Ain’t just imagination! Effects of motor imagery training on strength and power performance of athletes during detraining

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Title: Ain't just Imagination! Effects of Motor Imagery Training on Strength and Power Performance of Athletes during Detraining

Head Title: Motor imagery and detraining

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Abstract

Purpose: To investigate the effects of motor imagery (MI) training on strength and power performances of professional athletes during a period of detraining caused by the COVID-19 outbreak.

Methods: Thirty male professional basketball players (age = 26.1 ± 6.2 years) were randomly assigned to three counterbalanced groups: two MI training groups, who completed imagery training by mentally rehearsing upper and lower limbs resistance training exercises loaded with either 85% of one maximum repetition (85%1RM) or optimum power loads (OPL), or a control group. For six consecutive weeks, while all groups completed two weekly sessions of high-intensity running, only the MI groups performed three additional MI sessions a week. Maximal strength and power outpus were measured through 1RM and OPL assessments in the back squat and bench press exercises with a linear positioning transducer. Vertical jump and throwing capabilities were assessed with the countermovement jump and the seated medicine ball throw tests, respectively. Kinesthetic and visual imagery questionnaires, chronometry and rating of perceived effort scores were collected to evaluate MI vividness, MI ability, and perceived effort.

Results: Physical performances improved significantly following both MI protocols (range: ~2% to ~9%), but were reduced in the control group, compared to pre-intervention ($P \leq 0.016$). Moreover, interactions (time × protocol) were identified between the two MI groups ($P \leq 0.001$). While the 85%1RM led to greater effects on maximal strength measures than the OPL, the latter induced superior responses on measures of lower limbs power. These findings were mirrored by corresponding cognitive and psychophysiological responses.

Conclusion: During periods of forced detraining, MI practice seems to be a viable tool to maintain and increase physical performance capacity among professional athletes.

Key Words: *Cognitive intervention; COVID-19; elite athletes; neural excitability; neuromuscular performance.*

INTRODUCTION

Detraining is the partial loss or reversal of training-induced adaptations caused by the interruption or a markedly reduced training stimulus, with negative effects on physical capabilities and impaired athletic performance (1). Interruption of training routines may occur as an adverse consequence of illness and injury, be systematically designed during the off-season breaks of long-term training plans (2), or due to quarantine measures imposed for public safety as occurred in recent times following the unexpected COVID-19 pandemic outbreak (3).

Detraining effects are dependent on the duration of training cessation as well as the extent of reduced training (1), and may vary between highly trained athletes with extensive training background and moderately active individuals (1). In athletic populations, detraining periods longer than 4 weeks can adversely affect morphological (e.g., ↑ fat mass and body mass index and ↓ muscle mass) (4, 5), cardiorespiratory (e.g., ↑ maximal heart rate and recovery heart rate during and post exercise, respectively; ↓ maximal cardiac output and maximal oxygen uptake) (6-8), metabolic (e.g., ↑ submaximal blood lactate production; ↓ muscle glycogen level concentration) (8-10), hormonal (i.e. ↓ adrenaline stimulated lipolysis) (5) and muscular characteristics and function (e.g., ↓ oxidative enzyme activities; ↓ mean fibre cross-sectional area; fast-twitch to slow-twitch fibers area ratio; ↓ EMG activity) (5, 11-14), thus leading to considerable impairments of endurance (6, 7), strength and power performance (11-14).

In view of the negative effects on physiological characteristics and performance arising from long-term interrupted or insufficient training, alternative forms of training are recommended to avoid detraining (1). Coaches, fitness trainers or medical personnel commonly provide athletes with complementary training programs to complete by using dedicated cardiofitness equipment (e.g., running treadmill, bicycle, rowing ergometer), or portable and wearable resistance training kits (e.g., dumbbells, elastic bands, suspension straps, medicine balls). Alternatively, some forms of bodymass circuit-based training could be implemented to preserve neuromuscular adaptations (15) and to mitigate declines in muscular strength and power capabilties, which are particularly emphasized in team-sport athletes (16). However, while these solutions are easy to apply under normal circumstances, a few logistical and practical constraints emerge during forced periods of complete training interruption and more pertinently during COVID-19 home confinement. First, most athletes may have restricted or no access to sport playgrounds or gym facilities where sport-specific or personalized conditioning training can be performed. Second, they may be forced to train only at home with limited exercise equipment, on their own and unsupervised. Accordingly, it can be assumed that even alternative forms of training, although promptly and accurately designed for these scenarios, may be unfeasible for some and fail to induce the expected acute responses and long-term adaptations.

