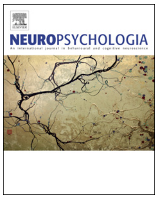
Neuropsychologia 124 (2019) 202–207

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia



Mental imagery and colour cues can prevent interference between motor tasks

Benedikt Lauber[a,b,*,1], Alexander Kurz[a,c,1], Albert Gollhofer[a], Wolfgang Taube[b]

[a] Department of Sport Science, University of Freiburg, Freiburg, Germany
[b] Department of Neurosciences and Movement Sciences, University of Fribourg, Fribourg, Switzerland
[c] Bernstein Centre Freiburg, Germany

ARTICLE INFO

Keywords:
Ballistic motor learning
Interference
Motor imagery
Memory consolidation
Colour cue

ABSTRACT

Motor interference can be observed when two motor tasks are learnt in subsequent order. The aim of the current study was to test two approaches potentially mitigating interference effects. The first approach used contextual colour cues requiring only little cognitive attention thus being assumed to be primarily implicit while the second, mental practice/rehearsal that demands much more active cognitive processing being considered explicit.

Six groups performed a ballistic strength training immediately followed by the practice of an interfering visuomotor tracking task. Two groups received a contextual colour cue when presenting feedback about ballistic performance. During the practice of the interfering motor task, one of the two groups received the same colour cue during random trials while the other group received a different colour cue and a third control group no colour cue at all. The forth group mentally rehearsed the ballistic task during the practice of the interference task, while the respective control groups either mentally rehearsed a ramp and hold contraction instead of the ballistic task or didn't rehearse any task. The ballistic performance was tested before and after the ballistic training and in an immediate retention test after the learning of the interfering motor task.

All groups significantly increased their ballistic performance after training. After practicing the interfering motor tracking, subjects receiving the same colour cue and subjects that mentally rehearsed the ballistic task did not show significant interference effect while all other groups did. These results indicate that implicit cuing with the same cue as well as explicit mental rehearsal of the initially learnt task can help to prevent motor interference without affecting performance improvements of the second motor task.

1. Introduction

Motor interference describes the case where the learning of a secondary motor task causes a reduction in performance of the primary task. A very common paradigm to test whether two motor tasks interfere with each other is when a secondary task B is learnt after the learning of a primary task A and performance of task A is retested. For ballistic motor learning it was shown that when subjects perform ballistic contractions (task A) with either the foot (Lundbye-Jensen et al., 2011) or the hand (Lauber et al., 2017, 2013) followed by the practice of a visuomotor tracking task (task B), ballistic task (task A) performance is impaired.

One reason for interference to occur is that the consolidation of task A is disrupted by the practice of task B causing the decline in task A performance (Krakauer and Shadmehr, 2006). There are, however, ways to facilitate motor memory consolidation. One well known method to promote motor learning and memory consolidation is motor imagery (MI). It was for example shown that MI can enhance movement accuracy (Afrouzeh et al., 2015; Guillot et al., 2015) movement speed (Boschker et al., 2000), muscular strength (Yue and Cole, 1992), postural coordination (Taube et al., 2014) and finger tapping tasks (Debarnot et al., 2012, 2009; Lacourse et al., 2004) and it is therefore suggested that MI is a reliable supplement to physical activity in promoting motor performance and thus supporting the process of motor memory consolidation (Debarnot et al., 2012; Jackson et al., 2001). Furthermore, Debarnot et al. (2012) showed that MI rather relies on explicit (declarative) memory than on implicit (procedural) memory, which suggests that MI has a strong conscious component.

This is in contrast to other forms of learning where it has been suggested that they are rather unconscious. For example, contextual

---

[*] Correspondence to: Department of Sport Science University of Freiburg, Schwarzwaldtsr 175, 79117 Freiburg, Germany.
E-mail address: benedikt.lauber@unifr.ch (B. Lauber).
[1] Equal contribution.

https://doi.org/10.1016/j.neuropsychologia.2018.12.010
Received 16 May 2018; Received in revised form 6 December 2018; Accepted 13 December 2018

cuing is considered to be a form of unconscious learning (Colagiuri and Livesey, 2016). One of the first experiments using contextual cuing by Chun and Jiang (1998) suggests that this type of learning is implicit which is confirmed by a recent study from Colagiuri and Livesey (2016) who showed that there was no relationship between the recognition and the positive effects of cuing on memory. Therefore, the authors concluded that contextual cuing is not dependent on conscious cue recognition. Several sensory cues such as odour (Chu and Downes, 2002), pre-movements (Sarwary et al., 2015), auditory feedback (Keough and Jones, 2011) have been used to investigate their potential influence on motor learning processes but colour cues have been used most often (Howard et al., 2013).

