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Article *in* Journal of Sports Sciences · January 2016

DOI: 10.1080/02640414.2015.1030342 · Source: PubMed

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Journal of Sports Sciences, 2015
http://dx.doi.org/10.1080/02640414.2015.1030342

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Effectiveness of motor practice in lucid dreams: a comparison with physical and mental practice

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(*Accepted 13 March 2015*)

Abstract

Motor practice in lucid dreams is a form of mental rehearsal where the dreamer can consciously rehearse motor skills in the dream state while being physically asleep. A previous pilot study showed that practice in lucid dreams can improve subsequent performance. This study aimed to replicate those findings with a different task (finger-tapping) and compare the effectiveness of lucid dream practice (LDP) not only to physical but also to mental practice (MP) in wakefulness. An online experiment was completed by 68 participants within four groups: LDP group, MP group, physical practice (PP) group and control (no practice) group. Pre-test was accomplished in the evening, post-test in the next morning, while the practice was done during the night. All three practice groups significantly improved their performance from pre-test to post-test, but no significant improvements were observed for the control group. Subjective sleep quality was not affected by night practice. This study thus corroborates the previous findings that practice in lucid dreams is effective in improving performance. Its effects seem to be similar to actual PP and MP in wakefulness. Future studies should establish reliable techniques for lucid dream induction and verify the effects of LDP in sleep laboratory conditions.

Keywords: *lucid dreams, motor learning, lucid dream practice, mental practice, finger-tapping*

Introduction

Mental practice (MP) is the cognitive rehearsal of a physical activity in the absence of overt physical movements (Richardson, 1967). It is a well-established technique in sports (Morris, Spittle, & Watt, 2005). Several meta-analyses demonstrated that MP significantly improves performance, albeit to a smaller extent than actual physical practice (PP) (Driskell, Copper, & Moran, 1994; Feltz & Landers, 1983). A novel and relatively unknown type of mental rehearsal is motor practice in lucid dreams (Erlacher, 2007).

Lucid dreams are dreams in which the dreamer is asleep but aware that he or she is dreaming and often can influence the dream plot (LaBerge, 1985). This ability to be aware in the dream state and deliberately perform actions while physically asleep opens up opportunities to use lucid dreams for sports practice, for example, to consciously rehearse specific motor tasks without waking up (Tholey, 1990). Practice in lucid dreams is similar to MP in wakefulness: movements are rehearsed with a representation of the body on a cognitive level without overt physical movements (cf. Erlacher, 2007).

The evidence suggests that imagined and executed actions to some extent seem to share the same neural structures (Decety, 1996). Motor and associated cortical areas involved in programming and preparations of actual movements are also active during mental simulation of movement (reviews: Jeannerod, 2001; Lotze & Halsband, 2006; Munzert, Lorey, & Zentgraf, 2009), autonomic responses of imagined actions mimic the actual autonomic responses during the exercise (review: Guillot & Collet, 2005a), and the timing of imagined and actual motor actions are closely related (reviews: Guillot & Collet, 2005b; Guillot, Hoyek, Louis, & Collet, 2012). According to the theory of neural simulation of action by Jeannerod (2001), in general, covert actions are actual actions, except for the fact that they are not executed. The theory thus predicts a neural similarity between the state where an action is simulated ("S-state") and the state of execution of this action. While for some S-states, such as action observation, the functional

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equivalence has been called into question (Lorey et al., 2013), the limited evidence from dream research suggest that dreamed actions do seem to share the same neural mechanisms with executed actions (Erlacher & Schredl, 2008b). For example, correspondences exist in underlying brain activity (cf. Dresler et al., 2011), autonomic responses (cf. Erlacher & Schredl, 2008a) and temporal dynamics (cf. Erlacher, Schädlich, Stumbrys, & Schredl, 2014).

Empirical evidence on lucid dream practice (LDP) is rather scarce. In a sample of 840 German athletes from various sports, 57% stated that they had at least one lucid dream in their life, 24% reported frequent lucid dreams (one or more lucid dreams per month), however only 9% of the lucid dreamers used this dream state to practice sport skills (Erlacher, Stumbrys, & Schredl, 2011–2012). Yet, the majority of those who practiced had the impression that the rehearsal within the lucid dream improved their subsequent performance in wakefulness. Several such anecdotal accounts on how practice in lucid dreams improved waking performance have also been reported in the literature (e.g. Erlacher, 2007; LaBerge & Rheingold, 1990; Tholey, 1990).