A viable strategy to counteract the effects of detraining is motor imagery (MI), namely the mental rehearsal of visual and kinaesthetic aspects of on overt action without any concomitant active body movement (17). Studies from cognitive sport psychology and neuroscience have shown that MI is an effective method to improve motor skills (18, 19) as well as to enhance motor performance (20). Notably, researchers have consistently reported both acute (i.e. after a single MI session) (21-23) and long-term (i.e. training) (24, 25) beneficial effects of MI on physical tasks that require muscular force production. The psychoneuromuscular theory (17) points to neural changes occurring in the primary somatosensory and motor areas, augmented spinal circuitry, and similar task-specific EMG patterns and subliminal muscle activity as the main pathway underpinning the force enhancing effects of MI. Interestingly, the neuromuscular responses induced by MI are activity and intensity dependent, with brain activations mediated by the imagined force level (26), and subliminal muscle activity reflecting the type of muscle contraction imagined by the subject (i.e., isometric, concentric and eccentric) (27). However, most studies investigating the long-term effects of MI often implemented only maximal voluntary isometric contractions (28). Moreover, the imagery practice involved only a single joint, which is quite distinct from the exercises commonly prescribed in resistance training (28). Finally, to our knowledge no previous study has examined the transfer effects of MI aimed at enhancing force and power production onto motor performances with similar mechanical characteristics in highly-trained populations (28), especially in the form of training to mitigate strength-related detraining effects.

Therefore, the aim of this study was to investigate and compare the effects of two MI protocols implementing dynamic resistance training exercises (i.e. back squat and bench press) loaded with different intensities on strength and power motor performances among professional basketball players during a period of interrupted training. We hypothesized that MI would enhance strength and power performances compared to a control condition (28). Second, and with reference to the principles of activity and intensity dependency (26), we expected the beneficial effects of the two MI protocols to transfer distinctly and specifically onto motor tasks with similar mechanical characteristics.

METHODS

Subjects

Two complementary sampling approaches were used in this study. The first – purposive sampling – was guided by the expertise paradigm of the strength-based approach proposed by MacIntyre et al (29). Accordingly, we recruited only expert athletes on the basis of their professional activity expertise. Criteria used for defining “expert athletes” were: competitive level (i.e. elite or professional), high-level basketball practice (≥ 5 years) and extensive experience in resistance training (≥ 3 years with an average of 50 resistance training practices per year). The second – *a priori* power analysis – was calculated using in the G∗Power software (Heinrich-Heine-Universitat Dusseldorf, Germany). A repeated measures Analysis of Variance (ANOVA) with an $\alpha = 0.05$, $\beta = 0.95$, moderate effect size ($ES \geq 0.5$) for between-group comparisons, and moderate correlation ($r \geq 0.3$) among repeated measures, gave an estimated sample size of twenty-seven subjects. Thirty male basketball players (age = 26.1 ± 6.2 years; height = 190.1 ± 3.6 cm; body mass = 89.6 ± 5.6 kg; BMI = 24.8 ± 1.9 kg/m^2), members of the first team and U-19 team of a professional basketball club volunteered to participate in the study. They had at least six years (range: 6-13) of high-level practice and 5 years (range: 5-13) of resistance training experience. They trained once a day for about 90 min, five days per week, and played one or two official matches per week. Additional inclusion criteria for participating in this study were: 1) Participation in ≥ 85% of the training sessions completed during the first part of the regular season (October 2019-February 2020); 2) Participation in all regular basketball matches in the preceding 4 weeks before study initiation; 3) No longstanding injury (≥ 6 weeks) in the upper and lower extremities in the preceding 6 months before the study initiation. Written informed consent was obtained after the subjects received an oral explanation of the purpose, benefits, and potential risks of the study. All procedures were conducted in accordance with the Helsinki Declaration and approved by the Institution's Ethics Committee (Approval IRB number: 16105).

