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RESEARCH ARTICLE

The use of motor imagery training to retain the performance improvement following physical practice in the elderly

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Abstract
With physiological aging, appears a deterioration of the ability to retain motor skills newly acquired. In this study, we tested the beneficial role of motor imagery training to compensate this deterioration. We tested four groups: young control group ($n=10$), elderly control group ($n=10$), young mental-training group ($n=13$) and elderly mental-training group ($n=13$). In pre- and post-tests, the participants performed three trials on a dexterity manual task (the Nine Hole Peg Test), commonly used in clinic. We recorded the movement duration as a factor of performance. Each trial, including 36 arm movements, consisted in manipulating sticks as fast as possible. The control groups watched a non-emotional documentary for 30 min and the mental-training groups imagined the task (50 trials). First, we observed a speed improvement during the pre-test session for all groups. Immediately after viewing the movie (post-test 1), the young control group showed a preservation of motor performance in comparison to the performance measured before the break (pret-test 3), while the young mental-training group improved performance after motor imagery practice. For the elderly, the control group showed a deterioration of motor performance at post-test 1, attesting a deterioration of the ability to retain motor skills with aging. Interestingly, the elderly mental-training group showed a preservation of motor performance between the pre-test 3 and the post-test 1. The present findings demonstrate the beneficial role of mental training with motor imagery to retain the performance improvement following physical practice in the elderly. This method could be an alternative to prevent the deterioration of motor skills.

Keywords Motor imagery · Mental training · Aging · Motor memory · Compensation

Introduction

Human physiological aging is associated with structural and neurophysiological changes in the central nervous system (Bishop et al. 2010), as well as with a general deterioration of cognitive function (Andrews-Hanna et al. 2007). Notably, memory processes are strongly impacted during aging (Light 1991), affecting thus motor control and learning (Evans 1984; Galganski et al. 1993). In motor learning, the elaboration of a motor memory is necessary to encode the planning details of the newly acquired movement (Classen et al. 1998). Interestingly, Sawaki et al. (2003) showed a negative correlation between the capacity to encode a novel elementary motor memory and age. Indeed, compared to younger adults, elderly had limitations to encode and to memorize the learned movement. Although the capacity to learn new skills is at play (Seidler 2007), the ability to preserve the acquired skill is altered. Indeed, during the learning of a new walking pattern, young and old adults present similar split-belt walking adaptation (Malone and Bastian 2016). However, after a short break (5 min), the elderly forgot part of the previous learning. Therefore, despite a good capacity to improve their performance, a difficulty to retain this performance is observed in the elderly.

Currently, medication is the main method to reduce this deficit in individuals. For instance, Flöel et al. (2005) showed that, before training, the administration of Dopamine, a neuromodulator that facilitates synaptic strength, helped the elderly to compensate the difficulty to retain the performance improvement normally observed with placebo. To reduce medication and avoid side effects, it is of importance to test whether non-medical interventions, such as mental training with motor imagery, would be effective to compensate the deficit. Motor imagery is the mental

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simulation of an action without any corresponding motor output (Jeannerod 1994). Motor imagery practice improves motor performance in healthy young adults, such as strength gain (Yue and Cole 1992) or movement speed (Gentili et al. 2006). Interestingly, positive results following motor imagery practice have been observed in motor rehabilitation, such as after stroke (Jackson et al. 2001), with Parkinson's patients (Tamir et al. 2007), or also during immobilization (Lebon et al. 2012). In elderly population, the combination of motor imagery with physical practice also showed its effectiveness. For example, Jiang et al. (2016) demonstrated a significant strength gain with the combination of motor imagery and physical practice, almost as important as physical practice alone. Up to date, no study explored the potential effects of motor imagery practice to compensate motor memory deficit in the healthy elderly. It has been proposed that motor imagery ability, estimated by self-report questionnaires, is preserved with aging (Malouin et al. 2007). In addition, the congruency between imagined and actual movement durations is preserved for speed-accuracy trade-off or walking tasks (Skoura et al. 2005; Schott and Munzert 2007).