In a qualitative study, Tholey (1981) asked six proficient lucid dreamers to perform and practice movements and complex sport skills, such as skiing on gymnastics, with which they were already familiar from waking life. The participants reported no difficulties while performing complex sport skills in their lucid dreams and had an impression that their movements improved following the practice.

Further, Erlacher and Schredl (2010) conducted a pilot study (field experiment) with a pre-post design in which the participants were asked to practice a simple motor task – to toss 10-cent coins into a cup, positioned at the distance of two meters, as many times as possible out of 20 trials. Twenty participants attempted to practice the task in a lucid dream on a single night and seven of them succeeded. Their performance was compared to a group which accomplished actual PP (n = 10) and a control group without practice (n = 10). Both practice groups showed significant increases in hitting the target from pre-test to post-test, while no increase was found for the participants who did not practice the task. Although the improvements following lucid dreaming practice were somewhat lower in comparison to PP, the differences were not significant.

The present study aimed to replicate these findings with a different motor task (a sequential finger-tapping task; cf. Karni et al., 1998; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002) and compare the effectiveness of LDP not only to awake PP but also to MP in wakefulness. It was expected that all three types of practice will improve subsequent performance. The gains from PP were expected to be higher than the ones from MP (cf. Driskell et al., 1994), whereas the gains from LDP were expected to fall in between, as the cognitive simulation in the dream state is much more realistic (cf. Tholey, 1990) and the perception in lucid dreams appears to be much more closer to actual perception than to waking imagination (LaBerge & Zimbardo, 2000).

Methods

Participants

The sample included 68 individuals (32 male and 36 female) who completed an online experiment. Their ages ranged from 19 to 54 years, with the mean age of 31.3 ± 7.3 years. Participants were recruited via electronic advertisements (posted on lucid dreaming-related discussion boards, social networking sites and via personal contacts) and assigned to one of four groups: (1) LDP group (if they were frequent lucid dreamers; n = 21); (2) MP group (n = 15); (3) PP group (n = 16); (4) control (no practice) group (n = 16). The data of four participants from the LDP group were excluded (reducing the sample to n = 17) as three participants reported that they practiced the task only very briefly (tapping the sequence only 2–4 times) and one participant reported additional practice in the evening while awake. Group characteristics are depicted in Table I. Participation

Table I. Group characteristics.

	LDP (n = 17)	MP (n = 15)	PP (n = 16)	Control (n = 16)	Statistical test	P
Age (y)	31.2 ± 8.1	32.1 ± 8.1	31.3 ± 6.0	30.1 ± 8.1	$F_{3,60} = 0.18$	.909
Male/Female	11/6	6/9	7/9	6/10	$\chi^2_3 = 3.08$	.379
Right-/Left-handers	13/4	15/0	15/1	15/1	$\chi^2_3 = 5.93$	.115
VMIQ-2						
External visual	31.4 ± 12.3	32.9 ± 10.3	33.3 ± 9.3	29.8 ± 9.6	$F_{3,60} = 0.36$	.781
Internal visual	30.7 ± 11.4	30.1 ± 9.3	29.2 ± 11.4	27.1 ± 10.8	$F_{3,60} = 0.34$	.800
Kinesthetic	28.8 ± 11.1	31.5 ± 9.3	24.8 ± 6.9	25.9 ± 9.3	$F_{3,60} = 1.63$	.192
Lucid dreams/month	8.8 ± 7.0	0.5 ± 1.1	0.4 ± 0.7	0.3 ± 0.6	$\chi^2_3 = 36.1$	<.001
Sleep quality	1.9 ± 0.7	1.9 ± 0.8	2.3 ± 0.8	1.8 ± 0.4	$\chi^2_3 = 3.70$	.296

was voluntary and unpaid. The study was conducted according to the principles of the Declaration of Helsinki. All participants signed an electronic informed consent form and were free to withdraw from the experiment at any time.

Motor task

A computerised online version of the sequential finger-tapping task was used, which requires the participant to press four keys on a computer keyboard with a non-dominant hand producing a sequence of five elements "as quickly and accurately as possible" for a period of 30 s (Walker et al., 2002). Each sequence started and finished with the little finger; index, middle and ring fingers were used once (e.g. "4–1–3–2–4"; cf. Karni et al., 1998). Four different sequences were prepared for each hand, allowing repeating the experiment up to four times. During the initial (learning) phase, the participants were asked to memorise the sequence shown on the screen and tap it correctly 10 times. Each correct key press produced a green dot on a corresponding finger in a hand picture presented on the screen, while an incorrect key press produced a red dot. The assessment phase consisted of two test periods of 30 s with a 30 s rest period in between. Each key press produced a white dot. No other feedback was provided. The number of correct sequences completed and the number of incorrect key presses were recorded. The average scores of two test periods were calculated.