Design

A randomized controlled trial design was used to investigate the effects of two MI protocols including imaginary dynamic resistance training exercises (i.e. back squat and bench press) loaded either with 85% of one repetition maximum (85%1RM) or optimum power loads (OPL) compared to a control condition. This study was conducted in the second part of the regular season (March-June 2020) during a period of forced detraining due to the COVID-19 outbreak. Overall, the study lasted fifteen weeks and consisted of one week of pre-testing, three weeks of familiarization, six weeks of intervention, one week of post-testing and four weeks of training monitoring (Figure 1 for overview). After pre-testing, subjects were assigned to one of three counterbalanced groups − 85%1RM, OPL or control − all with $n = 10$, through a fully randomized allocation approach . During the following three weeks, subjects did not participate in any team-based structured physical activity due to the COVID-19 lockdown restrictions, but completed a standard workout program designed by the coaching staff three times a week at home. The program included a structured warm-up followed by core stability and calistenic exercises for the upper (e.g., push-up) and lower body (e.g., jump squat), and lasted approximately 50-60 minutes per session. Moreover, subjects being allocated to either the 85%1RM or OPL group completed a few familiarization sessions, in which they were initially provided with an explanation of the specific MI procedures before completing short sessions ($n = 3$) of their respective MI protocols. In fact, subjects were mostly familiarized with the general concept of MI as it was already implemented by the coaching staff as a strategy to refine technical skills (i.e., throws). However, they had little to no experience with MI in the form of a substitute for physical training practice prior to the time of the study commencement. To this end, one coach and one researcher conducted an initial 20-min online introductory session using the “Zoom video communications” platform (San-Jose, CA) to explain the possible benefits associated to MI training, therefore facilitating buy-in and adherence across the participants. Then, for the next six weeks, while all subjects trained twice a week following a standard high-intensity running training program, only the 85%1RM and OPL groups completed three MI sessions per week. The effects of the MI protocols were investigated on upper and lower body strength and power performances measured through 1RM assessments, OPL assessments, the seated medicine ball throw test (SMBT) and the countermovement jump (CMJ) test across three non consecutive days. In the last four weeks, subjects performed actively six resistance training sessions, which replicated exactly (i.e. exercises, order, individual loads, training volumes and sets configurations) every first weekly session prescribed during the 6-week MI intervention. Kinesthetic and Visual Imagery Questionnaire (KVIQ) responses, mental chronometry scores and subjective rates of perceived effort (RPE) were collected throughout and at the end of the sessions, to evaluate MI vividness, MI ability, and perceived effort congruence between the MI sessions and the corresponding active training sessions, respectively. All testing and training sessions were performed at the same time of the day (5:00–7:00 PM) and in a similar ambient temperature (19–22° C). Coaches and athletes were asked to avoid intense exercise on the day before the tests and to maintain their normal nutritional practices. The latter were informed by the club's nutritional adviser and remained consistent across the study duration. The general objective of the nutritional advice was to maintain the actual body composition and the fat mass:free fat mass ratio. Recommended macronutrient intakes were as follows: carbohydrate (3.5–5.5 g/kg/day); protein (1.2–1.8 g/kg/day); and fat (0.8-1 g/kg/day). Based upon these guidelines, the recommended daily energy intake was ~2900 kcal (range: 2700–3350 kcal). During the study, athletes were encouraged to work closely with the club's nutritional advisor to translate their recommended nutrient guidelines into food equivalents.

*****Figure 1 about here*****

Procedures

The testing procedures at pre-intervention point took place before the COVID-19 outbreak as part of the normal routine without any restrinctions. On the contrary, at post-intervention point appropriate safeguards were put in place to follow the local government guidelines on physical distancing, cleaning and sanitizing management and any measures to avoid the risk of virus spread. In particular, facility maximum capacities adhered to the requirements in line with the facility risk assessment. Participants were instructed to wear a face covering while not performing testing, and to stay 2m apart from others, which was assisted through the use of floor markings. Testing equipment and other frequently touched objects and surfaces were wiped down with alcohol-based disinfectant at regular intervals between participants. Researchers wore gloves and face covering when administering testing cleaning procedures.