The aim of the present study was to test whether mental training alone, i.e., without afferent information from actual practice, could help to retain the performance improvement observed after physical practice in the elderly. During pre- and post-tests, young and elderly adults actually performed a dexterity manual task, a modified version of the Nine Hole Peg Test, commonly used in clinical practice. Between tests, for each age category, a control group and an experimental group watched a non-emotional documentary and repeatedly imagined the task, respectively. We hypothesized that the mental repetition of movement would induce performance improvement in young participants and would help to induce a preservation of level of performance in the elderly.

Experimental procedure

Participants

Forty-three right-handed healthy participants, without neurological or physical disorders, were recruited for the current experiment after giving their consent. They were distributed into four groups: the young control group ($n = 10$; mean age: 27 ± 6 year-old, 4 females), the young mental-training group ($n = 13$; mean age: 27 ± 4 year-old, 6 females), the elderly control group ($n = 10$; mean age: 74 ± 6 year-old, 9 females, MMSE; i.e. Mini Mental State Estimation, Folstein and Folstein 1975; $= 29 \pm 1$), and the elderly mental-training group ($n = 13$; mean age: 72 ± 4 year-old, 7 females, MMSE $= 29 \pm 1$). The experimental design of the study was approved by the regional ethic committee (CPP EST). The study conformed to the standards set by the Declaration of Helsinki, except for registration in a database. All participants gave their written consent after being informed of the experimental procedures.

Experimental device and procedure

The participants were comfortably seated on a chair placed at 20 cm in front of a table. They were asked to perform a modified version of the Nine Hole Peg Test (mNHPT). The NHPT is broadly used in clinical practice to measure the patients' ability in a manual dexterity task. We modified the original task to increase the difficulty, the duration, and especially the number of movements (36 for each trial). The mNHPT required moving the 9 sticks as fast as possible into 9 holes in a pre-determined order and then removing them back into a box (see Fig. 1a). Each hole corresponded to a specific letter. The participants started moving the stick from hole 1 to hole A, then from hole 2 to hole B, and so on. Once all sticks were placed into the corresponding holes, the participants had to immediately put them, one-by-one, into the box, starting with the stick positioned in hole A. Each trial included a total of 36 arm movements. Note that none of the participants was familiar with this task before taking part in the experiment.

All groups performed 3 actual trials (a total of 108 arm movements) in the PreTest and PostTest sessions (see Fig. 1b). We recorded the movement duration for each trial. The experimenter started the timer when the participant touched the first stick and stopped it when the last stick was put into the box. Between the PreTest and the PostTest, the two control groups watched a non-emotional documentary ("Home", directed by Y. Arthus-Bertrand, 2009) for 30 min (the approximate time of the mental training of the mental-training groups). The two mental-training groups were trained on the mNHPT task. Precisely, the participants were instructed to imagine themselves performing the task as fast as possible, combining the kinesthetic and visual (first-person perspective) modalities. They performed 5 blocks of 10 trials, with 5-s rest between trials and 1-min rest between blocks to avoid mental fatigue (Rozand et al. 2016).

We tested the motor imagery capacities of the young and elderly participants by employing two complementary methods. First, before the beginning of the experimental session, the participants of the two mental-training groups completed the revisited version of the Motor Imagery Questionnaire (MIQ-R; Hall and Martin 1997), which assesses the visual and kinesthetic movement imagery abilities on four different movements (minimum score = 8 ; maximum score = 56). In addition, after each block of mental-training, the participants reported the subjective estimation (SE) of the imagined movement quality by means of a 7-point Likert scale (1:

