparable to those of the SRTT.

EEG device and protocol

EEG recordings were performed using the Atlantis I 4x4 hardware and BrainMaster version 2.5SE software (BrainMaster Technologies, Inc., 2012). Specifically, the recordings targeted the Mu wave (8-12 Hz), which represents alpha band activity observed in the central derivations (C3/C4) over the motor strip. This area of the brain controls voluntary movement and is involved in the MI of motor actions. Electrode placement is adhered to the international 10-20 system.

In this protocol, the active electrode was positioned in the motor cortex, specifically at C3 or C4, depending on the participant's hand dominance (contralateral electrode placement), while the reference electrode was situated on the contralateral ear. The total recording time spanned 36 minutes, divided as follows: two 3-minute baseline recordings (at the beginning and end of the session) and five training segments, each lasting 6 minutes (one for each task outlined in Tables 1 and 2 of the protocol). Short breaks were provided between segments to assess the participant's comfort and address any task-related issues.

In the experimental group, all training segments involved tasks associated with (MI) execution. Theoretically, these tasks would transiently modulate the Mu waves, a phenomenon expected to be reflected in the IL task performance. Participants had to exceed the threshold automatically computed from the previous sixty seconds during 500 ms in order to be rewarded, followed by a refractory period of 1ms before the next reward. Voltages exceeding 240 µV were considered artifacts and excluded from the register. Conversely, in the control group, sham feedback was administered using pseudorandom data generated by the EEG, following the considerations raised by Aliño et al. (2016).

Participants' protection

All participants signed an informed consent form, which outlined the voluntary nature of their participation and provided details about the associated risks and benefits. Confidentiality and anonymity were assured for all information, which was stored securely on a private server accessible only to the research team. There was no real risk in the task the participants executed; nevertheless, throughout the session, participants were regularly asked about their comfort level and fatigue. If they expressed any discomfort or fatigue, they were encouraged to stop the task and exit the study without any repercussions (no participant opted to leave the experiment).

Data analyses

Immediately following the conclusion of the second session, participants were asked whether they could identify a sequence. If they were able to identify and replicate a sequence, those participants were excluded from subsequent analyses. However, none of the participants were able to identify the sequence.

The collected data were analyzed using the software R version 3.5.3 (R Core Team, 2019) with an analysis of covariance (ANCOVA) of repeated measures. The ANCOVA used as dependent variables the scores obtained in the VSRTT task after the MI or sham feedback protocols, and the independent variables were the scores obtained in the VSRTT task before the MI or sham feedback protocols, the participant's membership group (control vs. experimental), and the total Mu power (at baseline 1). We also considered the interactions between those variables in the protocol of MI, or sham feedback. This analysis allows us to identify the effects of the motor MI protocol on the IL of the participants.

We use the total Mu power at baseline 1 as a covariate for the analysis. This score was obtained using the R packages "psych" (Revelle, 2018) and "eegkit" (Helwig, 2018) to process the EEG data. The EEG was filtered with a Butterworth filter of 4th order, retaining only frequencies between 5Hz and 15Hz. The subsequent step involves applying the Fast Fourier Transformation to calculate the power of frequencies ranging from 8 Hz to 12 Hz using the entire 180-second block. The power values across all frequencies were then summed to obtain the total Mu power.

Results

Descriptive Data

The descriptive data of the VSRTT in both conditions and groups and the results of the ANCOVA can be found in Table 3.

As seen in Table 3, both groups exhibited a similar learning degree and learning rate in the pretest and posttest conditions, but the degree and learning rate of both groups in the posttest condition were smaller compared to those in the pretest condition. Regarding the random and sequence blocks, the random blocks showed a higher reaction time than the sequenced blocks. Figure 2 illustrates the graphical tendency of reaction times through the blocks of the VSRTT before the application of any protocol.

Figure 3 presents the graphical tendency of the RT through the blocks of the VSRTT after the application of the sham feedback protocol or the MI protocol. In the case of the experimental group, it is possible to appreciate a higher learning rate in the posttest condition, which is also reflected in the gradual reduction in the mean of the RT along the sequential blocks, as presented in Table 3.