Testing day 1

1RM assessments

Anthropometric measurements were taken and followed by 1RM assessments of the back squat and bench press exercises performed on a Smith-Machine (Technogym Equipment, Italy). In the back squat exercise, the required squat depth corresponding to a 90º knee angle was measured with a hand-held goniometer. To ensure similar depth across testing sessions, a box with adjustable height was placed underneath the participants to which they were required to gently squat onto. Subjects then performed a structured warm-up protocol consisting of dynamic stretching and calisthenics, followed by an individualized 5-min warm-up. Thereafter, subjects were assessed in the back squat 1RM followed by the bench press 1RM. The 1RM protocols consisted of consecutive lifts with progressively heavier loads until reaching the true 1RM. Two to three minutes of rest were provided between consecutive lifts once the loads reached 90% of estimated 1RM. The individual 1RM scores relative to body weight were used for analysis.

Testing day 2

Optimum power load assessments

For the OPL assessments, the same equipment, set up as well as the same standardized and individual warm-up procedures described above for the 1RM assessments were used. The OPL in the back squat and bench press exercises were determined following the protocols described by Dello Iacono et al. (30) with subjects lifting progressively heavier loads whereby individual load-power profiles were computed. Specifically, the first absolute load corresponded to an unloaded 20 kg barbell. Then, successive trials with increasing loads (i.e., additional ~5% and ~2.5% of body mass in each trial for the back squat and bench press, respectively) were performed until a decrease in the mean propulsive power (MPP) was observed. MPP refers to the upward portion of the lift during which barbell acceleration is greater than gravity (i.e. 9.81 $m \cdot s^{-2}$). The OPL was identified as the load with the highest MPP measured during trials. MPP was determined using a validated linear encoder (Chronojump, Barcelona, Spain) sampling at 1000 Hz, fixed to the bar of the Smith machine, and computed using the software provided by the manufacturer in conjunction with the device (31). The individual MPP outputs relative to body weight ($W \cdot kg^{-1}$) were used for analysis.

Testing day 3

Seated medicine ball throw test

Throwing performance was assessed with the SMBT test. Subjects were asked to sit on a chair placed against a wall, with their backs against the chair back for support and their feet flat on the ground. Subjects held a 3-kg medicine ball with both hands and with their arms extended away from the chest. They were then instructed to push the ball away from the center of their chest as forcefully and as far as possible, using a movement similar to a basketball chest pass. The proper angle of release (< 45º) was also suggested to achieve maximum distance. Subjects performed three attempts with passive recovery of 90 s between throws. The throws were filmed with a high-speed camera (Casio Exilim FH100, 240 fps, Tokyo, Japan), positioned (i.e. sagittal plane) on a tripod at a height of 2 m and a distance of 8 m from the testing area. A validated open source software (Kinovea, http://www.kinovea.org/) was used to measure throws displacements accordingly to the instructions described by Dello Iacono et al (32). The best result was used for analysis.

Countermovement Jump

Vertical jump performance was assessed with the CMJ test. Starting position was stationary, erect, with knees fully extended and hands kept on the waist. Subjects squatted down to a self-selected height before beginning a forceful upward motion. Subjects were also instructed to avoid bending hips, knees and ankles throughout the flight phase and at touchdown with the aim to limit any effect on jump height. Finally, they were instructed to jump as high as possible, and verbal encouragement was provided during the jumps. Subjects performed three attempts with passive recovery of 60 s between jumps, and the best result was used for analysis. The jump height (cm) was calculated according the flight time phase duration with the Optojump apparatus (Optojump, Microgate, Bolzano, Italy).

Vividness, mental imagery ability and perceived effort outcomes

The KVIQ questionnaire was used to assess visual and kinesthetic vividness of the MI protocols (33). It includes six items related to the specific sequential movements of the resistance training exercises implemented in the MI sessions (See Text, Supplemental Digital Content 1). The KVIQ uses two 5-point Likert scales to rate the clarity of the image (V subscale) and the intensity of the sensations (K subscale). A score of 5 corresponds to the highest level of imagery vividness and a score of 1 to the lowest. The KVIQ were completed on a weekly basis (*n* = 6) immediately after the first MI weekly sessions. The average scores of the responses were used for exploratory analysis.

Chronometry was used to assess imagery timing according to the mental paradigm (34) by measuring the isochrony (i.e. temporal congruence) between the resistance training sessions performed mentally and actively. To this end, subjects recorded the duration (i.e. effective time excluding inter-set and between-exercise rest intervals) of their MI sessions with the use of a timer. The recorded scores and the duration of the correspondent resistance training sessions performed actively during the last four weeks of the study were then used to calculate isochrony according to Beauchet et al (35). A value of 0 is the reference for strict isochrony, departures from 0 indicate the magniture for weaker isochrony, and the sign of the isochrony value indicates the direction of error. The average isochrony scores were used for exploratory analysis.