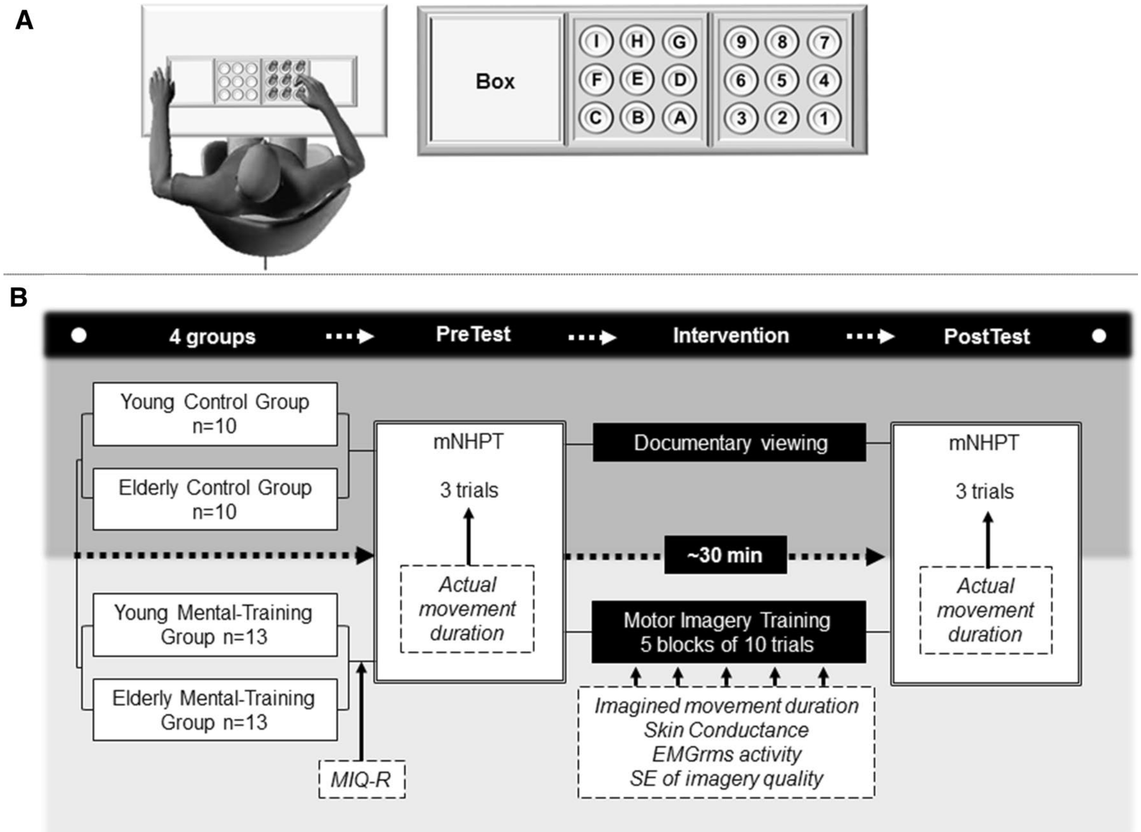

Fig. 1 Experimental design (**a**) and experimental procedure (**b**). *MIQ-R* revised version of the Movement Imagery Questionnaire, *mNHPT* modified version of Nine Hole Peg Test, *MI* motor imagery, *EMG* electromyography, *SE* self-estimation

very hard to feel and see the movement, 7: very easy to feel and see the movement, 2–6: intermediate scores).

To ensure the participants' arm immobility during mental training, electromyographic (EMG) activity of the biceps brachii (BB) and the triceps brachii (TB) muscles of the right arm was recorded and compared to the rest EMG activity (4-min recording before the training). We used pairs of bipolar silver chloride circular (recording diameter of 10 mm) surface electrodes positioned lengthwise over the middle of the muscles belly with an interelectrode (center to center) distance of 20 mm. The reference electrode was placed on the medial elbow epicondyle. Low resistance between the two electrodes was obtained by shaving the skin and cleaning it with alcohol. The Wilcoxon tests realized to compare the EMG activity at rest and during motor imagery training revealed no significant difference for the BB (young: $t=21.5$, $P=0.91$; elderly: $t=17.0$, $P=0.05$) and for the TB muscles (young: $t=1.96$, $P=0.51$; elderly: $t=23.0$, $P=0.11$; Table 1).

Furthermore, to confirm the participants' cognitive implication throughout the mental training, we assessed the arousal level by recording the electrodermal activity (Oishi et al. 2000). We used pairs of electrodes positioned on the second phalanx of the index and the ring fingers of the left hand. We measured the difference of the level of skin conductance (SC) between the beginning (SCb) and the end (SCe) of the training. We calculated the following ratio to estimate any modulation of the arousal level: (SCe − SCb)/SCb. A ratio close to 0 means a constant arousal level throughout the training. EMG activity and electrodermal activity were recorded using LabChart Software (LabChart 7, AD instruments) and analyzed a posteriori.

Statistical analysis

The normality of the data was verified by the Shapiro–Wilk test. We used parametric tests (ANOVA and Tukey post-hoc).

