Conscious awareness of others' actions during observational learning does not benefit motor skill performance

Arnaud Badets[1*], Camille Jeunet[1] , Françoise Dellu-Hagedorn[1], Mélissa Ployart[1],
Sandra Chanraud[1], & Arnaud Boutin[2]

Institution:
[1] Univ. Bordeaux, CNRS, INCIA, UMR 5287, F-33000 Bordeaux, France.
[2] Université Paris-Saclay, CIAMS, 91405, Orsay, France; Université d'Orléans, CIAMS, 45067, Orléans, France.

*Correspondence: arnaud.badets@u-bordeaux.fr
INCIA - Institut de Neurosciences Cognitives et Intégratives d'Aquitaine
Université de Bordeaux, Bât. 2A- 2ème étage
146 rue Léo Saignat,
33076 Bordeaux cedex

Abstract

The sudden conscious awareness of motor success during a motor learning task has recently been revealed as a learning factor. In these studies (Boutin et al., 2014; Ioannucci et al., 2021), participants had to learn a motor sequence task and to detect when they assumed the execution had reached a maximal fluidity (maximal fluidity is understood as a perfect, quick, and smooth execution of the motor sequence). The consciousness groups showed better motor performance during a delayed post-training test than the non-consciousness control groups. Based on the "similar mechanism" hypothesis between observational and physical practice, we tested this beneficial effect of the conscious awareness of action in an observational learning context. In the present study, two groups learned a motor sequence task by observing a videotaped human model performing the task. However, only the consciousness group had to detect the maximal fluidity of the learning human model during observational practice. Unpredictably, no performance difference was detected between groups during the post-training test. However, the consciousness group outperformed the non-consciousness control group only for tests that assessed the motor sequence knowledge. Consequently, we discuss these results in light of the prevailing cognitive theories emphasizing the different learning mechanisms between observational and physical practice.

Keywords:

Observational learning, consciousness, action awareness, motor sequence

1- Introduction

Motor skill learning represents a decisive way to adapt and improve our behaviors in various situations. For example, people have to acquire new skills to get or keep their jobs throughout their professional lifetime. At home, learning a new meal preparation with its associated ingredients sequence can represent a real challenge for a beginner cook. Consequently, understanding the cognitive mechanisms underlying motor skill learning is of particular interest in the domain of cognitive and behavioral sciences (Du, Krakauer, & Haith, 2022). Motor skill learning principles and their associated cognitive mechanisms can be highlighted when studies use independent variables that can influence the effectiveness and efficiency of motor behaviors (Schmidt & Lee, 2011; Wulf, Shea & Lewthwaite, 2010). While an important factor for skill acquisition is the physical practice itself (Adams, 1964; see Evans, Brown, Mewhort, & Heathcote, 2018, for this law of practice), the following sections will emphasize that the observation of a model and the conscious awareness of motor success can also represent crucial manipulations for the strength of motor representations.

During a physical practice condition, it has recently been shown that conscious awareness of maximal performance during the execution of a motor sequence task can also improve its encoding (Boutin et al., 2014; Ioannucci et al., 2021). In these studies, two groups physically performed a 12-element motor sequence task. During the acquisition phase, the participants of the consciousness group were required to learn and judge, after each trial, if their performed motor sequence reached a maximal fluidity level or not. Here, the maximal fluidity is assumed to reflect the best motor performance for the execution of a motor sequence, i.e., a perfectly smooth (without discontinuity), quick, and errorless execution of the motor sequence. The control group participants were only required to learn the motor sequence task without judgment about the maximal fluidity. Results revealed that the consciousness group outperformed the control no-judgment group. In both studies (Boutin et al., 2014; Ioannucci et al., 2021), improved motor performance for the consciousness groups compared to the non-consciousness control groups was mainly related to increased speed during task production, as expressed by reduced response time. Indeed, Ioannucci and colleagues did not reveal any beneficial consciousness-related effect on sequence accuracy, as indexed by error rates (errors such as wrong key presses). For Boutin and colleagues, improved task performance originates from high-level cognitive processes during encoding, at the level of the representation of the motor sequence (see also Ioannucci et al. 2021). In this view, the subjective motor plan associated with maximal fluidity is activated and mentally rehearsed during and after motor execution, allowing comparisons with actual experience on the motor sequence in order to judge whether maximal fluidity is reached or not. This execution-mental rehearsal processing has been shown to facilitate immediate performance through improved encoding mechanisms.

To determine the impact of explicit knowledge of the motor sequence with the consciousness-related effect, participants completed a free recall paper-and-pencil test (Boutin et al., 2014; Ioannucci et al., 2021). A recall of more than 5 key presses of the 12-element motor sequence reflected conscious-explicit knowledge (Willingham & Goedert-Eschmann, 1999). A lower score would instead reflect the involvement of implicit mechanisms (Destrebecqz & Cleeremans, 2001). Based on this sequence-knowledge test, the findings of Boutin and colleagues revealed no significant differences between groups, with the number of recalled sequence elements being lower than the 5-element criterion. This finding reinforces the likeliness of an implicit motor sequence learning for both the control and consciousness groups. Ioannucci and colleagues (2021) corroborated this implicit account by asking their participants to perform an additional implicit motor recall test, also called “free sequence generation task” (Destrebecqz & Cleeremans, 2001). Again, the results revealed no difference between both groups. Consequently, even though participants of the consciousness group were required to focus widely on motor fluidity during motor execution, they did not show enhanced explicit knowledge of the sequence.