Procedure

The study was conducted as a field experiment, that is, the participants accomplished the procedure by themselves in their home setting. Participants had to fill out an initial online questionnaire, which included demographical data (age, gender and country), questions about lucid dream recall, vividness of motor imagery and handedness. Lucid dream frequency was assessed on an 8-point scale (0 – never; 1 – less than once a year; 2 – about once a year; 3 – about 2–4 times a year; 4 – about once a month; 5 – about 2–3 times a month; 6 – about once a week and 7 – several times a week), with a high retest reliability (r = .89; Stumbrys, Erlacher, & Schredl, 2013). To ensure a clear understanding of lucid dreaming, a definition was provided: "In a lucid dream, one is aware that one is dreaming during the dream. Thus it is possible to wake up deliberately, or to influence the action of the dream actively, or to observe the course of the dream passively." In order to obtain units in frequency per month, the scale was recoded using the class means: 0 → 0, 1 → 0.042, 2 → 0.083, 3 → 0.25, 4 → 1.0, 5 → 2.5, 6 → 4.0, 7 → 18.0 (see Stumbrys et al., 2013). Further, the participants filled a revised version of the Vividness of Motor Imagery Questionnaire (VMIQ-2, Roberts, Callow, Hardy, Markland, & Bringer, 2008), which assesses three-factor (internal visual imagery, external visual imagery and kinesthetic imagery) individual imagery characteristics on a 5-point scale (ranging from 1 – perfectly clear and vivid to 5 – no image at all). VMIQ-2 has demonstrated acceptable factorial validity, construct validity and concurrent validity (Roberts et al., 2008). The order in which VMIQ-2 imagery modalities were presented was randomised. Lastly, the participants filled the Edinburgh Handedness Inventory – Short Form (EHI-SF, Veale, 2014), which contains four items for which the preference in the use of hands is scored on a 5-point scale (from 1 – always right to 5 – always left). The modification was shown to have good reliability, factor score determinacy and correlation with the original 10-item inventory (Oldfield, 1971).

After filling the initial questionnaire, the participants were assigned to one of the groups. The LDP group was assembled from the participants with a higher lucid dream frequency (2–3 or more lucid dreams per month). Other participants were put on the waiting list and randomly assigned to one of the other groups after the LDP group completed the experiment. Instructions to the participants were sent by email. All participants were asked to choose a time schedule for the experiment so that the time difference between the evening pre-test and the morning post-test would be 10 h. The MP and PP participants were assigned corresponding practice times (from the bed time) and durations as the LDP group. Two lucid dreamers practiced the task in two different dreams during the night, hence two corresponding participants in MP and PP groups were also asked to awaken and practice the task twice during the night (although one PP participant did only a single awakening). Further, all participants were asked to set an alarm clock to awaken at least 30 min before the post-test time, so that their performance would not be impaired by sleep inertia (Tassi & Muzet, 2000).

LDP group. The participants could use any technique to induce lucid dreams (cf. Stumbrys, Erlacher, Schädlich, & Schredl, 2012), with the exception of drug intake. After becoming lucid in a dream, they had to start immediately practicing the task (repeating the memorised sequence) and continue the practice for as long as possible. The participants were instructed to do the practice in 30 s (self-estimated) intervals with 30 s (self-estimated) rest periods in between. During the 30 s rest periods they were allowed to apply techniques that prolong lucid dreams (e.g. spinning, hand rubbing; LaBerge, 1995).

MP group. Each participant was assigned one exact practice time and duration from the LDP group. The participants were asked to awaken 30 min before the assigned practice time and keep themselves awake during this period (to avoid possible effects of sleep inertia). Then they were instructed to close their eyes and start practicing the task in their mind without moving their actual fingers during the practice. With their eyes closed, they had to attempt to imagine themselves producing the sequence by visualising the movement of each finger. The participants were asked to try to *feel* each movement of their fingers while repeating the memorised sequence. The practice had to be accomplished in 30 s (self-estimated) intervals with 30 s (self-estimated) rest periods in between.

PP group. As in the MP group, PP participants were assigned exact practice times and durations from the LDP group and asked to awaken 30 min before the practice time and keep themselves awake during this period. Then they were instructed to start practicing the task physically, also in 30 s (self-estimated) intervals with 30 s (self-estimated) rest periods in between.