We first compared the initial performance (i.e., the first Pretest trial) between the four groups (ANOVA with group as between-subject factor). Then, to evaluate the performance improvement in the PreTest session (between the PreTest trials 1, 2, and 3), we conducted a repeated measures ANOVA with group as between-subject factor (young control group, young mental-training group, elderly control

Table 1 Electromyographic (EMG) activity (mean ± standard deviation) in μV recorded for the biceps brachii (BB) and the triceps brachii (TB) at rest and during each block of MI training, for the young and elderly groups

	Rest		Block 1		Block 2		Block 3		Block 4		Block 5	
	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly
EMG BB	4.22 ± 2.25	4.31 ± 1.32	2.56 ± 0.62	4.23 ± 0.51	2.33 ± 0.64	3.62 ± 0.45	3.92 ± 0.56	4.00 ± 2.00	2.33 ± 0.50	4.31 ± 0.77	2.33 ± 0.47	4.38 ± 0.66
EMG TB	4.56 ± 1.76	10.69 ± 2.81	6.67 ± 2.89	12.92 ± 2.23	6.56 ± 3.09	13.38 ± 2.07	6.44 ± 3.46	13.46 ± 2.27	5.78 ± 2.80	14.46 ± 2.82	4.00 ± 1.35	15.77 ± 2.59

group, elderly mental-training group) and trial as within-subject factor (PreTest 1, 2, 3).

To test the impact of the break or of the mental training on the performance improvement, we compared the movement duration between the last PreTest trial (PreTest 3) and the 3 PostTest trials (PostTest 1, 2 and 3), with a rmANOVA: with group as between-subject factor and trial as within-subject factor (PreTest 3, PostTest 1, 2, 3).

To evaluate the motor imagery capacities of mental-training groups, we realized a *t* tests for independent samples between young and elderly participants for the MIQ-R score and for the SE score.

To test any modulation of the arousal level during the motor imagery training, we used a one-sample t-test comparing the ratio (SCe − SCb)/SCb to the reference value, i.e. 0.

To support our results, despite the low level of participants, eta-squared (η^2) effect sizes were calculated for the ANOVAs. In addition, the Cohen's *d* effect sizes were calculated for each post-hoc test. Statistical analysis was performed using STATISTICA (8.0 version; Stat-Soft, Tulsa, OK). Data are presented as mean ± (standard deviation).

Results

Motor performance in the PreTest session

Figure 2 illustrates trial-by-trial the improvement in movement duration in the PreTest and PostTest sessions for all groups. Regarding the initial performance (i.e., the first PreTest trial), the ANOVA revealed a significant difference between groups ($F_{3,27} = 6.595$; $P < 0.01$; $\eta^2 = 0.42$). Movement duration for the young groups was shorter than that for the elderly groups ($P < 0.05$; $d = 1.4$). The comparison between the two young groups or between the two elderly groups did not reach the level of significant ($P > 0.05$, $d = 0.66$ and $d = 0.41$, respectively).

The rmANOVA (four groups × three trials) did not reveal any interaction effect ($F_{6;84} = 1.286$; $P = 0.272$; $\eta^2 = 0.08$). Instead, we observed a group effect ($F_{3;42} = 7.563$; $P < 0.001$; $\eta^2 = 0.35$). The Tukey post-hoc analysis revealed a difference between the young control group and the elderly control group ($P = 0.02$, $d = 1.16$) and the elderly mental-training group ($P < 0.001$, $d = 1.92$), and between the young mental-training group and the elderly mental-training group ($P < 0.01$; $d = 1.26$). More, we observed a trial effect ($F_{2;84} = 42.25$; $P < 0.001$; $\eta^2 = 0.50$). The post-hoc analysis indicated that movement duration at the PreTest 2 and PreTest 3 were significantly shorter than that at the PreTest 1 (both *P*'s < 0.001; $d = 0.52$ and $d = 0.62$, respectively). Movement duration between PreTest 2 and PreTest 3 were not significantly different ($P = 0.345$; $d = 0.13$).