Rating of perceived exertion (RPE) was measured via the Borg CR-10 scale (36) ranging from 0 (no effort) to 10 (maximum effort). Subjects were asked to report the amount of mental or physical energy invested to perform either the MI or the active resistance training tasks (37). Subjective ratings were reported within 15 min after completing each session. Athletes were familiarized with this method as it had been used for load monitoring purposes for the last two seasons. The average RPE responses of MI and the correspondent active resistance training sessions in each condition were used for analysis.

Training intervention

MI training spanned over six consecutive weeks and consisted of three sessions per week of either 85%1RM or OPL back squat and bench press exercises. The two MI protocols were matched for training volume (i.e. sets × repetitions number), which progressively increased from eighteen repetitions in the first session of Week 1 to thirty-two repetitions in the last session of Week 6 (Table 1) (28), and lasted between 14 to 17 minutes including the rest intervals between consecutive sets. Before each MI session, subjects listened to an audiotrack playing a two-part script of instructions developed for this study according to the Physical, Environment, Task, Timing, Learning, Emotion, and Perspective (PETTLEP) model by Holmes and Collins (38) and the strength-based approach of Macintyre et al (29) (See Text, Supplemental Digital Content 2). Whereas the first part of the audiotrack was played only once, immediately after the warm-up and prior to the MI session start, the second part was played before consecutive sets. In addition to the MI sessions, both 85%1RM and OPL as well as the control group completed two physical training sessions per week of high-intensity running, which were performed individually outdoors (Table 1). High-intensity running training was prescribed in consideration of its high ecological validity and similarity with the intermittent profile of the physical demands of basketball. Also, it was the only form of controlled physical training that athletes were allowed to complete in respect of the local government restrictions in terms of social distancing due to COVID-19. All training sessions were completed at the same time of the day (5:00–7:00 PM) after a standard 10-min warm-up consisting of dynamic stretching, core stability and calisthenics (39). During the MI sessions, the control group did not perform any alterantive form of physical activity nor a MI neutral task. Researchers used the WhatsApp group chats (Facebook Inc., Menlo Park, CA) to deliver updates and reminders about dates and start times of the scheduled sessions. Before the MI training sessions, only participants belonging to the two MI groups were invited to join simultaneously a 5-min Zoom videocall whereby attendance was verified by name-reading. Finally, after each MI session and within 15 minutes from its completion, two coaches and two researchers contacted all participants via videocall to produce a detailed record of the sessions in a logbook containing attendance, KVIQ, chronometry and RPE scores or other personal issues that arose.

Statistical Analysis

All data are presented as means ± standard deviation (SD) and confidence interval (95% CI). Normality of the absolute data was investigated using the Shapiro-Wilk test. The intra-day reliability of the SMBT and CMJ tests at both testing points were examined using the Coefficient of Variation. A CV< 5% is considered a cut-off value for high reliability (40). The inter-day reliability of the vividness scores across the familiarization sessions and the MI sessions over the 6-week intervention was assessed by calculating the Intra-class Correlation Coefficient ($ICC_{3,1}$). Values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.9 were interpreted as indicative of poor, moderate, good, and excellent reliability, respectively. To compare the effects between the two MI protocols and control, a two-way (three groups [85%1RM, OPL, control] × two time-points [pre-intervention, post-intervention]) repeated measures Analysis of Variance (ANOVA) was used. This analysis was conducted for the following variables: relative 1RM values and relative MPP scores in the back squat and bench press exercises, SMBT distance and CMJ height. A paired samples *t*-test was used to analyze differences in chronometry and RPE scores collectively between the MI condition and the active condition. Finally, an independent samples *t*-test was used to analyze differences in chronometry and RPE scores between the two MI protocols within each training condition. Significance was at $P < 0.05$. The 95% CI are reported alongside the p values to allow for a better qualitative interpretation of the data. Greenhouse-Geisser correction was applied when violations of sphericity were present. If significant main effects or interactions were identified then post hoc analyses were conducted using the Holm-Bonferroni correction for the p values and CI. All statistical analyses were conducted using Jamovi (version 1.2.27.0).