Control group. The participants were not asked to do any practice (only pre-test in the evening and post-test in the morning).

The experimental night procedure is depicted in Figure 1. Upon completing the post-test, the participants had to fill out a report, indicating their bed times, and rating their sleep quality of the night on a 4-point scale (1 – very good to 4 – very bad). Three practice groups were further asked to provide their practice details. If unsuccessful, participants could repeat the experiment with a difference sequence (up to four times).

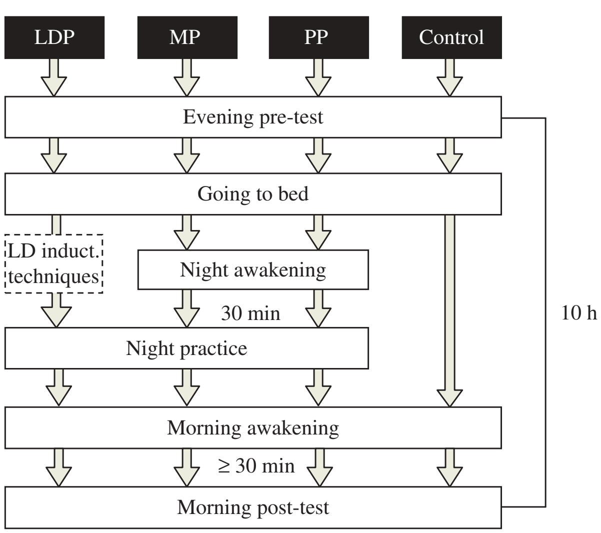

Figure 1. Experimental protocol of the four groups.

On one occasion (MP) no results were recorded for the second post-test interval, whereas in two other occasions (LDP and MP) the number of correct sequences produced during one of the pre-test intervals (in both cases the second interval) was very low (2 sequences) as compared to the average performance during the other three test intervals (16.0 and 13.7 sequences, respectively). To avoid possible distortions, the data from these intervals were excluded (thus only a single test interval result and not the average of the two test intervals were used).

Statistical analysis

IBM SPSS Statistics 20 software was used for statistical analysis. One-way ANOVA were performed to compare the characteristics of the four groups on interval variables (age, scores on motor imagery scales), whereas Kruskall–Wallis test was used for ordinal variables (sleep quality and lucid dream frequency) and Chi-square for categorical variables (gender and handedness). Two-way repeated measures ANOVA were conducted to compare the performance from pre-test to post-test between the groups. Differences between the groups were investigated with post-hoc least significant difference (LSD) tests. Student *t*-tests were used to compare the performance from the pre-test to the post-test for each individual group. Spearman's *rho* correlations were used to check the associations between changes in performance and potential confounding variables: lucid dream frequency and repeated trials. G*Power 3.1.7 software (Faul, Erdfelder, Buchner, & Lang, 2009) was used for calculating effect sizes *d*. An alpha = .05 significance level was employed.

Results

Group characteristics

According to the EHI-SF results, six participants were considered left-handed and were assigned to do the motor task with the right hand, whereas the rest 58 participants were right-handed and performed the task with the left hand. There were no significant handedness differences between the groups, as well as differences in motor imagery abilities as measured by VMIQ-2 and reported sleep quality of the night, although the groups differed in their lucid dream frequency (Table I). LDP participants in average had 2.1 ± 1.1 ($M \pm s$) trials.

Practice times and durations

A few participants in MP and PP groups slightly diverged from the original instructions (considering their exact practice times and durations), but the conditions were very much similar nevertheless. The LDP group carried out their practice on average at 6:07 ± 2:20 h since their bed time (range: 1:20–9:00), MP at 5:49 ± 2:17 h (range: 1:20–8:40) and PP at 5:51 ± 2:23 h (range: 1:20–9:00). The LDP group did 4.2 ± 6.3 blocks of 30 s practice (median: 2; range: 1–22), MP 5.3 ± 6.4 (median: 3; range: 1–22) and PP 3.8 ± 5.3 (median: 2; range: 1–22). Three practice groups did not differ in their amount of practice ($F_{3,60}$ = 0.08, P = .927) and duration ($F_{3,60}$ = 0.28, P = .760).