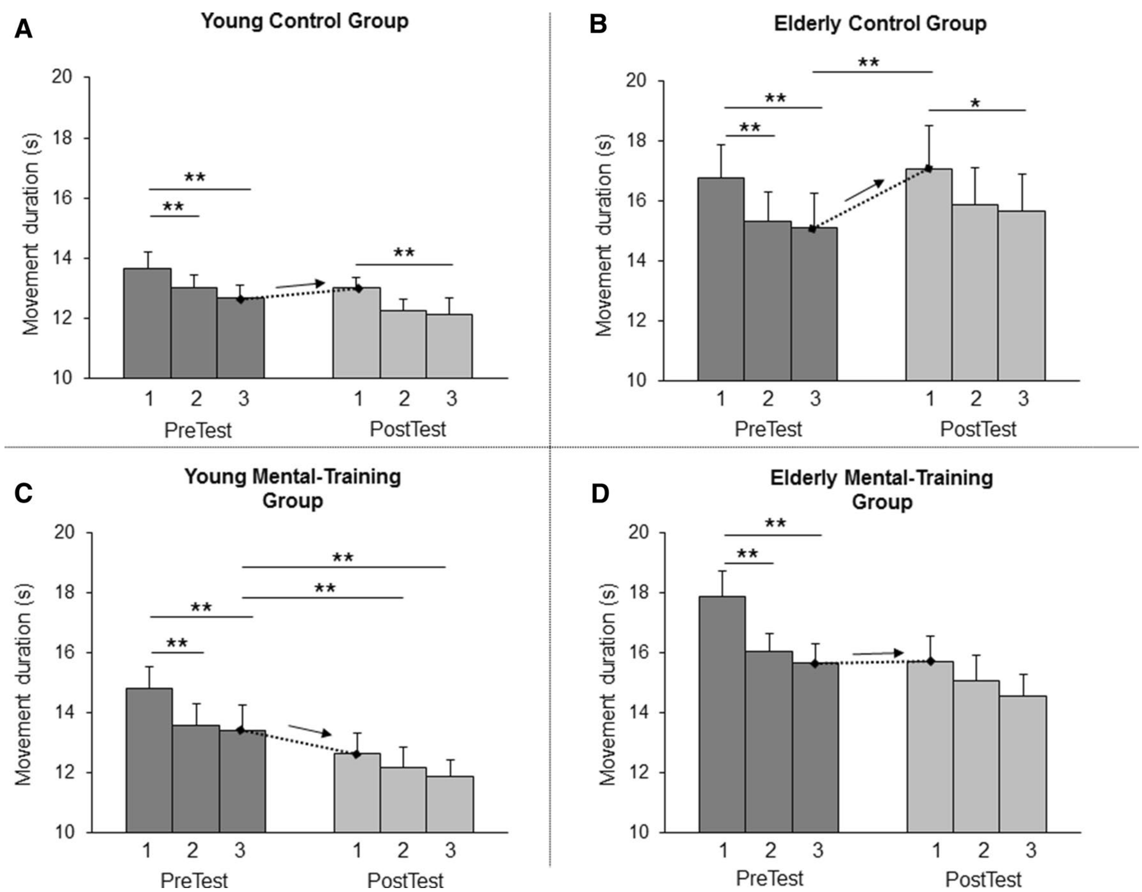

Fig. 2 Motor performance improvement for the young control group (**a**), the elderly control group (**b**), the young mental-training group (**c**) and the elderly mental-training group (**d**). *$P<0.05$, **$P<0.01$, ***$P<0.001$

Motor performance after the break (control groups) and after mental training (mental-training groups)

Following the pre-test session, the young and elderly control groups watched a documentary for 30 min, while the young and elderly mental-training groups mentally repeated the sequence during 30 min. The rmANOVA (four groups × four trials) revealed an interaction effect between the two factors ($F_{9;126}=3{,}779$; $P<0.001$; $\eta^2=0.21$).

For the young control group (Fig. 2a), the Tukey post-hoc analysis showed that the movement duration at PostTest 1 was similar compared to the PreTest 3 ($P=0.99$, $d=0.31$), indicating that motor performance was globally maintained after a 30-min break. The comparisons between PreTest 3 and PostTest 2 and 3 also did not show any significant difference ($P=0.99$, $d=0.33$ and $P=0.99$, $d=0.35$, respectively). Interestingly, for the elderly control group (Fig. 2b), the Tukey post-hoc analysis indicated that the movement duration at PostTest 1 significantly increased in comparison to the PreTest 3 ($P<0.001$, $d=0.56$), indicating that motor performance was deteriorated after the 30-min break. We observed a significant decrease in movement duration between PostTest 1 and PostTest 3 ($P=0.027$, $d=0.40$), but with PostTest 3 not different from PreTest 3 ($P=0.98$, $d=0.19$).