ANCOVA models

To evaluate the efficacy of the MI protocol, we ran two ANCOVA models as described in the data analysis section. The first model used as a dependent variable the learning degree, and the second used the learning rate. Both models used the same independent variables and the interaction of those variables as described above.

The results of the learning degree ANCOVA model showed a significant effect of the learning degree score before the experimental/sham feedback protocol (F (1, 37) = 13.731, p < .001, η^2 = .27).

Table 3. Descriptive statistics of VSRTT across conditions

	Control Group *M (SD)*	Experimental group *M (SD)*
Learning rate		
VSRTT Pretest	54.48ms (42.23ms)	51.93ms (45.63ms)
VSRTT Postest	30.58ms (18.56ms)	41.31ms (28.30ms)
Learning degree		
VSRTT Pretest	35.41ms (33.23ms)	36.69ms (26.07ms)
VSRTT Postest	29.63ms (19.36ms)	32.84ms (29.33ms)
Random Blocks		
VSRTT Pretest	456.70ms (43.03ms)	493.30ms (58.64ms)
VSRTT Postest	438.96ms (35.66ms)	458.04ms (44.82ms)
Sequenced Blocks		
VSRTT Pretest	430.06ms (43.53ms)	461.34ms (57.52ms)
VSRTT Postest	416.30ms (34.50ms)	428.24ms (54.49ms)
VSRTT Pretest	430.06ms (43.53ms)	461.34ms (57.52ms)
VSRTT Postest	416.30ms (34.50ms)	428.24ms (54.49ms)

Figure 2. Behavior of VSRTT pretest condition for both groups

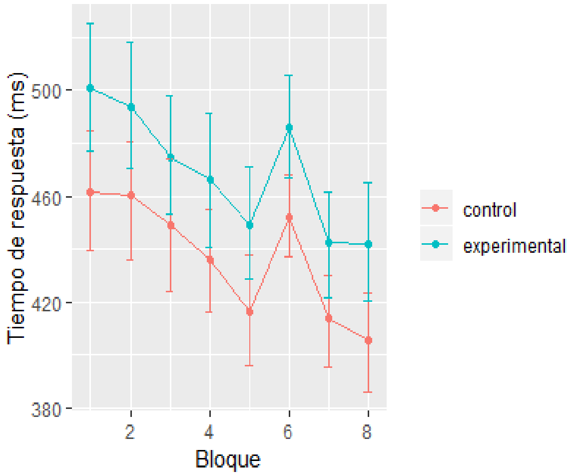
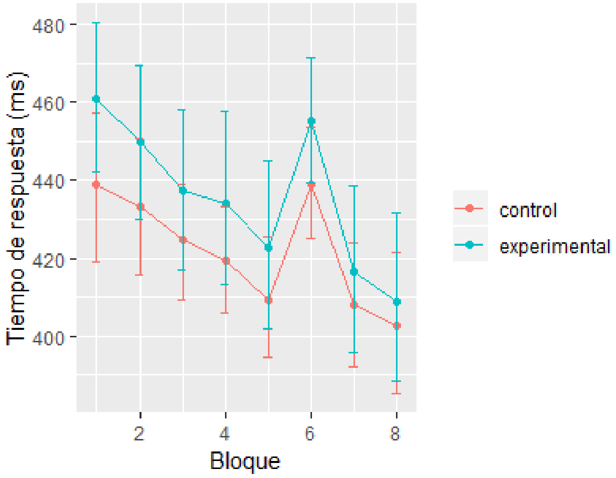


Figure 3. Behavior of VSRTT posttest condition for both groups



This did not happen in the case of the membership group (*F* (1, 37) = .213, $p < .647$, $\eta^2 = .27$), nor in the case of the total Mu power in baseline 1 (*F* (1, 37) = .36, $p < .55$, $\eta^2 = .20$).