Effects of practice

All three practice groups had significant improvements from pre-test to post-test in terms of the number of correct sequences produced, averaged across two 30 s test intervals, whereas the control participants had only nonsignificant improvements (Table II). There was a significant time (pre-test to post-test; $F_{1,60}$ = 50.12, P < .001) but not group ($F_{3,60}$ = 0.48, P = .695) effect. Group × time interaction was significant ($F_{3,60}$ = 3.43, P = .023), showing that four groups improved differently from the pre-test to post-test. Post-hoc LSD pair-wise comparisons showed significant differences between the LDP and control group (P = .003), as well as between the PP and control group (P = .031), but not between other pairs of the groups. Increases in performance from pre-test to post-test were not associated with lucid dream frequency (*rho* = .100, P = .432). Further, no significant association between changes in performance and the number of trials (*rho* = −.473, P = .055) was found in the LDP group, where most of participants attempted the experiment more than once. Practice times (since the bed time) were also not significantly associated with changes in performance (*rho* = .040, P = .785).

LDP group made on average 5.3 ± 5.2 errors on the pre-test, MP 5.5 ± 6.7, PP 5.0 ± 8.1 and control group 8.3 ± 13.0. On the post-test the respective error rates were 5.6 ± 5.0, 7.1 ± 7.8, 5.7 ± 9.7 and 10.9 ± 13.3. Differences between the two tests were significant for control group (more errors on the post-test; t = 3.76, P = .002) but not for practice groups (LDP: t = 0.23, P = .820; MP: t = 1.63, P = .125; PP: t = 0.69, P = .504). Overall differences for the change in the error rate between the four groups were not significant ($F_{3,60}$ = 0.95, P = .423).

Discussion

The present study corroborates the findings of a pilot study by Erlacher and Schredl (2010) that motor practice in lucid dreams enhances subsequent performance. All three types of practice lead to significant improvements from the pre-test to the post-test, whereas only a small but not statistically significant improvement was found in the control (no practice) group. LDP and PP participants had significantly higher improvements as compared to the control group who did only the test and retest. No significant differences were found between the three different practices, as well as between the MP and control group. LDP resulted in highest average gains (+20%), followed by PP (+17%) and MP (+12%), however the effect size was highest for PP (1.57), followed by MP (1.16) and LDP (0.91). All these effect sizes are considered large (≥0.8) according to Cohen (1992).

Before discussing the findings, several methodological issues have to be acknowledged. Firstly, the study was conducted as a field experiment and therefore the experimental control was lacking (i.e. only the test procedure but not the experimental treatment can be controlled by the experimenter online). For example, it is possible that some participants did not adhere to the instructions correctly. Although instructions sent to the participants were written as clearly as possible, in a few cases the participants slightly diverged (e.g. by awakening for practice at a slightly different time, by doing a somewhat different number of practice intervals, or by forgetting to do rest periods during LDP). To have a better experimental control, sleep laboratory studies are

Table II. Effects of practice on motor task performance (number of correct sequences averaged across two 30 s periods per test).

	Pre-test			Post-test				T-test		
	M	*s*	SEM	M	*s*	SEM	Change in %	T	*P*	Effect size
Lucid dream practice	17.1	4.1	1.00	20.5	4.7	1.14	+20%	3.75	.001	0.91
Mental practice	15.4	4.9	1.27	17.3	5.6	1.45	+12%	4.46	<.001	1.16
Physical practice	16.2	5.8	1.45	18.9	6.4	1.60	+17%	6.25	<.001	1.57
Control (no practice)	17.1	6.8	1.70	17.9	7.7	1.93	+5%	1.56	.070	0.39

Note: One-tailed T-tests were used.