RESULTS

Raw data of the physical performance outcomes at pre-intervention and post-intervention time points for all groups are shown in Data, Supplemental Digital Content 3. Raw data of vividness, chronometry and RPE scores for the two MI groups are shown in Table 2. All data were normally distributed. The CV% of the intra-day SMBT and CMJ were 1.1% (95% CI: 0.9, 1.2) and 0.8% (95% CI: 0.7, 0.9) and 1.3% (95% CI: 0.9, 1.1) and 1.5% (95% CI: 0.9, 1.1) at pre-intervention and post-intervention time points, respectively. The ICC of the vividness scores across the familiarization sessions was 0.92 (95% CI: 0.88, 0.96). These results demonstrate high intra- and inter-day reliability.

First, a significant main effect of time was observed for relative 1RM in the back squat ($F_{(1, 9)} = 6.83$, $p = 0.028$) and bench press exercises ($F_{(1, 9)} = 11.37$, $p = 0.008$), relative MPP in the back squat ($F_{(1, 9)} = 20.88$, $p = 0.001$) and bench press exercises ($F_{(1, 9)} = 7.1$, $p = 0.026$), SMBT distance ($F_{(1, 9)} = 8.93$, $p = 0.015$) and CMJ height ($F_{(1, 9)} = 8.64$, $p = 0.016$). Post-hoc analyses revealed significant time × protocol interactions between both MI conditions and control for relative 1RM in the back squat exercise ($F_{(2, 18)} = 28.25$, $p < 0.001$) and bench press exercise ($F_{(2, 18)} = 63.11$, $p < 0.001$), relative MPP in the back squat ($F_{(2, 18)} = 52.68$, $p < 0.001$) and bench press exercises ($F_{(2, 18)} = 48$, $p < 0.001$), SMBT distance ($F_{(2, 18)} = 154$, $p < 0.001$) and CMJ height ($F_{(2, 18)} = 68.29$, $p < 0.001$). Specifically, a consistent pattern emerged with all physical performances improved following both MI protocols, but reduced in the control group, compared to pre-intervention (Figure 2). Moreover, significant interactions were also identified between the two MI conditions for relative 1RM both in the back squat ($F_{(2, 18)} = 28.25$, $p < 0.001$) and bench press ($F_{(2, 18)} = 63.11$, $p < 0.001$) exercises, relative MPP in the back squat exercise ($F_{(2, 18)} = 52.68$, $p < 0.001$), and CMJ height ($F_{(2, 18)} = 68.29$, $p < 0.001$). Briefly, while the 85%1RM led to greater effects on the maximal strength measures than the OPL, the latter induced superior responses on the measures of lower limbs muscular power (Figure 2). We note that the inferential statistics (adjusted 95% CI and p values) of the Holm-Bonferroni post-hoc multiple comparisons tests are reported in Data, Supplemental Digital Content 3.

Collectively, significant differences were found for the RPE scores between the active condition and the MI condition (Mean difference = 2.63 [95% CI: 2.22, 3.04]; $t = 13.33$, $p < 0.001$), but no differences emerged for the chronometry score (Mean difference = 1.38 [95% CI: -1.31, 4.07]; $t = 1.27$, $p = 0.29$; isochrony = 0.32 ± 1.39 [95% CI: -0.29, 0.93]). Finally, significant differences were found consistently across conditions both for chronometry (MI: Mean difference = 8.39 [95% CI: 3.25, 13.5]; $t = 3.043$, $p = 0.003$; active: Mean difference = 15.19 [95% CI: 9.5, 20.9]; $t = 5.61$, $p < 0.001$) and RPE scores (MI: Mean difference = 1.69 [95% CI: 0.97, 2.41]; $t = 4.91$, $p < 0.001$; active: Mean difference = 1.11 [95% CI: 1.12, 2.1]; $t = 2.35$, $p = 0.03$).

*****Figure 2 and Table 2 about here*****

DISCUSSION

The present study investigated the effects of two MI training protocols on strength and power motor performances of professional basketball players during a period of interrupted physical training. Two main findings emerged: (i) an increase of maximal strength and power motor performances following both protocols as compared to a control condition after 6-week of MI training; (ii) distinctive effects across the two MI protocols, with the 85%1RM protocol leading to greater effects on maximal strength, and the OPL inducing superior adaptations on the lower limbs, especially in terms of muscle power output and jumping performance. These findings were mirrored by corresponding cognitive and psychophysiological responses, and can be explained by underpinning psychoneuromuscular pathways.