The results of the learning rate ANCOVA model showed a significant effect of the interaction between the learning rate score before the experimental/sham feedback protocol and the total of Mu power in baseline 1 (*F* (1, 37) = 4.84, $p < .034$, $\eta^2 = .20$). This did not happen in the case of the learning rate score before the experimental/sham feedback protocol (*F* (1, 37) = 177, $p < .191$, $\eta^2 = .20$), nor the membership group (*F* (1, 37) = 2.21, $p < .145$, $\eta^2 = .20$), neither the principal effect of the total Mu power in baseline 1 (*F* (1, 37) = 1.36, $p < .250$, $\eta^2 = .20$).

Discussion

All the data together shows how the MI protocol does not have a clear impact on the IL process, as the membership group lacks significance. However, it should be noted that, in the posttest, the experimental group had a higher learning rate (although not statistically significant). Also, it is important to note that in both ANCOVA, the pretest condition assessment of learning degree and learning rate (in interaction with Mu power) were the only variables that were significant. This suggests that the best predictor of change is individual ability for both learning rate and learning degree.

Likewise, it is considered that this improvement in the posttest learning rate can be understood as a result of having greater alpha power (in the form of Mu activity) at baseline. Possessing a higher alpha power could indicate greater connectivity at the level of neural network activity (Benedek et al., 2011; Curran & Schacter, 2001). A resting-state greater connectivity is hypothesized to be a factor that could facilitate a greater capacity to learn (Van Dyck et al., 2021), which in this case would be seen in the posttest learning rate. This change in learning rate could be associated with improvements in IL.

It is important to acknowledge the relevance of IL and the ways we can promote it. In this context, to master any skill, it is necessary to practice it. That's because during the repeat process, there is information that is impossible to learn via explicit instructions (Reber et al., 2019). The use of new techniques like MI could be a tool that promotes IL and reduces the time required to master a skill related to the imagery exercise (even though the results obtained here were not clear enough and only descriptive data shows some limited tendency for improvements in the VSRTT that could reflect some IL improvements). For instance, Toth et al. (2020) conducted a meta-analysis on mental practice, which they defined as "the systematic application of motor imagery for the cognitive rehearsal of a task in the absence of overt physical movement" (p. 1). Their analysis revealed a small yet statistically significant positive effect on motor performance. They also observed that the duration of the mental practice protocol, with optimal values between 20 and 30 minutes to prevent cognitive fatigue, and the type of imagery used, particularly kinesthetic imagery, have a significant effect on performance.

Based on the results and the literature review, there are a few considerations to take into account before concluding that MI does not facilitate IL or that its impact is insignificant. Firstly, in this MI protocol, the MI tasks were not directly linked to the VSRTT. According to Schack et al. (2014), the simulated movements in MI should be task-specific to the target task in order to observe an effect. This aspect could have influenced the results, as it is plausible that the MI did not produce an effect due to its lack of relevance to the task. Consequently, the improvement was not thoroughly assessed in conjunction with the VSRTT.

Furthermore, an individual's capacity for motor imagery (MI) is contingent upon the level of detail in the mental representations they can generate (Schack et al., 2014). Lebon et al. (2018) found that vividness of MI can predict the performance of a finger sequence after training. While we did not assess participants' imagery skills, future research could employ tools like those proposed by Ladda et al. (2021) to monitor and control imagery performance. These two factors, the dissimilarity between the MI tasks and the VSRTT and individual imagery abilities, may influence the efficacy of the MI protocol in promoting IL as evaluated by the VSRTT, thus potentially explaining the shortcomings of our results, which should be addressed in subsequent studies.

Moreover, the MI protocol implemented in this study involved using the non-dominant hand. Gentili & Papaxanthis (2015) noted that employing the dominant hand typically yields greater and more robust improvements in motor learning during both imagery and physically demanding exercises. Additionally, the protocol's duration exceeded that recommended by Toth et al. (2020), and it exclusively utilized visual imagery rather than employing kinesthetic or combined imagery strategies. While it is impossible to guarantee significant improvement, we must not underestimate the potential impact of these differences on our findings.

References

Aliño, M., Gadea, M., & Espert, R. (2016). A critical view of neurofeedback experimental designs: sham and control as necessary conditions. *International Journal Neurology and Neurotherapy*, *3*(1), 1-2. https://doi.org/10.23937/2378-3001/3/1/1041

BrainMaster Technologies, Inc. (2012). *BrainMaster 2.5 Software User Manual*. BrainMaster Technologies, Inc.