Conscious awareness of maximal performance can improve significantly motor sequence learning through physical practice (Boutin et al., 2014; Ioannucci et al., 2021), but this beneficial effect of consciousness is unknown for an observational practice condition. Theoretical approaches proposed that observational and physical practice share some common mechanisms at the cognitive and neural levels (Hardwick et al., 2018; Shea et al., 2000), suggesting a neuro-cognitive functional equivalence between both practice conditions (Blandin & Proteau, 2000; Gallese et al., 1996; Hardwick et al., 2018). For instance, it has been shown that the knowledge of results given throughout a certain bandwidth schedule during the acquisition phase (i.e., here, the knowledge of results was distributed to the observer when the models’ performance fell outside a predefined and accepted performance range) can be equally beneficial for an observational or physical practice condition (Badets & Blandin, 2010). For authors, such knowledge of results schedule assists participants for both groups to use the same motor program in order to stay inside the bandwidth. This similar motor improvement comes from the cognitive mechanism in charge of encoding the same and efficient motor program throughout trials (Lee & Carnahan, 1990). Because there is no need to change the behavior from trial to trial, the repetition of the same movement improves its encoding throughout the learning phase. For observers, the formation of this efficient encoding mechanism comes from the models' performance. However, physical practice is also required to refine motor processes during actual task production (Boutin et al., 2010). More recent findings have further revealed that combining both practice conditions can also offer unique opportunities to learn a motor task (Badets, Boutin, & Michelet, 2018; Larssen, Ho, Kraeutner, & Hodges, 2021; Shea, Wright, Wulf, & Whitacre, 2000), revealing a specificity for observational learning and thus questioning the general "similar mechanism" hypothesis between observational and physical practice (Badets & Blandin, 2010; Ghamari, Sohrabi, & Saberi Kakhki, 2019). For example, Badets and colleagues (2018) have shown that observers can avoid encoding failed motor sequence performance from the models. In this study, participants in the physical practice group performed two different motor sequences, but only one was interrupted during the acquisition phase. For these interrupted trials, a "stop" signal prompted participants to stop the execution of the motor sequence. The results for the physical practice group revealed that the interrupted motor sequence was not well encoded in comparison to the non-interrupted one. However, no difference between the two motor sequences was detected for the participants in the observational-practice group. For authors, in contrast to the physical-practice learning model, observers were able to learn equivalently the interrupted and the non-interrupted motor sequences from a single and abstract cognitive representation of the two motor tasks.

Despite the fact that it exists different cognitive mechanisms between physical and observational practice conditions (as assessed by the interrupted learning paradigm, Badets et al. 2018), based on the current observational learning protocol we have chosen to use the most simple expectation throughout the similar mechanism hypothesis (Adams, 1986; Ghamari et al., 2019). Indeed, it can be easily predicted that conscious awareness of actions may also benefit motor learning through observational practice. In this view, in order to judge whether maximal fluidity is reached or not, the subjective motor plan associated with maximal fluidity should be activated and mentally rehearsed during and after observation, allowing improved motor learning. Hence, the main goal of the present study was to compare two groups of observers who only differed with respect to their subjective conscious awareness of actions, as previously done for physical practice (Boutin et al., 2014; Ioannucci et al., 2021). We expected improved task performance for the consciousness group in comparison to the no-judgment control group. However, no difference between groups was expected in terms of motor sequence accuracy or explicit/implicit sequence knowledge.

2- Method

2.1- Participants

For this experiment, we estimated the sample size based on the previous studies on conscious awareness of action during physical practice (Boutin et al., 2014; Ioannucci et al., 2021; $N = 15$ per group), and more precisely using the G*Power software (Faul et al., 2007) from the Boutin and colleagues' design. We used the analysis of variance on response time between three groups X three tests (Cohen's d = 0.87, correlations among repeated measures = 0.5). Statistical significance was set at $p < .05$ and the power at 0.80. The results indicated that 13 participants per group would be enough to provide an estimated power of 0.82. Consequently, we collected data on 28 students ($N = 14$ per group) from the University of Bordeaux in this study (*mean age*: 21.2 years; *SD* = 2 years; 19 females; 2 participants were classified left-handed, as assessed by the Edinburgh test). None of them had prior experience with the motor sequence task or the experimental procedure. Each participant was requested to read and sign an informed consent form about the general procedure. This study was implemented in accordance with the ethical principles detailed in the 1964 Helsinki Declaration.

2.2- Apparatus and task

The apparatus was identical to the one used by Badets and colleagues (2018) (see Figure 1). Specifically, participants sat on a chair in front of a computer screen which was positioned approximately at a 50 cm viewing distance. Four horizontally aligned white empty squares (4.5 cm wide × 4.5 cm high, spaced 2 cm apart) were presented on a black background in the center of the screen and corresponded to the spatial locations of the response keys (1, 2, 3, and 4) on the response box from an E-prime Chronos device. Each imperative stimulus involved one of the four squares to be filled in white. An E-prime program (Schneider et al., 2002) was employed to run the experiment and store raw data for following offline analysis.