According to the robust findings of improved motor memory consolidation by explicit (MI) and implicit (sensory cuing) strategies and the idea that motor interference is related to disturbed consolidation, the present study aimed to investigate whether MI and sensory cuing will be effective in reducing motor interference. In contrast to previous studies using adaptation tasks such as force field adaptations or visuomotor rotations (Addou et al., 2011; Osu et al., 2004), we used a ballistic task to test whether MI or colour cues can prevent interference between two motor tasks. It needs to be highlighted, though, that our colour cue paradigm differed to previously used approaches in that the colour cue was used to 're-activate' the previously learnt motor memory. In contrast, previous studies provided colour cues with the idea that subjects can use this contextual information enabling them to differentiate between two different motor memories (i.e. separating different force fields or visuomotor maps).

Therefore, subjects first trained ballistic isometric ballistic flexions (Task A) followed by a visuomotor tracking task (Task B) with the same finger in the same movement direction. This paradigm was shown to be effective in testing learning related interference effects (Lauber et al., 2017, 2013; Lundbye-Jensen et al., 2011). We hypothesized that MI (the more explicit strategy) as well as colour cueing with the same cue (the more implicit strategy) are able to reduce motor interference.

2. Material and methods

2.1. Subjects

In total, 66 healthy subjects (44 males, 22 females, 26.8 ± 3.1 years) participated. Subjects were divided into six groups. Groups 1,3,4,6 were comprised of 12 subjects in each group and groups 2 + 5 of nine subjects. Hand dominance was tested using the Oldfield handedness inventory (Oldfield, 1971) and all subjects gave written informed consent before participation. The experiment was approved by the local ethics committee (257/14) and was in accordance with the latest version of the Declaration of Helsinki.

2.2. General experimental procedure

The present study was divided into two experiments. In Experiment A, subjects of group 1 mentally rehearsed previously practiced ballistic contractions (task A) while performing an interfering accuracy task (task B; *see explicit motor consolidation;* Fig. 1). Group 2 performed the same tasks but mentally rehearsed a ramp and hold contractions instead of the ballistic contractions. Group 3 did not mentally rehearse during the learning of task B. In Experiment B, subjects of group 4 received the same contextual cue during the practice of the interference task (accuracy task; task B) as during the practice of the ballistic task (task A; *see implicit motor consolidation;* Fig. 1) while group 5 received a different colour cue. Group 6 performed the same tasks in the same order but without contextual cues. For both experiments, the ballistic task (BT; task A) and the accuracy task (AT; task B) consisted of isometric contractions of the dominant index finger against a custom built robotic device (see Lauber et al., 2013a) equipped with a torquemeter (LCB 130, ME-Meßsysteme, Neuendorf, Germany) to the robot arm. The forearm of the dominant hand was fixed in a custom-made arm and hand cast to prevent movements of the arm and wrist while subjects practiced with the index finger. The index finger was fixed to a splint which was mounted to the arm of the robot while the axis of rotation of the robot arm was aligned with the metacarpophalangeal joint of the subject's right hand. Thus, the axis of the subject's joint and the centre of rotation of the robot arm were aligned. Subjects were allowed to accustom and to perform 5 submaximal isometric contractions at their preferred timing and intensity.

2.2.1. Ballistic task (BT)

The goal of the ballistic task was to improve the rate of force development (RFD) on a trial by trial basis. Before the recording started, all subjects were instructed to produce maximal lateral force as fast as possible by solely flexing the index finger. These contractions were timed according to auditory tones. A first warning tone (100 ms, 500 Hz sine wave) preceded a second imperative tone (200 ms, 600 Hz sine wave) by two seconds. Subjects should start their contraction around the second tone. Following each contraction, subjects were provided with visual feedback about their rate of force development (RFD) calculated form the force-time curve. The feedback was displayed in black letters with white background on a computer screen placed in front of the subjects, and appeared 1 s after each contraction for a duration of 5 s. Subjects were verbally encouraged after every 10 contractions to increase the RFD of the contraction.