After the mental training, we observed, for the young mental-training group (Fig. 2c), a decrease of movement duration between the PreTest 3 and the PostTest 2 ($P=0.02$, $d=0.59$) and PostTest 3 ($P<0.001$, $d=0.76$) but not between PreTest 3 and PostTest 1 ($P=0.63$, $d=0.38$). Interestingly, contrary to the elderly control group, for the elderly mental-training group (Fig. 2d), the Tukey post-hoc analysis revealed that the movement duration at PostTest 1 did not increase in comparison to Pretest 3 ($P=0.1$, $d=0.03$), indicating that motor performance was not deteriorated. In addition, when normalized to Pretest 3, PostTest 1 for the elderly mental-training group was lower than that for the elderly control group ($t=2.54$, $P=0.019$, $d=0.99$).

Motor imagery capacities and skin conductance

Concerning the motor imagery capacities, the statistical analysis (t tests for independent samples) did not reveal significant difference between youth and elderly for the

MIQ-R score ($t=0.46$; $P=0.67$; $d=0.17$) and for the SE score ($t=-1.22$; $P=0.23$; $d=0.47$). Figure 3 depicts the mean values (± sd) of the MIQ-R and SE scores for the two groups.

The skin conductance (SC) was stable between the beginning (SCb) and the end (SCe) of the training for the young mental-training group (SCb = 11.22 µS ± 2.23; SCe = 10.75 µS ± 2.50; $t=0.73$; $P=0.48$) and for the elderly mental-training group (SCb = 9.04 µS ± 1.34; SCe = 7.18 µS ± 1.93; $t=0.55$; $P=0.59$). This result shows that the participants maintained their attention to the task throughout the mental training.

Discussion

The aim of the current study was to investigate the beneficial role of motor imagery training used to retain the performance improvement observed after physical practice in the elderly. While the elderly control group showed performance deterioration after the 30-min break, the elderly mental-training group maintained their performance measured before training. This finding highlights the positive effect of motor imagery training on the preservation of level of performance without physical practice in the elderly.

Motor adaptation after physical repetition

We first compared the initial performance at the mNHPT between groups. Movement duration at PreTest 1 was longer for the elderly groups than the young groups. This result is in accordance with previous studies, showing a decline in fine motor skills with aging (Smith et al. 1999). Interestingly, physical repetitions induced a decrease in movement duration for all groups, indicating the ability for the elderly to quickly improve motor performance. In other studies, results indicated that the elderly needed much longer practice to get better, compared to the young adults (Shea et al. 2006). Negative effects of aging were observed, notably on the cerebellum level, strongly involved in error-based motor learning. For example, Bickford (1993) showed, with aging, a loss of neurotransmitters activity such as norepinephrine, and a correlation between this loss and motor learning capacities. The neurophysiological declines observed in the elderly explained, in some cases, the difficulty to learn a new motor skill. Though, in our study, we demonstrated the preservation of seniors to improve their motor performance. The modalities of the task, and particularly its difficulty, could explain these contrasted results. In simpler motor sequences, such as the one performed in this study, the elderly are able to compensate the structural and neurophysiological decline of the central nervous system observed with aging (Seidler 2006).

Motor performance decrease after the break

Even if the elderly are able to quickly improve their performance, they have difficulties to maintain the level of performance without physical practice (Flöel et al. 2005; Malone and Bastian 2016). Our results reflect this finding as we observed performance deterioration between the last trial before and the first trial after the 30-min break, for the elderly control group. The level of performance at Posttest returned to the initial level, as if the subjects never learned the task. On the contrary, the young control group did not disclose any significant deterioration of their performance: after the break, they maintained the level reached at the end of the PreTest. These results confirm the difficulty to maintain a level of performance without physical practice observed in the elderly (Malone and Bastian 2016). During the acquisition of a new motor skill, the cerebellum plays a crucial role in the learning phase, while the primary motor cortex (M1) is fundamental for the memorization and the retention (Muellbacher et al. 2002; Galea et al. 2010).