Participants were asked to press with their four right-hand fingers (without the thumb) the appropriate response key as quickly and accurately as possible in order to complete and learn a second-order conditional (SOC) 12-element motor sequence (keys 2-4-2-1-3-4-1-2-3-1-4-3; see Badets et al., 2018). A trial for this sequence began with the presentation of the word "SEQUENCE". The participant pressed any one of the four response keys when she/he felt ready to begin the entire sequence. Immediately after this key press, four empty squares were displayed on the screen for a fixed foreperiod of 1 second before the first imperative stimulus appeared. The participant's response triggered the presentation of the next stimulus until the completion of the entire sequence.

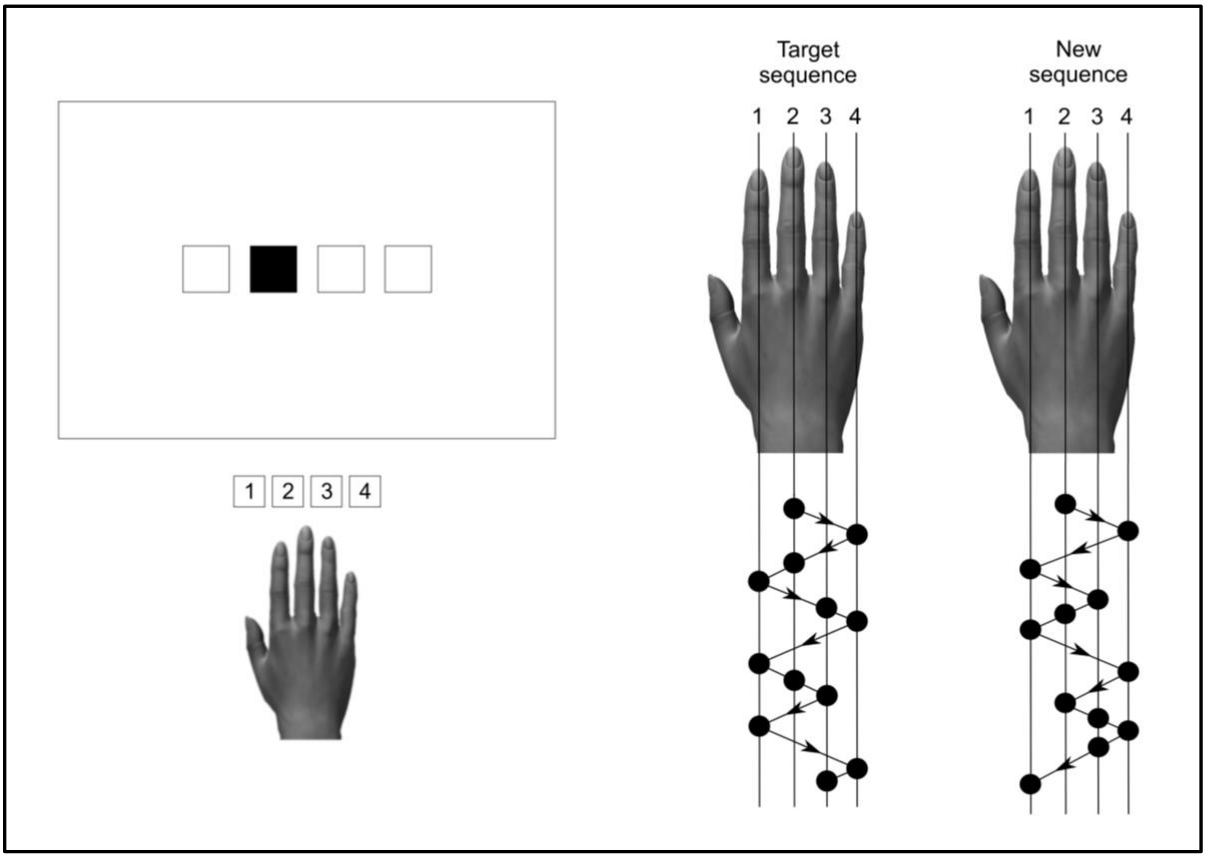

Figure 1. Experimental setup and task. Illustration of the apparatus and order of finger presses in the Target and New motor sequences. The Target and New sequences were matched for the number of movements per digit and two-finger transitions. Note that the response buttons are numbered from left to right and the fingers from the index finger to the little finger for illustration purposes only.

2.3- Procedure and groups

The whole experiment comprised five phases (pre-test, acquisition, post-test, transfer test, and two free-recall tests). Participants were distributed randomly across the two groups (the consciousness and the non-consciousness group; see Table 1). During the pre-test, all participants physically performed four trials of the to-be-learned "Target" motor sequence task. During the acquisition phase, participants of both groups observed the same video of a human model practicing the Target motor sequence during 10 blocks of 10 trials each (the video lasted about 18 minutes). As previous studies have shown that the correspondence between the gender of the observer and the gender of the actor performing an action may influence performance during the observation of the action (e.g., Bidet-Ildei et al., 2010), the model wore a black glove to limit such social influence. To keep the material quite similar for the model and the observer, the camera was located above the model's right shoulder in order to capture visual information of the fingers on the response box and the targets on the screen. During observation, individuals were instructed to observe the video intently (the model's action and the stimuli). Participants had to place their hands in front of the monitor to avoid any finger movement.