The first main finding of this study provides evidence that MI training was adequate to counteract the expected detraining caused by the period of forced training interruption as concurrently observed in the control group (Figure 2). More importantly, it was effective at improving strength and power capabilities of both upper and lower body limbs irrespective of the implemented MI protocol. Although direct comparisons between the present study and previous investigations should be made with caution due to differences in research designs, characteristics of the participants and their training status, MI training protocols and primary outcome measures, the beneficial effects on maximal strength levels are somewhat comparable. The magnitude of the improvements in maximal strength measured through direct 1RM assessments ranged from ~2% to ~9% (Figure 2), and was consistent with the MI literature reporting similar strength enhanching effects following four to six weeks of MI training (21, 24, 25). Due to the short duration of the MI training intervention and the concurrent absence of anthropometric changes between the pre-intervention and post-intervention time points, the beneficial effects of MI maximal strength capabilities have likely stemmed from a neural origin of force gains (41), and align with the hypothesis of central adaptations in response to MI training (42-46). While in this study we did not collect neural measures enabling to infer further about the mechanisms underpinning our findings, previous experimental studies implementing MI interventions comparable to the protocols we used, which targeted muscles with large cortical area surface representation, seem to corroborate our assumption. In particular, the observed findings may be expected due to cerebral reorganizations driving the motor units to a higher intensity or leading to the recruitment of motor units that remain otherwise inactive with resulting motor output increases (42-47).

The novelty of the present study was the use of MI protocols consisting of mental rehearsal of multi-joint dynamic exercises loaded with intensities individually prescribed rather than single-joint maximal isometric contractions of fixed duration as commonly used in previous studies (42-46). To our knowledge, the effects of MI training including dynamic contractions on motor performances were only investigated in one other study by Lebon et al (25). The authors reported greater improvements of the 1RM in the leg press exercise but not in the bench press exercise following a 4-week training period including 12 sessions, in which the MI group combined mental rehearsal of both exercises during the inter-set rest intervals of their actual training as opposed to a control group who completed only the physical training. While the study by Lebon et al. (25) is an initial step in examining the potential benefits of MI practice according to consolidated paradigms (29, 38) grounded on the functional equivalence construct, it includes a number of limitations that warrant consideration. First, the participants did not perform regular and intensive resistance training nor MI with the aim of improving motor performance prior to the study commencement. Since MI efficacy depends on the level of expertise (29) both in MI practice itself and in the motor task intended to enhance, the beneficial effects of MI training may have been hindered by the characteristics of the participants (38). Second, while the MI training included motor sequences replicating exactly the two resistance training exercises, it failed to account for task and timing equivalence (38). In fact, the participants were intructed to mentally rehearse repetitions only as concentric contractions, according to training configurations not aligning with any evidence-based recommendations (48), and without any knowledge of the load to be lifted. Accordingly, the inconsistency of greater maximal strength gains across exercises between the MI and control groups in the study Lebon et al. (25) may be in part explained by the lacking mechanical correspondence with different mechanical characteristics (concentric contractions only vs eccentric-concentric contractions and time under tension) between the MI training protocol and the resistance training exercises (27). Finally, the MI practice was implemented concurrently with actual physical training and not during a period of interrupted training as in the present study, which precludes to make any inferences about the effectiveness of MI training to counteract detraining in professional athletes. In contrast, the promising findings of the present study indicates that MI training protocols designed according to the functional equivalence construct (29, 38) may be a viable substitute for conventional resistance training to counteract the advserse effects of detraining.