To determine the baseline performance, subjects performed 10 contractions (Pre) without the presentation of feedback. During the BT training, subjects performed 3 sets of 15 contractions with 3 min breaks between the sets and received feedback for all of the trials. After the BT training, subjects again performed 10 contractions without feedback (Post). To test learning-related interference effects, BT performance was re-tested in an immediate retention test after the practice of an interfering accuracy task (Fig. 1), every time without the provision of feedback.

2.2.2. Accuracy task (AT)

The AT was identical to the one previously used (Lauber et al., 2017, 2013) and consisted of tracking a computer-generated sinusoid curve. The duration of the tracking was 30 s and the total path consisted of alternating sine waves of different frequencies ranging from 0.5 to 3 Hz. On two occasions within the tracking cycle, there were periods showing a flat line (one period in the middle of the tracking cycle and one at the end) lasting for 2 s where the subjects were allowed to rest. The curve was presented on a computer screen and was displayed as a running black line from the right to the left side with a visible sequence of 6 s (Fig. 1). A red line at the trough of the sine wave indicated the force output produced by the subjects when flexing their index finger. Subjects were told to maintain the red line, which served as feedback for their accuracy performance, as closely as possible to the black target line by an isometric contraction of the index finger pushing against the robot arm. The required force which was needed to match the highest point of the sine was 9 N. Thus, the force required for the task was low. Similar to performing the BT, the AT also depended on augmented feedback (i.e. the red line) and on the activation of the same muscles acting in the same movement direction as during the BT. Subjects were verbally encouraged to improve their performance trial by trial while practicing the 30 s sequence. Subjects were allowed to rest for 3 min after the completion of 20 trials. The training ended after the completion of 60 trials.

2.2.3. Explicit motor consolidation

In the course of the AT, subjects of Group 1 were asked to mentally rehearse the BT. After each trial of the AT, subject mentally practiced the BT in exactly the same way as during the BT training but without actually performing the contractions. Group 2 mentally rehearsed a ramp and hold contraction and subjects from this group were allowed

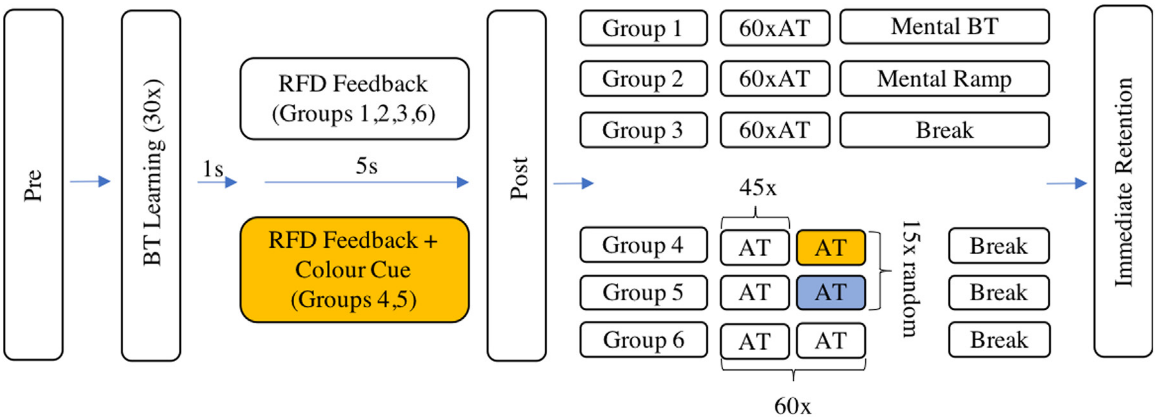


Fig. 1. Overview of the procedure of the experiment. After the Pre test, all groups practiced the BT (BT Learning) where all groups feedback about their RFD. This was followed by the Post test. Subsequently, during the learning of the AT, Group 1 mentally practiced the BT at certain resting periods during while Group 2 mentally practiced a ramp and hold contraction at the same instances while Group 3 only practiced the AT without mental training. Group 4 received the same colour cue (change in background colour of the screen during feedback presentation) during the AT than during the BT during random AT trials while Group 5 received a different colour cue. Group 6 did not receive colour cues.

to physically practice the ramp and hold contraction 10 times before the Pre-test. Therefore, subjects saw their isometric force as a red line on the computer screen and where asked to match this line with a black line showing a ramp followed by a hold phase. The ramp represented a gradual increase in force from zero to the maximum of 9 N over a timespan of three seconds followed by a hold period of three seconds. Thus, the increase in force was much slower than during the BT contractions. During mental practice, muscle activity was monitored on a computer screen to ensure that the subjects did not activate their prime mover, the first dorsal interosseous (FDI) muscle. Note that a control group was included (Group 3) which did not perform MI but otherwise was treated the same as Groups 1 + 2.