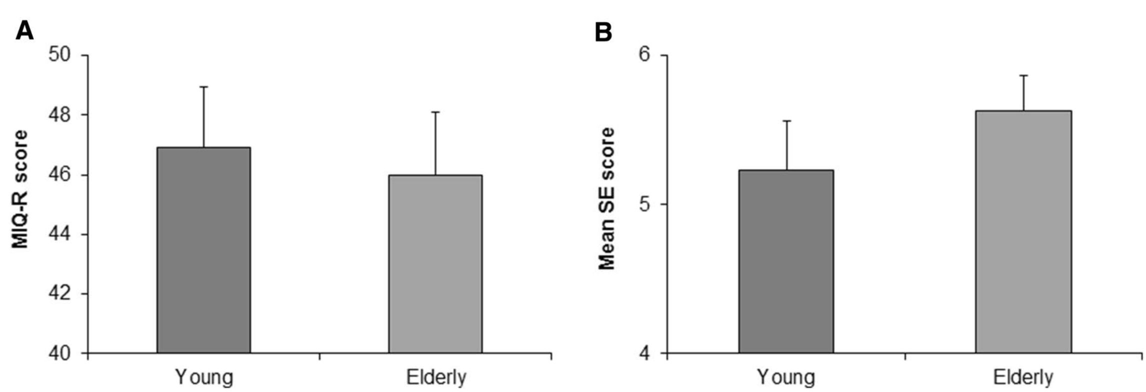

Fig. 3 MIQ-R scores for the young and the elderly mental-training groups (**a**) and mean subjective estimation (SE) score of all imagery blocks (**b**)

Indeed, Muellbacher et al. (2002) showed that the repetitive transcranial magnetic stimulation of M1 disrupted the retention of learning., In addition to the cerebellum dysfunctions, studies noted alterations at M1 level during aging (Jouvenceau et al. 1998; Sawaki et al. 2003). For example, Jouvenceau et al. (1998) observed a decrease of the NMDA receptors, essential for memory and synaptic plasticity (Nitsche et al. 2003), and a cholinergic dysfunction (Bartus et al. 1982), strongly involved in motor learning. These alterations may partially reduce the memorization of new motor skills for the elderly.

Motor performance improvement after motor imagery training

As expected, the young mental-training group improved their motor performance following motor imagery practice. This result confirms the positive benefits of mental training in young healthy adults (Yue and Cole 1992; Gentili et al. 2006). Interestingly, the main finding of the current study relies on the absence of performance deterioration following mental training for the elderly. Contrary to the control group, the movement duration at PostTest 1 was similar to that at PreTest 3 for the elderly mental-training group. This result indicates that imagined movements allowed a preservation of level of performance. Furthermore, motor performance increased, i.e. movement duration decreased, with actual execution throughout the PostTest. The positive impact of motor imagery training, notably on the building of a motor memory, can be explained by the cognitive adaptations, with an improvement of the mental representations (Frank et al. 2014), and by neural adaptations at several levels (Ruffino et al. 2017). More specifically, the specific plasticity processes induced by motor imagery the benefits could be attributed by the generation of a subliminal motor command during motor imagery (Grosprêtre et al. 2016). Indeed, during and after motor imagery training, modulations at the cortical and spinal level are observed, such as a reinforcement of the sensibility and the conductivity of synapses in the corticospinal pathway (Avanzino et al. 2015). The mental repetition of movements may have reinforced the binding between the pre- and the post-synaptic neurons, thus increasing the effectiveness of the connection. Thus, these reinforcements would induce a better encoding of the kinematic details of the movement, even in the case of aging.

Conclusion

In this study, we demonstrated the direct benefits of motor imagery training in the elderly population. Our results indicate, in the elderly, that mental training could be used to maintain motor performance reached after physical practice. This method would be an alternative drug-free method to prevent the deterioration of motor skills. More, using motor imagery would be of interest to improve motor performance when physical fatigue prevents actual practice. Indeed, the elderly are more fatigable that young people (Allman and Rice 2002). In this way, alternating actual and imagined movements would be the best compromise to potentiate learning. A limit of our study is the single mental training session-induced effect on motor performance. To further explore the impact on motor learning, it would be of interest to test the influence of several sessions combining actual and imagined movements on the performance improvement and consolidation.

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