In accordance with our hypotheses, the two MI protocols induced specific and distinct transfer effects on motor tasks underpinned by similar force-velocity characteristics. These findings have practical applications and can be explained by the psychoneuromuscular theory. MI and motor execution are known to share common neural substrates and mechanisms (49), with the neuromuscular responses and adaptations induced by MI practice being activity (27) and intensity (26) dependent. MI replicates muscle synergies through specific corticospinal facilitation (50) and subsequent EMG patterns mirroring those usually recorded during physical movement. Interestingly, Guillot et al (27) demonstrated that the EMG activity and intermuscular coordination of all muscles involved in a movement rehearsed during MI practice vary as a function of the lifted load and the muscular contraction type. In line with this evidence, we assume that the two MI protocols used in the present study may have primed neural excitability via task-specific somatic pathways, leading to selective muscle activation and motor units recruitment patterns, and correspondent long-term transfer effects. This assumption is supported by the results of this study. In particular, while greater 1RM increases in the back squat and bench press exercises (9 ± 3.9 vs 5 ± 2.5 kg and 7 ± 1.7 vs 2 ±1.4 kg, respectively) were found in the 85%1RM group compared to the OPL group, an opposite trend was observed for the power outputs in the same exercises as well as for the vertical jump performance (0.7 ± 0.5 vs 0.2 ± 0.6 cm). Albeit this remains a hypothesis that warrants further examination, we speculate that the functional congruence in terms of force-velocity characteristics between the motor sequence mentally rehearsed and the task intended to enhance is a factor likely mediating the beneficial effects of MI practice. In practical terms, MI training should be designed by selecting *ad hoc* exercises, prescribed with bespoke training configurations and loading schemes when aiming to improve motor tasks featured by analogous functional equivalence.

The main and distinct effects of the two MI protocols observed in this study should be further interpreted by considering the vividness, mental imagery ability and perceived effort outcomes. First, exploratory analyses of the KVIQ and isochrony scores highlighted high levels of engagement and MI ability (Table 2), which have likely mediated the main beneficial effects of MI training. Second, analyses of the chronometry and RPE scores provide further evidence that MI and motor execution share common neural mechanisms paralleled by mirroring psychophysiological responses. This was confirmed through the mental chronometry scores as no difference emerged between actual and imagined durations. Furthermore, significant differences in RPE scores emerged both between imagined and actual training when the two MI groups were pooled together, as well as between the 85%1RM and OPL protocols when compared separately across conditions (Table 2). These findings are not surprising and confirm the psychophysiological nature of the perception of effort (51). In fact, the differences between training conditions and between the two protocols in the active condition stem from the actual execution of the lifting tasks and the different training intensities, respectively. Moreover, the differences between the two protocols in the MI condition clearly reflect the mental component of perceived effort, which arises from the tacit knowledge of how difficult it is to lift heavy loads as compared to lighter loads and the mirroring sensation of efforts usually reported during MI (52).

In conclusion, the present study demonstrated that a 6-week MI training intervention translated into an increase of maximal strength and power output performances as compared to a control condition. Secondary to the latter findings, a distinct effect across the two MI protocols was observed, with the 85%1RM protocol leading to greater effects on maximal strength, while the OPL protocol was instrumental to superior adaptations on lower-limbs jumping capacity and muscular power. Future studies should focus on determining neural pathways responsible for strength, power output and jumping ability impovements observed here. Neverthless, the present findings clearly highlight that the MI practices is a viable tool to maintain and increase physical performance among profesional athletes during periods of forced detraining.

This study has a number of limitations worthy of discussion. First, for practical reasons, the sample was limited to a single cohort of basketball players which limits our ability to generalize the results to other populations. Second, due to logistical constraints, the effects of the two MI protocols were investigated only on strength and power motor performances which were assessed in gym- and field-based environments without collecting any supraspinal, spinal, and peripheral correlates. This fact narrows the ability to draw conclusions from this study on the neural origin and mechanisms underpinning the observed findings. Finally, this study did not include an intervention group performing only MI during the detraining period. While this design limited the ability to determine the specific effects of pure MI training in a period of detraining, it increased the ecological validity of the study as well as the buy-in of the coaching staff and athletes.

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Conflict of Interest

The results of the study do not constitute endorsement by the American College of Sports Medicine. The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate datamanipulation. The authors have no conflicts of interest to disclose.

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Figure Captions

Figure 1. Schematic representation of the study design.

Figure 2. Changes in performances between pre- and post-intervention (i.e., after 6-week MI training) in the three experimental groups. RM: repetition maximum; kg: kilogram; MPP: mean propulsive power; W: watt; OPL: optimum power load. * indicates significant differences between both MI groups and control; δ indicates significant differences between the two MI groups.

List of Supplemental Digital Content

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Supplemental Digital Content 3. docx