	Experimental groups and procedures					
	Pre-test	**Acquisition**	**Post-test**	**Transfer test**	**Free-recall tests**	
Groups						
Consciousness	PP Target sequence	OBS Target sequence + Maximal fluidity judgment	PP Target sequence	PP New sequence	Paper-and-pencil test	Sequence generation test
Non-consciousness	PP Target sequence	OBS Target sequence	PP Target sequence	PP New sequence	Paper-and-pencil test	Sequence generation test

Table 1. Experimental groups and procedures. The five experimental phases (pre-test, acquisition, post-test, transfer test, and two free-recall tests) are reported for each experimental group (consciousness and non-consciousness control group). PP: Physical practice; OBS: Observational practice.

Based on previous motor sequence learning findings (Boutin et al., 2010), the performance of the model improved across the 10 training blocks and followed the power law of practice (732, 564, 398, 367, 362, 349, 333, 316, 297, and 307 ms, from the block 1 to the block 10, respectively; with 0.25% of erroneous key presses). Physical practice trials during training were the same as during the pre-test, except that a question mark was presented on the screen for 3 seconds at the end of each trial. Both groups were instructed to learn the motor sequence through observation, but only the participants of the consciousness group were required, after the presentation of this question mark, to estimate whether the observed motor sequence was performed at its "maximal fluidity". The responses "YES" and "NO" corresponded to an estimated maximal fluidity or not, respectively. Specifically, participants were instructed that maximal fluidity corresponds to the trial where they estimate that the model could no longer improve the fast and smooth execution of the motor sequence (Ioannucci et al., 2021). Before the post-test, the participants were required to discuss with the experimenter for 5 minutes (time assessed by a chronometer) about their hobbies and family as a distractive activity between the acquisition phase and the post-test in order to divert participants from the learning of the motor sequence task. The post-test was similar to the pre-test. All participants physically performed four trials of the "Target" motor sequence task.

A transfer test block with a new sequence of stimuli was presented after the post-test to differentiate sequence learning from generalized practice effects. During the transfer test, participants performed four trials on a new 12-element SOC motor sequence (keys 2-4-1-3-2-1-4-2-3-4-3-1; see Figure 1). This new motor sequence was used as a reference to determine sequence-specific learning from the practiced "Target" motor sequence (see Krakauer et al., 2019, for a review). Indeed, if performance is equivalent between the New motor sequence and the Target sequence, then no specific learning can be attributed to the Target sequence. From this equivalent performance, we could only conclude that a general musculoskeletal component has been improved from the acquisition phase of the Target motor sequence. However, higher performance (i.e., lower response times and error rates) on the Target motor sequence than on the New one would indicate sequence-specific learning. The order of stimuli in the New sequence differed from the Target sequence but contained all the two-finger transitions that composed the learned sequence during acquisition (see Boutin, Massen & Heuer, 2013). In both the Target and New sequences, the same key was not pressed twice in succession, and the same two-finger transition never occurred twice. Also, no mention was made regarding the regularities in the order of stimuli.

Finally, participants were given two post-experimental free-recall tests: a paper-and-pencil test and the sequence generation task (SGT) (see Boutin et al., 2014; Destrebecqz & Cleeremans, 2001; Destrebecqz et al., 2005). These tests respectively assess explicit sequence knowledge and the conscious contribution of action awareness upon task performance (the order of the tests counterbalanced across participants). In the paper-and-pencil test (explicit sequence knowledge), participants were requested to write down the sequential order of the 12 elements that composed the learned motor sequence on a sheet of paper from memory. Performance was scored by determining the number of serial positions for which the correct element was recalled. In the SGT (implicit sequence knowledge), participants were asked to physically reproduce from memory the learned motor sequence by successively pressing the corresponding 12 keys that composed the sequence. The SGT was composed of three trials. Participants were explicitly told to be as accurate as possible and not to put emphasis on speed. SGT performance was scored by determining the number of serial positions for which the correct element was recalled. We then computed the mean SGT scores for each participant by averaging scores over the three trials. No feedback was given to the participants to avoid further learning during the paper-and-pencil and SGT tests.

2.4- Dependent variables

The dependent variables in this study were: (1) the response time, which represents the time between the imperative stimuli and the appropriate response keys; (2) the error rate, which represents the percent of the number of erroneous key presses; (3) the SGT score, which represents the number of recalled sequence elements through correctly pressed keys; and (4) the paper-and-pencil score, which represents the number of correctly recalled sequence elements. In this observational learning study, the expected pattern of results was similar to the one previously found during motor sequence learning through physical practice (Boutin et al., 2014; Ioannucci et al., 2021). Therefore, lower response times (i.e., higher performance) were expected on the learned Target motor sequence for the consciousness group in comparison to the non-consciousness group during the post-test, but not on the New sequence during the transfer test. The three other variables would not be affected.