2.2.4. Implicit motor consolidation

During the BT training, Group 4 received a colour cue in form of a change in background colour during the presentation of the RFD-value (i.e. the presentation of the augmented feedback) of the ballistic contraction on a computer screen (Fig. 1). The background colour of the computer screen changed from white to orange as soon as the augmented feedback was presented as a black number. When the feedback disappeared after 5 s, the entire screen turned white again. The cue was provided after the movement with the presentation of feedback as we assumed that this external stimulus can be used together with sensory information to update and form the internal model for the ballistic task (Wolpert et al., 1995).

While practising AT, during 15 (out of 60) randomly chosen trials, the background colour changed from white to orange so that the background colour was the same as during the presentation of the augmented feedback during the BT training (Fig. 1). Subjects were not informed about the meaning of the colour. Group 5 followed exactly the same procedure and also received an orange colour cure during the ballistic contractions but a blue and thus different colour cue during the AT practice. Again, a control group was included (Group 6) that received no change in colour meaning that the background colour was always white and only the feedback (number in black letters) appeared for 5 s on the screen and then disappeared again. There was also no change in the background colour during the AT practice and thus no cues referring to the BT were given.

2.3. Data analyses

2.3.1. BT

RFD was calculated as the maximal slope of the force time curve (dT/dt) in each trial in a time window of the produced force (Gruber et al., 2007). The mean RFD values for the Pre, Post and Immediate Retention tests were calculated. In order to highlight changes in the course of the BT training, we compared the mean of the initial five with the last five contractions of the BT training. To test the effect of the AT on the BT performance, we compared the BT performance of the Post-test with the BT performance of the Immediate Retention test.

All values were normalized to the mean of the Pre-values except the BT values of the training, which were normalized to the initial contraction of the training (Lauber et al., 2017, 2013; Lundbye-Jensen et al., 2011). Normalization of motor performance to baseline was necessary for comparisons across subjects.

2.3.2. AT

The performance in the AT was calculated as the mean values representing the difference between the target curve and the curve produced by the subjects at each data point. All values were normalized to the mean value of the initial trial. To quantify changes in performance during training, the average of the initial 5 values of the AT training were compared to the final 5 values.

All data analyses were performed offline using custom written Matlab scripts (Mathworks Inc., Chatswool, MA).

2.4. Statistics

Normal distribution of the data was tested with a Shapiro-Wilks test.

Two-way repeated measures ANOVAs with factors TIME (Post, Immediate Retention) and GROUP (1,2,3,4,5,6) were calculated to evaluate changes in BT performance from the Post to the Immediate Retention test. Changes in the course of the BT and AT were calculated using separate repeated measures of ANOVA with factors TIME (initial five values, last five values) and GROUP (1,2,3,4,5,6). To identify group differences between the Group 1 (MI) and Group 4 (same colour cue), a two-way ANOVA with factors TIME (Pre, Post, Immediate Retention) and GROUP (1,4) was calculated. The pre-values were not included in the ANOVA as the values were normalized and therefore had no variance. If the ANOVA revealed significant interactions, Bonferroni corrected *t*-tests were calculated to identify changes within the groups. The level of significance for all statistical tests was set a priori to $p = 0.05$. All data are represented as means ± standard error of the mean (SEM). To further assist the understanding how the BT performance changed within and between the individual groups, results are also expressed as percentage changes.