recommended where actions in lucid dreams can be monitored by using eye movements (cf. Erlacher et al., 2014). Yet such sleep laboratory studies are always affected by small sample sizes (limited usually only to a few successful participants), because it is very difficult to recruit proficient lucid dreamers. In the general population, only 5% of people have at least one lucid dream a week (Schredl & Erlacher, 2011), which is necessary for sleep laboratory studies, often restricted only to a few nights. The biggest advantage of online field experiments is that they allow the recruitment of participants from all over the world (e.g., 21 lucid dreamers who completed the present study represented 11 different countries) and therefore samples can be much higher. Secondly, the assignment to the experimental groups was not completely randomised, as the LDP group was selected by lucid dream frequency. Improvements in performance, however, were not associated with lucid dream frequency. Further, a number of participants who registered for the experiment did not complete it. Participation in the study was quite demanding for MP and PP participants, as they had to awaken at a certain time during the night and wait for half an hour before starting to practice. Lucid dreamers could have had an additional stress "to be successful" (i.e. to be able to have a lucid dream and practice the task in it). Thus, this might have resulted that only certain (e.g. highly motivated) individuals completed the study, and therefore the findings should be interpreted cautious. Thirdly, most participants in the LDP group and a few participants in the other practice groups did the experiment a few times (up to four). While each time a different sequence was used, there is a possibility that some transfer (positive or negative) in learning had occurred. The possibility to have a task which could be repeatable with a different variation was important to increase the chances of success for lucid dreamers – for example, out of 21 lucid dreamers who completed the study, only 6 were successful on their first trial. Yet multiple trials did not seem to influence the performance: No significant association was found between the changes in performance and the number of trials in LDP group. The trend, in fact, was negative: Further trials were associated with lesser performance improvements. Fourthly, practice times and durations for all practice conditions were derived from the lucid dreamers' estimates of time, which might be somewhat inaccurate. For example, lucid dreamers and participants in the two other intervention groups might have considerably deviated in their actual practice times and durations. Sleep laboratory research, however, demonstrated that time in dreams is perceived very similarly as to when awake and while motor actions might take longer times in lucid dreams, this difference exists only for absolute but not for relative durations, which is crucial for motor skill learning (Erlacher et al., 2014). Under- and overestimations of motor imagery durations also happen during MP (Guillot & Collet, 2005b; Guillot et al., 2012). In this study, participants in all three practice groups were asked to estimate their practice durations.

As in the previous study (Erlacher & Schredl, 2010), LDP was found to improve subsequent performance in wakefulness. This group had the highest gains but the lowest effect size, which suggests that its effects might be more variable. The previous study (Erlacher & Schredl, 2010) with a different – aiming – task found higher improvements (+43% for LDP and +88% for PP), but the reanalysis of the data showed that effect sizes for practices were similar (LDP: 1.24; PP: 1.32) and the effects of PP showed greater variability than of LDP. Considering the results of the two studies together, LDP appears to be similar or slightly less effective than PP. The comparison with MP is somewhat less clear. LDP showed significantly greater improvements as compared to control group, whereas MP did not significantly differ from any of groups. LDP resulted in somewhat higher performance gains as compared to MP, yet somewhat lower effect size, which might be considered a better indicator of improvement than the percentage gains taking into account fairly large standard deviations (Table II). Previous studies with similar finger-tapping tasks have shown that MP improves performance and the gains are similar or slightly lower as compared to PP (e.g. Debarnot, Creveaux, Collet, Doyon, & Guillot, 2009; Nyberg, Eriksson, Larsson, & Marklund, 2006). The present study corroborates those findings and suggests that the effectiveness of LDP might be similar to the effectiveness of MP, however more research is needed.

Both lucid dream and wakeful MPs are cognitive rehearsals with a representation of the body without overt physical movements and both seem to some extent to share the same neural mechanisms that produce actual movements (Decety, 1996; Erlacher & Schredl, 2008b), supporting the notion of functional equivalence (Jeannerod, 2001). Thus, lucidly dreamed and imagined movements would have similar functional outcomes with actual physical movements, allowing motor learning to occur. A recent functional magnetic resonance imaging/near-infrared spectroscopy study showed that brain activity in the sensorimotor cortex is similar during imagined and lucidly dreamed movement (Dresler et al., 2011). The perception in lucid dreams, however, seems to be much closer to actual perception and both are quite distinct from imagination (LaBerge & Zimbardo, 2000). In lucid dreams the simulation is experienced as real (not just existing in imagination) and therefore it has been suggested that LDP should be more effective than MP performed in wakeful imagination (Tholey, 1990). The present study, however, did not show a clear difference between the two types of practice.

All three types of practice increased performance speed without compromising accuracy – the error rate did not significantly differ between the two tests, which is consistent with previous research (cf. Walker et al., 2002). Only the control group showed a significant increase in the error rate, which perhaps might be linked to changes in motivation (i.e. less motivated to retake the same test without any practice in between). A finger-tapping study by Debarnot et al. (2009), for example, also found somewhat increased error rate during the retest, although the difference did not reach significance.

