Cardiovascular Responses to Dreamed Physical Exercise During REM Lucid Dreaming

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Previous studies have demonstrated intriguing psychophysiological correspondences when lucid dreamers carried out specific tasks during lucid dreams (e.g., eye movements and EMG activities). But only a few studies have investigated cardiovascular changes during dreamed physical activities. This study tests the hypothesis that physical activity (performing squats) carried out in a lucid dream increases cardiovascular parameters in the sleeping body. Therefore, 5 proficient lucid dreamers experienced with the eye-signaling method during lucidity spent 2 to 4 nonconsecutive nights in a sleep laboratory. Instructed to carry out specific tasks (counting and performing squats) while lucid dreaming, the participants reported becoming lucid and signaling in 11 REM periods recorded. Fourteen complete lucid dream tasks were verified by eye signaling. The results showed a statistically significant increase of heart rate between the preexercise and exercise periods and the postexercise period. The results for respiration rate were less clear. Even though respiration rate during the exercise period was higher than during the pre- and postexercise period, statistical significance was only found for the second comparison. Overall, the results support the hypothesis that lucidly dreamed motor action causes increases at the level of peripheral effectors.

Keywords: lucid dreaming, psychophysiology, physical activity, heart rate, respiration rate

Since the discovery of REM sleep by Aserinsky and Kleitman (1953), the study of the relationship between dream content and REM sleep physiology has provided an interesting area for the study of psychophysiological interactions in general (Schredl, 2000). One of the reasons is that during REM dreams, the efferent motor commands are actively suppressed by neural structures in the brain stem (Jouvet, 1965), keeping dreamers from actually acting out their dreams. This circumstance provides the possibility of measuring physiological changes in the sleeping body, for example, heart rate, simultaneously with different activities of the dreamer in her

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or his dream without actual movements of the body. Dream research (for overviews, see Pivik, 1994; Schredl, 2000) has provided evidence that there is a correlation between dreamed actions and physiological measurements of the sleeping body. Correlations can be found for eye movements (e.g., Dement & Wolpert, 1958), brain activity measured by electroencephalography (e.g., Hong et al., 1996), limb twitches measured by electromyography (e.g., Gardner, Grossman, Roffwarg, & Weiner, 1975), and cardiovascular parameters (e.g., Baust & Engel, 1971).

Because the emphasis in this article is on the association between dream content and cardiovascular parameters, we review the few studies from nonlucid dream research investigating this relationship. On one hand, Hobson, Goldfrank, and Snyder (1965) found a positive correlation between global dream content ratings (including ratings of emotion, physical activity, and vividness) and respiration rate and respiration rate variability. Hauri and Van de Castle (1973) differentiated the dream content ratings in emotionality, physical activity, and involvement and found that physical activity is correlated with heart rate variability. However, a large number of correlation coefficients were computed, and 17 of 100 coefficients reached significance ($p < .05$) and a correction for multiple comparisons was not attempted. Baust and Engel (1971) found that large respiration amplitudes correlated with intensive active participation in the dream. On the other hand, high variability of respiration frequency was associated—in contrast to the findings from Hobson et al.—with little active participation in the dream. No correlation was found for heart rate and dream content in this study.

The mixed results for the correlation studies between dream content and autonomic parameters can be explained by the large variability of the dream content (Schredl, 1998) because the dream content cannot be manipulated experimentally in a marked way, for example, by films shown before sleep (cf. Schredl, 1999). This problem can be solved by using lucid dreams because lucid dreamers are able to execute prearranged tasks in their lucid dreams and mark the beginning and end of the task with eye signals in the electrooculogram (EOG) recording. The term *lucid dream* designates a dream in which the dreamer—while dreaming—is aware that she or he is dreaming and can consciously influence the action in the dream (LaBerge, 1985; Schredl & Erlacher, 2004). Studies from lucid dream research (for an overview, see LaBerge, 2000) have demonstrated a strong correlation between lucidly dreamed actions and physiological measurements. Correlations can be found for eye movements (LaBerge, Nagel, Dement, & Zarcone, 1981), brain activation measured by electroencephalography (e.g., Erlacher, Schredl, & LaBerge, 2003), limb twitches measured by electromyography (EMG; e.g., Fenwick et al., 1984), and cardiovascular parameters (e.g., LaBerge, Greenleaf, & Kedzierski, 1983). Two lucid dream studies (LaBerge & Dement, 1982; LaBerge et al., 1983) investigated the correlation between cardiovascular parameters and activities in lucid dreams. The pilot study of LaBerge et al. (1983) showed a correspondence between subjectively experienced sexual activity during REM lucid dreaming and several autonomic parameters such as respiration rate, skin conduction, vaginal EMG, and vaginal pulse amplitude. The parameters increased significantly during experienced lucid dream orgasm, but contrary to expectations, heart rate increase was nonsignificant. The second study by LaBerge and Dement (1982) showed that a single lucid dreamer was able to voluntarily control respiration (breath faster and stop breathing) during lucid REM dreaming and that this respiration pattern was found in the measurement of the nasal airflow recorded in the sleeping body.