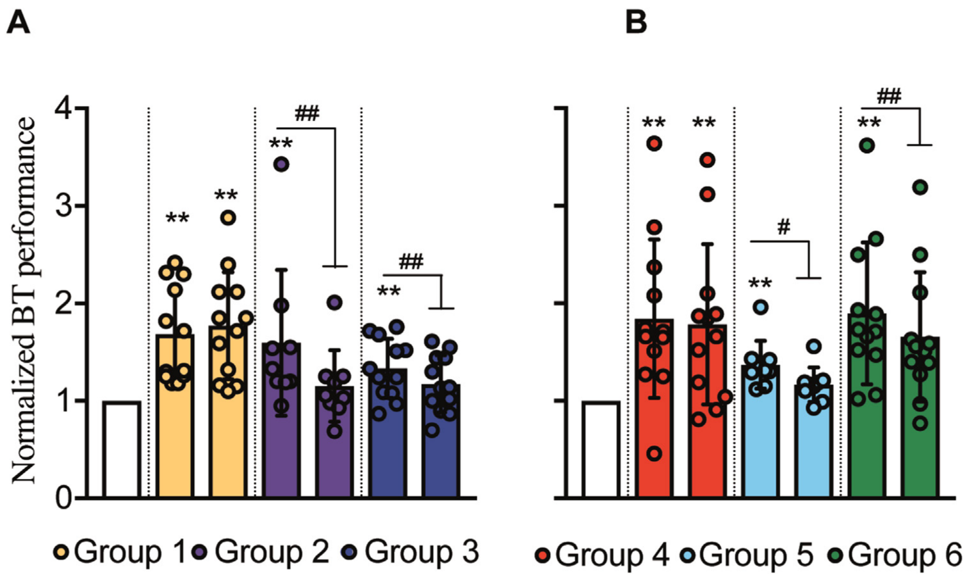


Fig. 2. **A**: BT performance values of the mental training groups (Groups 1 & 2) and the control group (Group 3). **B**: BT performance values of the colour cue groups (Groups 4, 5) and the control group (Group 6). After the BT training, there was a significant (**$p < 0.01$; *$p < 0.05$) and similar increase in BT performance (*depict significant differences after the BT in relation to the Pre-test) all groups. However, after the AT training, the group that mentally rehearsed the BT task (Group 1) and the group that received the same colour cue during the BT and AT (Group 4) did not show significant interference effects. All other groups showed a significantly interference effects (##$p < 0.01$; #$p < 0.05$) by a lower BT performance in the Immediate Retention than in the Post test (# depict significant difference between the Post- and the Immediate Retention test).

3. Results

Before the BT training, comparison of the raw data revealed no significant difference between groups for the ballistic task (GROUP: $F_{5,65} = 1.55$; $p = 0.19$).

3.1. Pre versus post

BT performance: To quantify the effects of the BT training, we compared the initial five contractions of the training with the last five contractions and there was a significant increase in BT performance (TIME: $F_{1,60} = 81.13$; $\eta^2 = 0.55$, $p < 0.001$). This performance increase was similar between the six groups (TIME*GROUP: $F_{5,60} = 1.47$; $\eta^2 = 0.11$, $p = 0.21$, Fig. 2).

3.2. Post versus immediate retention

There was a significant TIME effect ($F_{1,60} = 25.74$; $\eta^2 = 0.29$, $p < 0.001$) and a significant TIME*GROUP interaction ($F_{5,60} = 4.47$; $\eta^2 = 0.27$ $p = 0.002$). Post-hoc *t*-tests revealed unchanged performance levels in Group 1 (+1.52 ± 9.5%, $p = 0.50$) and Group 4 (+7.4 ± 7.5%, $p = 0.44$). In contrast, groups (Groups 2, 3, 5, 6) showed significant reductions in the BT performance after AT practice (Group 2: −12.1 ± 2.1%, $p = 0.001$; Group 3: −12.72 ± 2.7%, $p = 0.001$, Group 5: - 15.56 ± 2.5%, $p = 0.04$; Group 6: −16.64 ± 0.7%; $p = 0.002$). The separate two-way Anova showed that there was no significant difference between Group 1 and Group 4 between the Post and the Immediate Retention test (Time*Group: $F_{1,22} = 1.10$; $\eta^2 = 0.05$, $p = 0.30$). Furthermore, the decline in performance after AT practice between the control groups (Group 2, 3, 5, 6) was similar (Time*Group: $F_{1,38} = 2.93$; $\eta^2 = 0.19$, $p = 0.06$).

AT performance: To quantify the effects of the AT, we compared the initial five trials with the last five trials and there was a significant decrease in error (TIME: $F_{1,60} = 43.99$; $\eta^2 = 0.42$, $p < 0.001$). This decrease in error (i.e. performance increase) was similar between the all groups (TIME*GROUP: $F_{5,60} = 0.72$; $\eta^2 = 0.06$, $p = 0.61$, Fig. 2+3).

4. Discussion

The aim of the present study was to investigate whether two very different approaches (MI vs. visual cue) can mitigate interference effects caused by learning of two subsequent motor tasks. The first approach was considered as a more implicit approach using contextual colour cues where very little cognitive attention is needed (Colagiuri and Livesey, 2016). The second approach involved mental practice or rehearsal, thus, a more explicit way to improve consolidation as it requires active cognitive processing (Debarnot et al., 2012). The results show that the explicit (Group 1; MI) as well as the implicit approach (Group 4; same colour cue) can prevent interference which otherwise occurs due to the learning of a subsequent motor task.