Benedek, M., Bergner, S., Könen, T., Fink, A., & Neubauer, A. (2011). EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia*, *49*(12), 3505-3511. https://doi.org/10.1016/j.neuropsychologia.2011.09.004

Bostrom, N., & Sandberg, A. (2009). Cognitive Enhancement: Methods, ethics, regulatory challenges. *Science and Engineering Ethics*, *15*(3), 311-341. https://doi.org/10.1007/s11948-009-9142-5

Caligiore, D., Mustile, M., Spalletta, G., & Baldassarre, G. (2017). Action observation and motor imagery for rehabilitation in Parkinson´s disease: A systematic review and integrative hypothesis. *Neuroscience and Biobehavioral Reviews*, *72*, 210-222. http://dx.doi.org/10.1016/j.neubiorev.2016.11.005

Curran, T., & Schacter, D. (2001). Implicit learning and memory: Psychological and neural aspects. *International Encyclopedia of the Social & Behavior Sciences*, 7237-7241. https://doi.org/10.1016/B0-08-043076-7/03513-0

Dahm, S. & Rieger, M. (2016). Is there symmetry in motor imagery? Exploring different versions of the mental chronometry paradigm. *Attention, Perception, & Psychophysics*, *78*, 1794-1805. https://doi.org/10.3758/s13414-016-1112-9

Dubljević, V., Venero, C., & Knafo, S. (2015). What is Cognitive Enhancement? En S. Knafo & C. Venero (Eds.), *Cognitive Enhancement: Pharmacologic, Environmental and Genetic Factors* (pp. 1-9). Academic Press.

Gallant, C., Drumheller, A., & Mckelvie, S. (2016). Effect of improper soccer heading on serial reaction time task performance. *Current Psychology*, *36*, 286-296. https://doi.org/10.1007/s12144-016-9414-6

Gentili, R., & Papaxanthis, C. (2015). Laterality effects in motor learning by mental practice in right handers. *Neuroscience*, *297*, 231-242. http://dx.doi.org/10.1016/j.neuroscience.2015.02.055

Hardwick, R. M., Caspers, S., Eickhoff, S. B., & Swinnen, S. P. (2018). Neural correlates of action: Comparing meta-analyses of imagery, observation, and execution. *Neuroscience & Biobehavioral Reviews*, *94*, 31-44. https://doi.org/10.1016/j.neubiorev.2018.08.003

Helwig, N.E. (2018). *eegkit: Toolkit for Electroencephalography Data*. https://CRAN.R-project.org/package=eegkit

López-Ramón, M., Introzzi, I., & Richard's, M. (2009). La independencia del aprendizaje implícito con respecto a la inteligencia general en niños de edad escolar. *Anales de Psicología*, *25*(1), 112-122. https://revistas.um.es/analesps/article/view/71561

Kim, Y., Park, E., Lee, A., Im, C., & Kim, Y. (2018). Changes in network connectivity during motor imagery and execution. *PLoS ONE, 13*(1), e0190715. https://doi.org/10.1371/journal.pone.0190715

Ladda, A. M., Lebon, F., & Lotze, M. (2021). Using motor imagery practice for improving motor performance - A review. *Brain and Cognition, 150*, 105705. https://doi.org/10.1016/j.bandc.2021.105705

Leap Motion Developer (2016, 28 de julio). *API Overview.* https://developer.leapmotion.com/documentation/v2/python/devguide/Leap_Overview.html

Lebon, F., Horn, U., Domin, M., & Lotze, M. (2018). Motor imagery training: Kinesthetic imagery strategy and inferior parietal fMRI activation. *Human Brain Mapping, 39*(4), 1805-1813. https://doi.org/10.1002/hbm.23956

Lewkowicz, D., Delevoye-Turrell, Y., Bailly, D., Andry, P., & Gaussier, P. (2013). Reading motor intention through mental imagery. *Adaptative Behavior, 21*(5), 315-420. https://doi.org/10.1177/1059712313501347

Marcuse, L., Fields, M., & Yoo, J. (2016). *Rowan's Primer of EEG*. Elsevier.