In comparison with the earlier study (Erlacher & Schredl, 2010), this study involved a larger sample and practice times were matched. In the previous study, the PP group accomplished practice in the evening, whereas lucid dreamers practiced at some later point at night. Sleep memory consolidation research shows that improvements in performance seem to be associated with various sleep parameters, such as a higher amount of rapid eye movement (REM) sleep (Fischer, Hallschmid, Elsner, & Born, 2002) or a greater proportion of time spent in Stage 2 sleep (Walker et al., 2002). Therefore, the PP group might have had an advantage in the previous study. In this study, the practice times were matched. PP and MP participants had a small disadvantage to awaken at night and wait 30 min before starting their practice. The LDP group, however, also had to awaken after a lucid dream (to write down the dream) and several lucid dreamers indicated that they used Wake-up-Back-To-Bed method for lucid dream induction, which requires to awaken at night and stay awake for some time (cf. Stumbrys et al., 2012). Thus, the conditions were comparable and the awakenings did not seem to significantly disturb the sleep – all groups rated their subjective sleep quality similarly. While there are some indications that the brain seems to be more active during lucid as compared to non-lucid REM sleep (Dresler et al., 2012; Voss, Holzmann, Tuin, & Hobson, 2009), there appears to be no evidence in the literature about negative effects of frequent lucid dreaming on sleep quality.

In summary, the present study corroborates the findings that motor practice in lucid dreams improves subsequent performance in wakefulness. No significant differences were found when comparing the effectiveness of LDP to PP and MP in wakefulness. While further research with more complex skills is very much needed, current research with simple motor skills, such as finger-tapping or coin-tossing, shows that LDP gives an additional opportunity to athletes to practice specific sport skills during the night time when physiologically asleep. LDP provides a more realistic simulation of the waking environment than MP (cf. LaBerge & Zimbardo, 2000; Tholey, 1990) and could be alternatively used when an athlete is injured, unable to practice physically or actions are dangerous. LDP may be more beneficial for those athletes who have lucid dreams more often but lack vivid wakeful imagination. While only a limited number of athletes have lucid dreams on a frequent basis (Erlacher et al., 2011–2012), there is a wide range of techniques that can be used for lucid dream induction (Stumbrys et al., 2012), yet none of them has been verified to induce lucid dreams reliably and consistently. This is one the main challenges facing lucid dream research. Future studies should establish reliable techniques for lucid dream induction and examine the effects of LDP in controllable sleep laboratory conditions.

Acknowledgement

The authors would like to thank Laurens Van Keer from Snoozon.com for developing the online finger-tapping application.

References

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159.

Debarnot, U., Creveaux, T., Collet, C., Doyon, J., & Guillot, A. (2009). Sleep contribution to motor memory consolidation: A motor imagery study. *Sleep*, *32*(12), 1559–1565.

Decety, J. (1996). Do imagined and executed actions share the same neural substrate? *Cognitive Brain Research*, *3*(2), 87–93.

Dresler, M., Koch, S. P., Wehrle, R., Spoormaker, V. I., Holsboer, F., Steiger, A., & Czisch, M. (2011). Dreamed movement elicits activation in the sensorimotor cortex. *Current Biology*, *21*(21), 1833–1837.

Dresler, M., Wehrle, R., Spoormaker, V. I., Koch, S. P., Holsboer, F., Steiger, A., & Czisch, M. (2012). Neural correlates of dream lucidity obtained from contrasting lucid versus non-lucid REM sleep: A combined EEG/fMRI case study. *Sleep*, *35*(7), 1017–1020.

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology*, *79*(4), 481–492.

Erlacher, D. (2007). *Motorisches Lernen im luziden Traum: Phänomenologische und experimentelle Betrachtungen* [Motor learning in lucid dreams: Phenomenological and experimental aspects]. Saarbrücken: VDM.

Erlacher, D., Schädlich, M., Stumbrys, T., & Schredl, M. (2014). Time for actions in lucid dreams: Effects of task modality, length, and complexity. *Frontiers in Psychology*, *4*, 1013.

Erlacher, D., & Schredl, M. (2008a). Cardiovascular responses to dreamed physical exercise during REM lucid dreaming. *Dreaming*, *18*(2), 112–121.

Erlacher, D., & Schredl, M. (2008b). Do REM (lucid) dreamed and executed actions share the same neural substrate? *International Journal of Dream Research*, *1*(1), 7–13.

Erlacher, D., & Schredl, M. (2010). Practicing a motor task in a lucid dream enhances subsequent performance: A pilot study. *The Sport Psychologist*, *24*(2), 157–167.

Erlacher, D., Stumbrys, T., & Schredl, M. (2011–2012). Frequency of lucid dreams and lucid dream practice in German athletes. *Imagination, Cognition and Personality*, *31*(3), 237–246.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160.

Feltz, D. L., & Landers, D. M. (1983). The effects of mental practice on motor skill learning and performance: A meta-analysis. *Journal of Sport Psychology*, *5*(1), 25–57.

Fischer, S., Hallschmid, M., Elsner, A. L., & Born, J. (2002). Sleep forms memory for finger skills. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(18), 11987–11991.