Motor imagery (MI) has received a lot of attention in recent years because of its potential to influence motor learning processes. During MI, subjects mentally practice or rehearse a motor task which has been shown to improve motor memory consolidation (Debarnot et al., 2012; Jackson et al., 2001; Murphy, 2008) and might therefore be beneficial in reducing interference. The common belief that MI has a strong conscious component and thus, rather relies on explicit than on implicit memory, is supported by recent studies (Debarnot et al., 2012, 2010). The first study (Debarnot et al., 2010) tested interference effects of an explicit procedural interference task that was performed after a 2 h rest interval following an explicit MI practice or after physical practice of the same task. Interestingly, explicit MI practice was less prone to retroactive interference than physical practice. In the second study, Debarnot et al. (2012) demonstrated that subjects displayed substantial interference effects over night and daytime when a declarative task was practiced after MI while procedural task execution did not cause interference after MI. Based on these studies the authors suggested that MI predominantly affects declarative (explicit) memory and relies less on procedural (implicit) processes. The results of the present study extend these findings by showing that the ‘explicit’ rehearsal of motor memory by MI prevents interference despite the learning of an interfering motor task. The importance of MI to facilitate consolidation could be nicely seen in the control group (Group 3) performing no MI. This group displayed large interference effects indicated by pronounced reductions in BT performance. Thus, ‘explicit’ rehearsal of motor memories by MI seems to be a highly efficient way to prevent motor interference.

The question was whether a more ‘implicit’ approach by using contextual cues would lead to comparable effects. In the present study, we used only one colour cue with the aim to reactivate the motor memory of the initially learnt task (BT). This is in contrast to previous studies using different colour cues to help establishing two separate, concurrent memories that are being learnt in the same training block. Furthermore, we used ballistic contractions as the initial learning task and visuomotor tracking as the interfering motor task meaning that the task used in the present study was very different than the ones used in previous experiments (e.g. force-field adaptations, visuomotor rotations). This was done because it has previously been shown that this experimental arrangement can cause substantial in-between task interference (Lundbye-Jensen et al., 2011). This means that even though the tasks require the subjects to make movements in the same direction in space, the tasks are very different in terms of their movement dynamics. The BT requires the subjects to produce as much force as possible within a very short period of time whereas the AT demands fine-tuned movements, where the subjects has to produce much lower forces (max. 9 N). These differential motor control strategies for the same muscle groups probably lead to the pronounced interference that is known from previous studies combining BT and AT (Lauber et al., 2013; Lundbye-Jensen et al., 2011).

This behavioural observation is confirmed in the present study as Group 6 (control) showed substantial interference in BT performance after practicing AT (Fig. 2). Therefore, it is remarkable that Group 4, receiving the same colour cues, did not show any interference effects and displayed a significantly better immediate retention performance than Groups 5 + 6. Thus, the contextual cues very likely helped to form two separate motor memories for the BT and AT preventing in-between task interference. In the present study, subjects performed ballistic contractions as the initial learning task where they were required to make very fast contractions with no time for online corrections during the movement. We therefore provided the cue after the movement when subjects were given feedback about their task performance assuming (even though we have no direct evidence) that this external stimulus can be used together with sensory information to update and form the internal model for the ballistic task (Wolpert et al., 1995). In addition, we did not provide a separate cue (e.g. different colour) for the AT but presented the same cue given during the feedback phase of BT in randomized trials during the AT practice. The idea was to reactivate the motor memory and to improve memory consolidation of the previous task – very much alike the procedure during ‘explicit’ motor memory retrieval by MI. As we indeed did not observe decreased BT performance in Group 4 but strong interference in Group 5 + 6 that did not receive the same or any cue (Fig. 2), it is argued that presentation of the same cue during AT caused a recall of the motor memory formed during the BT task and thus prevented interference. Even though it has been shown that the reactivation of a motor memory can destabilize the memory by making it prone to interference even 24 h later (de Beukelaar et al., 2014), we did not see any effect of the practice of AT on BT performance in Group 4. In the study by de Beukelaar et al. (2014), motor memory was reactivated by recalling a previously learnt finger sequence which was then followed by practicing a different sequence causing substantial interference between the tasks 24hrs after the learning of the initial sequence. In the present study, however, subjects did not practice the BT during the AT practice but only received the same cue, which was already given during the BT practice. It therefore seems when a previously formed motor memory is repeatedly reactivated by the same colour cue or by MI, it can be protected against interference caused by the learning of task B. In this kind of way, the presentation of colour cues and MI during the learning of task B might act like variable practice that has repeatedly been shown to circumvent interference (Schmidt and Lee, 2011).