3- Results

3.1- Speed: Response time analysis

The response times were submitted to a multivariate analysis of variance (ANOVA) with the following factors: 2 *groups* (consciousness and non-consciousness group) X 3 *tests* (pre-test, post-test, transfer test) with repeated measures for the last factor. The ANOVA revealed only a main effect for the factor *tests*, $F(2, 52) = 47.5$, $p < .001$, $\eta^2 = .64$. For this main effect, Duncan's post-hoc comparisons revealed that participants of both groups were faster during the post-test (M = 378 ms) on the learned Target motor sequence in comparison to the pre-test (M = 499 ms, p < .001) and transfer test (M = 460 ms, p < .001). The New motor sequence during the transfer test was also performed faster than the initial Target motor sequence during the pre-test (p = .003). Finally, the factor *groups* and the interaction *groups* X *tests* were not significant ($F(1, 26) = 1.3$, $p = .26$, and $F(2, 52) = 1.75$, $p = .18$, respectively; see Table 2).

	Experimental groups and response time data		
	Pre-test	**Post-test**	**Transfer test**
Groups			
Consciousness	**480** (*110*)	**376** (*86*)	**435** (*69*)
Non-consciousness	**518** (*85*)	**380** (*54*)	**485** (*78*)

Table 2. Behavioral results – Speed. Mean response time (ms) and standard deviations (ms; in brackets) are provided for each experimental groups (consciousness and non-consciousness control group) .

3.2- Accuracy: Error rate analysis

A similar multivariate ANOVA was performed on the error rates. The analysis revealed a significant interaction between the factors *groups* and *tests*, $F(2, 52) = 3.85$, $p = .027$, $\eta^2 = .13$. Duncan's post-hoc analysis revealed that only the consciousness group made more errors during the transfer test than during the pre-test. The error rate for the non-consciousness group did not differ between the three tests $M_{\text{Pre-test}} = 2\%$, $M_{\text{Post-test}} = 5\%$, and $M_{\text{Transfer}} = 7\%$ for the consciousness group, and $M_{\text{Pre-test}} = 5\%$, $M_{\text{Post-test}} = 3\%$, and $M_{\text{Transfer}} = 5\%$ for the non-consciousness group; see Figure 2, panel A). Also, the error rate for the two groups did not differ during the pre-test (p = .25). Finally, the main effects of the factors *groups* and *tests* were not significant ($F(1, 26) = 0.02$, $p = .86$, and $F(2, 52) = 2.76$, $p = .07$, respectively).

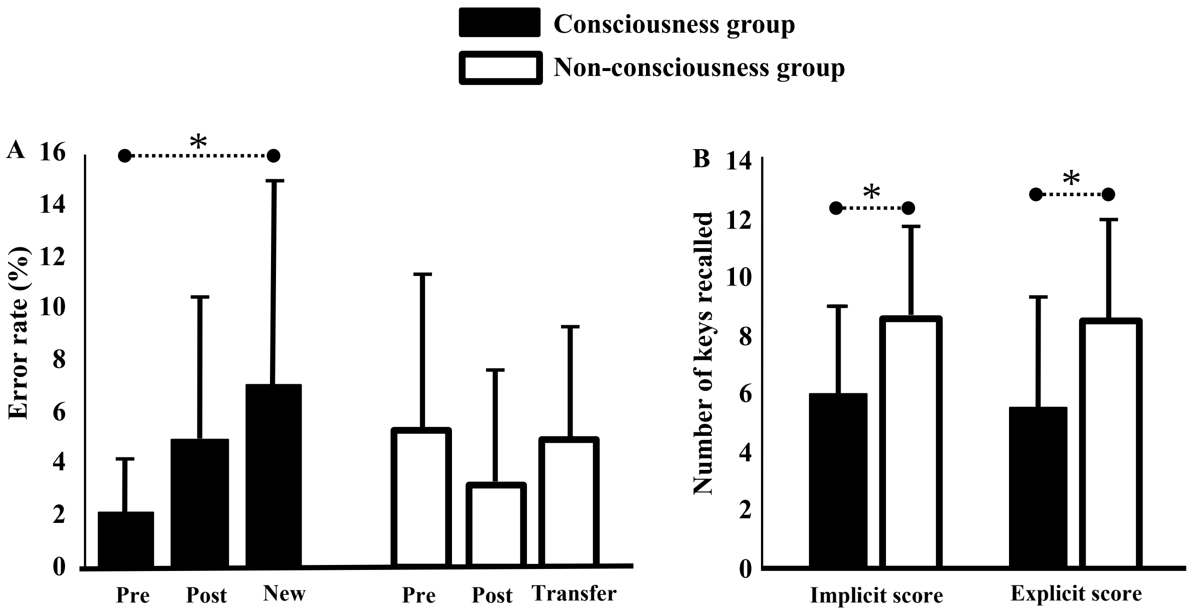

Figure 2. Behavioral results – Accuracy. Panel A: Error rate in percent for the pre-test, post-test, and transfer test. Panel B: Number of keys recalled during the free recall paper-and-pencil (Explicit score) and sequence generation task tests (Implicit score). Error bars represent the standard deviation of the means, and * $p < .05$.