Guillot, A., & Collet, C. (2005a). Contribution from neurophysiological and psychological methods to the study of motor imagery. *Brain Research Reviews*, *50*(2), 387–397.

Guillot, A., & Collet, C. (2005b). Duration of mentally simulated movement: A review. *Journal of Motor Behavior*, *37*(1), 10–20.

Guillot, A., Hoyek, N., Louis, M., & Collet, C. (2012). Understanding the timing of motor imagery: Recent findings and future directions. *International Review of Sport and Exercise Psychology*, *5*(1), 3–22.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*(1), S103–S109.

Karni, A., Meyer, G., Rey-Hipolito, C., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G. (1998). The acquisition of skilled motor performance: Fast and slow experience-driven changes in primary motor cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *95*(3), 861–868.

LaBerge, S. (1985). *Lucid dreaming. The power of being awake and aware in your dreams*. Los Angeles, CA: Tarcher.

LaBerge, S. (1995). Prolonging lucid dreams. *NightLight*, *7*(3–4), 22–27.

LaBerge, S., & Rheingold, H. (1990). *Exploring the world of lucid dreaming* (p. 277). New York, NY: Ballantine Books.

LaBerge, S., & Zimbardo, P. (2000, April 10). *Smooth tracking eye-movements discriminate both dreaming and perception from imagination*. Abstract of talk presented at the Toward a Science of Consciousness Conference IV, Tucson.

Lorey, B., Naumann, T., Pilgramm, S., Petermann, C., Bischoff, M., Zentgraf, K., … Munzert, J. (2013). How equivalent are the action execution, imagery, and observation of intransitive movements? Revisiting the concept of somatotopy during action simulation. *Brain and Cognition*, *81*(1), 139–150.

Lotze, M., & Halsband, U. (2006). Motor imagery. *Journal of Physiology – Paris*, *99*(4–6), 386–395.

Morris, T., Spittle, M., & Watt, A. P. (2005). *Imagery in sport*. Champaign, IL: Human Kinetics.

Munzert, J., Lorey, B., & Zentgraf, K. (2009). Cognitive motor processes: The role of motor imagery in the study of motor representations. *Brain Research Reviews*, *60*(2), 306–326.

Nyberg, L., Eriksson, J., Larsson, A., & Marklund, P. (2006). Learning by doing versus learning by thinking: An fMRI study of motor and mental training. *Neuropsychologia*, *44*(5), 711–717.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113.

Richardson, A. (1967). Mental practice: A review and discussion. Part I. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *38*(1), 95–107.

Roberts, R., Callow, N., Hardy, L., Markland, D., & Bringer, J. (2008). Movement imagery ability: Development and assessment of a revised version of the vividness of movement imagery questionnaire. *Journal of Sport & Exercise Psychology*, *30*(2), 200–221.

Schredl, M., & Erlacher, D. (2011). Frequency of lucid dreaming in a representative German sample. *Perceptual and Motor Skills*, *112*(1), 104–108.

Stumbrys, T., Erlacher, D., Schädlich, M., & Schredl, M. (2012). Induction of lucid dreams: A systematic review of evidence. *Consciousness and Cognition*, *21*(3), 1456–1475.

Stumbrys, T., Erlacher, D., & Schredl, M. (2013). Reliability and stability of lucid dream and nightmare frequency scales. *International Journal of Dream Research*, *6*(2), 53–56.

Tassi, P., & Muzet, A. (2000). Sleep inertia. *Sleep Medicine Reviews*, *4*(4), 341–353.

Tholey, P. (1981). Empirische Untersuchungen über Klarträume [Empirical study on lucid dreams]. *Gestalt Theory*, *3*(1/2), 21–62.

Tholey, P. (1990). Applications of lucid dreaming in sports. *Lucidity Letter*, *9*(2), 6–17.

Veale, J. F. (2014). Edinburgh handedness inventory – short form: A revised version based on confirmatory factor analysis. *Laterality: Asymmetries of Body, Brain and Cognition*, *19*(2), 164–177.

Voss, U., Holzmann, R., Tuin, I., & Hobson, J. A. (2009). Lucid dreaming: A state of consciousness with features of both waking and non-lucid dreaming. *Sleep*, *32*(9), 1191–1200.

Walker, M. P., Brakefield, T., Morgan, A., Hobson, J. A., & Stickgold, R. (2002). Practice with sleep makes perfect: Sleep-dependent motor skill learning. *Neuron*, *35*(1), 205–211.