5. Limitations

A limitation of the present experiments is the lack of mechanistic information of why interference was impaired with MI and colour cues. One possibility could be that the interventions improved consolidation of the motor memory. Another possibility could be that MI and the use of identical colour cues further improved motor performance during the time when participants practiced AT. The latter possibility could mean that interference also took place in the intervention groups, and that the extended training during the AT phase counteracted the interference effects. Unfortunately, according to our task design we are unable to disentangle these two possibilities. It could have also been that the presentation of any cue and the MI of any contractions affected the attention of the subjects reducing interference. This seem very unlikely, however, as groups 2 & 4 did show substantial interference even though they were presented with a colour cue or mentally rehearsed a motor task. The amount of interference (reduction in BT performance) reported here ranged between 12.1% and 16.4% and is therefore smaller than in studies using force field adaptations or other types of adaptation tasks (e.g. Krakauer and Shadmehr, 2006). However, studies using the same paradigm as employed in the current study (learning of a ballistic task followed by visuomotor tracking task and the re-testing of the ballistic task) showed similar amounts of interference ranging from 14.11% to 29.9% (Lauber et al., 2013, Lundbye-Jensen et al., 2013, Lauber et al., 2017). Thus, we are convinced that the effects presented in this study actually represent interference.

6. Conclusion

The aim of this study was to investigate whether motor interference can effectively be reduced by MI and contextual cuing. The present results are therefore of practical relevance. For instance, physical rehabilitation programs often consist of blocked multiple task practice within one training session. This may, bear the risk of motor interference mitigating training effects and thus the intended outcome of the exercise protocol. A promising way to prevent potential interference during rehabilitation could be to apply explicit (MI) and implicit (colour cuing) strategies during practice, so that the practiced motor tasks do not interfere with each another.

Acknowledgements

The authors would like to thank Christian Leukel for his help in the design of the experiment and the interpretation of the results.

Declarations of interest

None.

References

Addou, T., Krouchev, N., Kalaska, J.F., 2011. Colored context cues can facilitate the ability to learn and to switch between multiple dynamical force fields. J. Neurophysiol. 106, 163–183. https://doi.org/10.1152/jn.00869.2010.

Afrouzeh, M., Sohrabi, E., Haghkhan, A., Rowshani, F., Goharrokhi, S., 2015. Effectiveness of PETTLEP imager on performance of passing skill in volleyball. J. Sports Med Phys. Fit. 55, 30–36.

Boschker, M.S., Bakker, F.C., Rietberg, M.B., 2000. Retroactive interference effects of mentally imagined movement speed. J. Sports Sci. 18, 593–603. https://doi.org/10.1080/02640410050082305.

Chu, S., Downes, J.J., 2002. Proust nose best: odors are better cues of autobiographical memory. Mem. Cogn. 30, 511–518.

Chun, M.M., Jiang, Y., 1998. Contextual cueing: implicit learning and memory of visual context guides spatial attention. Cogn. Psychol. 36, 28–71. https://doi.org/10.1006/cogp.1998.0681.

Colagiuri, B., Livesey, E.J., 2016. Contextual cuing as a form of nonconscious learning: Theoretical and empirical analysis in large and very large samples. Psychon. Bull. Rev. 23, 1996–2009. https://doi.org/10.3758/s13423-016-1063-0.

de Beukelaar, T.T., Woolley, D.G., Wenderoth, N., 2014. Gone for 60 s: reactivation length determines motor memory degradation during reconsolidation. Cortex: J. Devoted Study Nerv. Syst. Behav. 59, 138–145. https://doi.org/10.1016/j.cortex.2014.07.008.

Debarnot, U., Castellani, E., Guillot, A., Giannotti, V., Dimarco, M., Sebastiani, L., 2012. Declarative interference affects off-line processing of motor imagery learning during both sleep and wakefulness. Neurobiol. Learn. Mem. 98, 361–367. https://doi.org/10.1016/j.nlm.2012.10.009.