3.3- The explicit-implicit scores

Figure 2 (panel B) illustrates the explicit-implicit scores for both experimental groups. To compare both tests for the explicit and implicit knowledge of the learned SOC motor sequence, the scores have been submitted to an ANOVA with the following factors: 2 *groups*

X 2 *tests* (paper-and-pencil test (explicit) and SGT test (implicit)) with repeated measures for the last factor. The ANOVA revealed only a main effect of the factor *groups*, $F(1, 26) = 7.12$, $p = .012$, $\eta^2 = .22$. The non-consciousness group (8.5 and 8.6 recalled elements for the paper-and-pencil and SGT tests, respectively) recalled significantly more items than the consciousness group (5.5 and 6 recalled elements, respectively). Finally, the factor *tests* and the *groups* X *tests* interaction were not significant ($F(1, 26) = 0.13$, $p = .71$, and $F(1, 26) = 0.07$, $p = .78$, respectively).

4- Discussion

The primary purpose of this study was to assess the beneficial effect of the conscious awareness of others' actions during motor sequence learning by observation. As for previous studies on physical practice (Boutin et al., 2014; Ioannucci et al., 2021), we expected improved motor learning for the consciousness group in comparison to the non-consciousness group, as expressed by faster execution of the motor sequence. Moreover, no group differences were expected for motor sequence accuracy and explicit-implicit sequence knowledge assessed through free-recall tests. Unexpectedly, our findings revealed a different pattern of results. On the one hand, the response time analysis failed to reveal any significant advantage of the consciousness group over the non-consciousness control group in the learning of the motor sequence task. Indeed, both groups demonstrated performance improvements throughout the observational procedure, from the pre-test to the post-test. Also, these performance improvements were specific to the learned motor sequence since higher RT performance was found on the post-test than on the transfer test, which required the practice of a new unpracticed motor sequence. In previous physical practice studies, the task-related judgments required in the consciousness groups led to improved performance (i.e., lower response time) during both acquisition and post-test sessions in comparison to control groups where no judgment or task-unrelated judgments were afforded (Boutin et al., 2014; Ioannucci et al., 2021). Here, such practice-related performance improvements from the pre-test to the post-test were not observed. On the other hand, analyses revealed higher error rates on the transfer test than on the pre-test for participants of the consciousness group only. It is important to take this finding with caution because of the low eta-squared and the fact that during the pre-test, the error rate was relatively low for the consciousness group, permitting a significant performance decrement on the transfer test. Finally, results on the explicit-implicit sequence knowledge revealed better scores for the non-consciousness group than for the consciousness group.

This general knowledge impairment (i.e., explicit-implicit scores) for the consciousness group could come from the fact that the tasks which had to be managed during the observation created a double challenge for the learners. The first challenge was to form and encode a cognitive representation of the motor sequence to be learned throughout the observation of the model. At this step, the observers acquired their own cognitive representation of the task, which is actually independent from the one developed by the physical-practice model. The second challenge was to judge the maximal performance of the model on the motor sequence task, in terms of speed and fluidity, by the mere observation of his behavior. This second task required a cognitive mechanism that differs from the initial motor learning task, by retrospectively focusing attention on the model's movement and consequently not reinforcing the genuine cognitive representation of the observer. These active double tasks for the observers impaired motor encoding and differed from traditional single-task observational protocol where the observers have only to watch the model and interpret the feedback given by the experimenter during observational practice (Badets & Blandin, 2010; Ghamari, Sohrabi, & Saberi Kakhki, 2019). For a physical practice condition (and not observation), Hemond and colleagues (2010) have suggested that when a distractive task engages different cognitive mechanisms during motor enactment, the performance is generally impaired. Thus, from this double-challenge interpretation, it is tempting to assume that participants in the non-consciousness group benefited the most from observational learning because of this single challenge, allowing an improved sequence knowledge of the motor task.

The explicit-implicit sequence knowledge scores obtained on the free recall paper-and-pencil and SGT tests support this assumption. For the consciousness group, the recall was about 6 elements on both tests, while the number of recalled elements for the non-consciousness group reached about 9 elements on both tests. For both groups, the number of recalled sequence elements on the two tests was above 5 over the 12 elements composing the motor sequence. Thus, it reflected for both tests (i.e., the free recall paper-and-pencil and SGT tests) a primarily conscious-explicit knowledge of the sequence, not an implicit one (Willingham & Goedert-Eschmann, 1999). Consequently, our results revealed that participants of the non-consciousness group performed the learned motor task during the post-test as efficiently as their consciousness group counterparts (response time data) but with a more pronounced conscious-explicit knowledge of the motor sequence.