Nissen, M., & Bullemer, P. (1987). Attentional requirements of learning: evidence from performance measures. *Cognitive Psychology, 19*(1), 1-32. https://doi.org/10.1016/0010-0285(87)90002-8

Poldrack, R., Sabb, F. W., Foerde, K., Tom, S. M., Asarnow, R. F., Bookheimer, S. Y., & Knowlton, B. J. (2005). The neural correlates of motor skill automaticity. *Journal of Neuroscience, 25*(22), 5356-5364. https://doi.org/10.1523/JNEUROSCI.3880-04.2005

R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/.

Racine, E., Sattler, S., & Boehlen, W. (2021). Cognitive enhancement: Unanswered questions about human psychology and social behavior. *Science and Engineering Ethics, 27*(19), 1-25. https://doi.org/10.1007/s11948-021-00294-w

Reber, J., Batterink, L., Thompson, K., & Reuveni, B. (2019). Implicit learning: history and applications. En A. Cleeremans, V. Allakhverdov & M. Kuvaldina (Eds.), *Implicit Learning: 50 Years* (pp. 16-37). Routledge.

Revelle, W. (2018). *psych: Procedures for Psychological, Psychometric, and Personality Research*. Northwestern University, Evanston, Illinois. https://CRAN.R-project.org/package=psych

Robertson, E. (2007). The serial reaction time task: Implicit motor skill learning? *The Journal of Neuroscience, 27*(38), 1073-1075. https://doi.org/10.1523/JNEUROSCI.2747-07.2007

Ros, T., Munneke, M., Parkinson, L., & Gruzelier, J. (2014). Neurofeedback facilitation of implicit motor learning. *Biological Psychology, 95*, 54-58. http://dx.doi.org/10.1016/j.biopsycho.2013.04.013

Schack, T., Essig, K., Frank, C., & Koester, D. (2014). Mental representation and motor imagery training. *Frontiers in Human Neuroscience, 8*, 1-10. https://doi.org/110.3389/fnhum.2014.00328

Toth, A. J., McNeill, E., Hayes, K., Moran, A. P., & Campbell, M. (2020). Does mental practice still enhance performance? A 24 year follow-up and meta-analytic replication and extension. *Psychology of Sport and Exercise, 48*, 101672. https://doi.org/10.1016/j.psychsport.2020.101672

Van Dyck, D., Deconinck, N., Aeby, A., Baijot, S., Coquelet, N., Trotta, N., Rovai, A., Goldman, S., Urbain, C., Wens, V., & De Tiège, X. (2021). Resting-state functional brain connectivity is related to subsequent procedural learning skills in school-aged children. *NeuroImage, 240*, 118368. https://doi.org/10.1016/j.neuroimage.2021.118368

Vinicius M., Catelli, A., & Cagy M. (2010). EEG changes during sequences of visual and khinesthetic motor imaginery. *Arq Neuropsiquiat., 68*(4), 556-561. https://doi.org/10.1590/s0004-282x2010000400015

Unsworth, N., & Engle, R. (2005). Individual differences in working memory capacity and learning: Evidence from the serial reaction time task. *Memory & Cognition, 33*(2), 213-220. https://doi.org/10.3758/bf03195310

Wilkinson, L., Teo, J., Obeso, I., Rothwell, J., & Jahanshahi, M. (2010). The contribution of primary motor cortex is essential for probabilistic implicit sequence learning: evidence from theta burst magnetic stimulation. *Journal of Cognitive Neuroscience, 22*(3), 427-436. https://doi.org/10.1162/jocn.2009.21208

Williams, J., Pearce, A. J., Loporto, M., Morris, T., & Holmes, P. S. (2012). The relationship between corticospinal excitability during motor imagery and motorimagery ability. *Behavioural Brain Research*, *226*(2), 369–375. https://doi.org/10.1016/j.bbr.2011.09.014

Wiestler, T., & Diedrichsen, J. (2013). Skill learning strengthens cortical representations of motor sequences. *eLlife*, *2*, e00801. https://doi.org/10.7554/eLife.00801