Debarnot, U., Creveaux, T., Collet, C., Doyon, J., Guillot, A., 2009. Sleep contribution to motor memory consolidation: a motor imagery study. Sleep 32, 1559–1565.

Debarnot, U., Maley, L., Rossi, D.D., Guillot, A., 2010. Motor interference does not impair the memory consolidation of imagined movements. Brain Cogn. 74, 52–57. https://doi.org/10.1016/j.bandc.2010.06.004.

Gruber, M., Gruber, S.B.H., Taube, W., Schubert, M., Beck, S.C., Gollhofer, A., 2007. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. J. Strength Cond. Res./Natl. Strength Cond.

Assoc. 21, 274–282. https://doi.org/10.1519/R-20085.1.

Guillot, A., Di Rienzo, F., Pialoux, V., Simon, G., Skinner, S., Rogowski, I., 2015. Implementation of motor imagery during specific aerobic training session in young tennis players. PLoS One 10, e0143331. https://doi.org/10.1371/journal.pone.0143331.

Howard, I.S., Wolpert, D.M., Franklin, D.W., 2013. The effect of contextual cues on the encoding of motor memories. J. Neurophysiol. 109, 2632–2644. https://doi.org/10.1152/jn.00773.2012.

Jackson, P.L., Lafleur, M.F., Malouin, F., Richards, C., Doyon, J., 2001. Potential role of mental practice using motor imagery in neurologic rehabilitation. Arch. Phys. Med. Rehabil. 82, 1133–1141. https://doi.org/10.1053/apmr.2001.24286.

Keough, D., Jones, J.A., 2011. Contextual cuing contributes to the independent modification of multiple internal models for vocal control. J. Neurophysiol. 105, 2448–2456. https://doi.org/10.1152/jn.00291.2010.

Krakauer, J.W., Shadmehr, R., 2006. Consolidation of motor memory. Trends Neurosci. 29, 58–64. https://doi.org/10.1016/j.tins.2005.10.003.

Lacourse, M.G., Turner, J.A., Randolph-Orr, E., Schandler, S.L., Cohen, M.J., 2004. Cerebral and cerebellar sensorimotor plasticity following motor imagery-based mental practice of a sequential movement. J. Rehabil. Res. Dev. 41, 505–524.

Lauber, B., Franke, S., Taube, W., Gollhofer, A., 2017. The effects of a single bout of exercise on motor memory interference in the trained and untrained hemisphere. Neuroscience. https://doi.org/10.1016/j.neuroscience.2017.01.048.

Lauber, B., Lundbye-Jensen, J., Keller, M., Gollhofer, A., Taube, W., Leukel, C., 2013. Cross-limb interference during motor learning. PLoS One e81038. https://doi.org/10.1371/journal.pone.0081038.

Lundbye-Jensen, J., Petersen, T.H., Rothwell, J.C., Nielsen, J.B., 2011. Interference in ballistic motor learning: specificity and role of sensory error signals. PLoS One 6, e17451. https://doi.org/10.1371/journal.pone.0017451.

Murphy, S.N., 2008. Imagery in Sport, Exercise and Dance, Advances in Sport and Exercise Psychology. Human Kinetics, Chamapgne, IL.

Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9, 97–113.

Osu, R., Hirai, S., Yoshioka, T., Kawato, M., 2004. Random presentation enables subjects to adapt to two opposing forces on the hand. Nat. Neurosci. 7, 111–112. https://doi.org/10.1038/nn1184.

Sarwary, A.M.E., Stegeman, D.F., Selen, L.P.J., Medendorp, W.P., 2015. Generalization and transfer of contextual cues in motor learning. J. Neurophysiol. 114, 1565–1576. https://doi.org/10.1152/jn.00217.2015.

Schmidt, R.A., Lee, T.D., 2011. Motor Control and Learning: A Behavioral Emphasis, 5th edition. Human Kinetics, Champaign.

Taube, W., Lorch, M., Zeiter, S., Keller, M., 2014. Non-physical practice improves task performance in an unstable, perturbed environment: motor imagery and observational balance training. Front. Hum. Neurosci. 8, 972. https://doi.org/10.3389/fnhum.2014.00972.

Wolpert, D.M., Ghahramani, Z., Jordan, M.I., 1995. An internal model for sensorimotor integration. Science 269, 1880–1882.

Yue, G., Cole, K.J., 1992. Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. J. Neurophysiol. 67, 1114–1123. https://doi.org/10.1152/jn.1992.67.5.1114.