The present results are also not in accordance with the similar mechanism hypothesis between physical and observational practice, and further emphasize the existence of specific learning mechanisms between the two conditions of practice (Badets, Boutin, & Michelet, 2018; Larssen, Ho, Kraeutner & Hodges, 2021; Shea, Wright, Wulf, & Whitacre, 2000). Hence, in the present study, we suggest that the instructions given at the beginning of the experiment triggered the engagement of such different mechanisms. In the previous studies relating to conscious awareness of action during physical practice (Boutin et al., 2014; Ioannucci et al., 2021), the specific instructions about learning the motor sequence task and judging their own performance may have engaged the participants on similar and/or convergent cognitive mechanisms devoted to the learning of the task itself. However, in the present study, similar instructions have probably engaged the participants to learn the motor task and concomitantly (retrospectively) evaluate another person's behavior. Such differences have yielded a different pattern of results between the two learning conditions: conscious awareness of action during physical practice promotes motor sequence learning but does not influence sequence task performance in an observational learning context.

A limitation of the present study is that it was not designed to determine whether such memory improvements are supported by a genuine learning mechanism or a temporary encoding mechanism during practice. Indeed, the post-training tests in this study were delayed and administrated after a short 5-minute rest period following the end of the acquisition phase. Motor learning experiments with post-practice tests performed after short (from seconds to a couple of hours) or long delays (approximately 24 hours) do not assess the same learning mechanisms (e.g., Kantak & Winstein, 2012). Indeed, the strengthening of newly acquired motor skills depends on consolidation processes which require time and/or sleep to become effective (see King et al., 2017; Doyon et al., 2018, for reviews); consolidation is the offline process that transforms new and initially labile memories into more stable representations (see Krakauer & Shadmehr, 2006). However, recent studies revealed that a form of offline consolidation that substantially contributes to early skill learning might also occur rapidly, in a timescale on the order of seconds to minutes, instead of hours or days traditionally reported in the scientific literature (see Bönstrup et al., 2019). Hence, our 5-minute delayed post-tests may have enabled an early consolidation and learning of the practiced motor sequence. Yet, additional work is needed to disentangle the effects of conscious awareness of action in motor skill encoding (short-term) and learning (long-term), and to determine the underlying neuro-cognitive mechanisms.

Testing our double-challenge hypothesis for observers should be easily achievable in a future study on motor skill learning using a pupil dilatation paradigm. In this perspective, Ioannucci and colleagues (2021) have already revealed that in a physical practice context, participants in the consciousness group, which is associated with the detection of maximal fluidity, exhibited a smaller pupil dilatation during motor learning than their non-consciousness group counterparts. While pupil dilatation is considered a physiological marker of cognitive effort (see Zenon, 2019, for a review), such reduction during the physical practice condition suggests that the detection of the maximal fluidity decreases the cognitive effort during motor sequence encoding. Moreover, by contrasting single and multitasking conditions, Lisi and colleagues (2015) provided evidence of pupil dilatation as a function of task demand. For the authors, such pupil dilatation is the hallmark of a top-down allocation of attentional resources during task processing. Consequently, in the current protocol, which combines observational practice and the retrospective judgment of maximal fluidity from the model's behavior, pupil dilatation may provide insight into the potential additional cognitive effort of the double challenge processing for observational learning.

In conclusion, it is important to keep in mind that the similar mechanism hypothesis has been, and is still, a relevant theoretical approach for investigating the underlying cognitive mechanisms of observational learning. Indeed, the learning factors that can improve action encoding throughout a simple observation can be central in situations where an overt behavior is not recommended, like a medical task for an apprentice surgeon. However, the present findings reveal that it is also important to have some reservations about the learning factors that can a priori improve observational learning. Here, the beneficial effect of the conscious awareness of action in motor skill learning during physical practice (Boutin et al., 2014; Ioannucci et al., 2021) was not replicated in an observational learning context. Consequently, more studies are needed to fully understand the effects of conscious awareness of action in motor skill learning by physical practice and action observation.

Compliance with Ethical Standards:

The authors declare that they have no conflict of interest.
All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee, and with the 1964 Helsinki declaration. Finally, informed consent was obtained from all individual participants included in the study.

Data availability
The data that support the results of this study are available from the corresponding author upon reasonable request.

References

Adams, J. A. (1964). Motor skills. *Annual Review of Psychology*, 15, 181-202.

Adams, J. A. (1986). Use of model's knowledge of results to increase the observer's performance. *Journal of Human Movement Studies*, 12, 89-98.

Badets, A., & Blandin, Y. (2010). Feedback schedules for motor-skill learning: the similarities and differences between physical and observational practice. *Journal of Motor Behavior*, 42, 257-268.

Badets, A., Boutin, A., & Michelet, T. (2018). A safety mechanism for observational learning. *Psychonomic Bulletin & Review*, 25, 643-650.

Bönstrup, M., Iturrate, I., Thompson, R., Cruciani, G., Censor, N., & Cohen, L. G. (2019). A Rapid Form of Offline Consolidation in Skill Learning. *Current biology, 29*(8), 1346-1351.e4.

Boutin, A., Massen, C., & Heuer, H. (2013). Modality-specific organization in the representation of sensorimotor sequences. *Frontiers in Psychology, 4*, 937.

Boutin, A., Blandin, Y., Massen, C., Heuer, H., & Badets, A. (2014). Conscious awareness of action potentiates sensorimotor learning. *Cognition*, 133, 1-9.

Boutin, A., Fries, U., Panzer, S., Shea, C. H., & Blandin, Y. (2010). Role of action observation and action in sequence learning and coding. *Acta Psychologica*, 135(2), 240-251.

Bidet-Ildei, C., Chauvin, A., & Coello, Y. (2010). Observing or producing a motor action improves later perception of biological motion: Evidence for a sex effect. *Acta Psychologica*, 134(2), 215-224.

Blandin, Y., & Proteau, L. (2000). On the cognitive basis of observational learning : Development of mechanisms for the detection and correction of errors. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, 53(3), 846-867.

Destrebecqz, A., & Cleeremans, A. (2001). Can sequence learning be implicit? New evidence with the process dissociation procedure. *Psychonomic Bulletin and Review*, 8, 343-350.

Destrebecqz, A., Peigneux, P., Laureys, S., Degueldre, C., Del Fiore, G., Aerts, J., Luxen, A., Van Der Linden, M., Cleeremans, A., & Maquet, P. (2005). The neural correlates of implicit and explicit sequence learning: Interacting networks revealed by the process dissociation procedure. *Learning & Memory, 12*(5), 480-490.

Doyon, J, Gabitov, E., Vahdat, S., Lungu, O., & Boutin, A. (2018). Current issues related to motor sequence learning in humans. *Current Opinion in Behavioral Sciences*, 20, 89-97.

Du, Y., Krakauer, J. W., & Haith, A. M. (2022). The relationship between habits and motor skills in humans. *Trends in Cognitive Sciences*, 26, 371-387.

Evans, N. J., Brown, S. D., Mewhort, D. J. K., & Heathcote, A. (2018). Refining the law of practice. *Psychological Review*, 125, 592-605.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain: A Journal of Neurology,* 119, 593-609.

Ghamari, A., Sohrabi, M., & Saberi Kakhki, A. (2019). Effects of Physical and Observational Practice on Intermanual Transfer. *Advances in Cognitive Psychology,* 15, 21-29.

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 and Biobehavioral Reviews*, 94, 31-44.

Hemond, C., Brown, R. M., & Robertson, E. M. (2010). A distraction can impair or enhance motor performance. *Journal of Neuroscience*, 30, 650-654.

Ioannucci, S., Boutin, A., Michelet, T., Zenon, A., & Badets, A. (2021). Conscious awareness of motor fluidity improves performance and decreases cognitive effort in sequence learning. *Consciousness and Cognition*, 95, 103220.

Kantak, S. S., & Winstein, C. J. (2012). Learning-performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioural brain research*, 228(1), 219-231.

King, B.R., Hoedlmoser, K., Hirschauer, F., Dolfen, N., & Albouy, G. (2017). Sleeping on the motor engram: the multifaceted nature of sleep-related motor memory consolidation. *Neuroscience and Biobehavioral Reviews*. 80, 1–22.

Krakauer, J. W., & Shadmehr, R. (2006). Consolidation of motor memory. *Trends in Neurosciences,* 29(1), 58-64.

Krakauer, J. W., Hadjiosif, A. M., Xu, J., Wong, A. L., & Haith, A. M. (2019). Motor learning. *Comprehensive Physiology,* 9(2), 613–663.

Larssen, B. C., Ho, D. H., Kraeutner, S. N., Hodges, N. J. (2021). Combining Observation and Physical Practice: Benefits of an Interleaved Schedule for Visuomotor Adaptation and Motor Memory Consolidation. *Frontiers in Human Neuroscience*, 15, 614452.

Lee, T. D., & Carnahan, H. (1990). Bandwidth knowledge of results and motor learning: more than just a relative frequency effect. *The Quarterly Journal of Experimental Psychology*, 42A, 777–789.

Lisi, M., Bonato, M., & Zorzi, M. (2015). Pupil dilation reveals top–down attentional load during spatial monitoring. *Biological Psychology*, 112, 39-45.

Schmidt, R. A., & Lee, T. D. (2011). Motor control and learning: a behavioral emphasis (5th ed.). Champaign: Human Kinetics Publishers.

Schmidt, R. A., Lee, T. D., Winstein, C. J., Wulf, G., & Zelaznik, H. N. (2019). Motor Control and Learning: A Behavioral Emphasis (6th ed.). Champaign: Human Kinetics Publishers.

Schneider, W., Eschmann, A., & Zuccolotto, A. (2002). E-prime reference guide. PsychologySoftware Tools, Pittsburgh.

Shea, C. H., Wright, D. L., Wulf, G., & Whitacre, C. (2000). Physical and observational practice afford unique learning opportunities. *Journal of Motor Behavior*, 32, 27-36.

Willingham, D. B., & Goedert-Eschmann, K. (1999). The relation between implicit and explicit learning: Evidence for parallel development. *Psychological Science*, 10, 531-534.

Wulf, G., Shea, C., Lewthwaite, R. (2010). Motor skill learning and performance: a review of influential factors. *Medical Education*, 44, 75-84.

Zénon, A. (2019). Eye pupil signals information gain. *Proceedings of the Royal Society of London. Series B*, 25;286(1911):20191593.