In this study, we examine the psychophysiological correlation between consciously dreamed physical activities in lucid dreams and physiological parameters in more detail. We instructed participants to perform a specific physical activity in their lucid dreams while monitoring cardiovascular parameters. We hypothesized that cardiovascular parameters would increase while participants performed a physical activity in a lucid dream. Because of the small sample size, this study should be considered as a pilot study.

METHOD

Participants

Five lucid dreamers (23–34 years old, M = 28 years; 1 woman and 4 men) volunteered to participate in the study. The 4 male participants had been enrolled in previous studies, and the female participant was recruited through an Internet page (http://klartraum.de) about lucid dreaming set up by Daniel Erlacher. All participants had had lucid dreams for many years, ranging from 30 to 1,000 lucid dreams a year, and were familiar with the method of signaling by means of characteristic, predetermined eye movements. Four of the participants had no athletic background and practiced sport irregularly and less than 1 hr a week. One participant had athletic experience and practiced sport regularly (an average of 3 hr per week). Informed consent was obtained from the participants, and participation was paid.

Experimental Protocol for Lucid Dream Task

First thing after becoming aware of dreaming and signaling with eye movements (see below), the lucid dreamers had to get in a standing position and relax. The participants' task was to count from 21 to 25 (preexercise), perform 10 squats (exercise), and to count again (postexercise). The lucid dreamers were instructed to mark the following events by means of left–right–left–right (LRLR) eye movements: the onset of lucidity, the beginning and end of the entire lucid dream task, and the transitions between counting to performing squats to counting. Therefore, a correct lucid dream task included five eye signals (see Figure 1).

After finishing the task correctly or being unable to complete the task, the lucid dreamer could start the entire task for a second time after a short pause. This new beginning had to be signaled by three series of LRLR eye movements (i.e., LRLR LRLR LRLR). After a maximum of two sequences of the lucid dream task, the participant was to wake himself or herself by focusing on a fixed spot in his or her lucid dream (Tholey, 1983). The awakening had to be signaled by two series of LRLR eye movements (i.e., LRLR LRLR). After a lucid dream, participants wrote a complete and precise dream report. They were instructed to be very detailed about the lucid dream task and to record every LR eye signal. Differences from the

onset lucidity	
LRLR	1. eye signal
Start lucid dream task	
LRLR	2. eye signal
Counting (twenty-one to twenty-five)	→ pre-exercise
LRLR	3. eye signal
Performing squats (10 times)	→ exercise
LRLR	4. eye signal
Counting (twenty-one to twenty-five)	→ post-exercise
LRLR	5. eye signal
Stop lucid dream task	

Figure 1. The precise protocol of the lucid dream task. For one successful lucid dream task, five left–right–left–right (LRLR) eye movements had to be performed.

presleep instructions had to be highlighted (e.g., "only a single left-right eye movement instead of a pair").

Procedure

The participants spent 2–4 nonconsecutive nights in a sleep laboratory. Before sleep onset, participants received concise instructions about the experimental task they had to fulfill in their lucid dreams (see above). Sleep was recorded by means of the following standard procedures: electroencephalogram (EEG; C3-A2 and C4-A1), EOG (left eye A1 and right eye A1), submental EMG, and electrocardiogram. Additionally, respiration rate by nasal airflow was recorded during the entire night by the standard recording device of the Schwarzer ComLab 32 or NeuroScan.

The experimenter woke participants up when recordings showed either of the following criteria: (a) a false awakening, that is, the recording showed four pairs of LR eye movements (signal for being awake), but the EEG and EMG channel still showed characteristics of REM sleep, and (b) loss of lucidity, that is, the recording showed five correct LRLR eye movements in the EOG channel, but after the last signal no further eye signal occurred for 30 s. Both circumstances might bias the dream report of the lucid dream task as a result of forgetting specific parts of the dream.

Data Acquisition

For the polysomnographic recordings, sleep stages were scored according to Rechtschaffen and Kales (1968). In 15 nights, the participants reported 19 attempts to perform the task in 14 lucid dreams. In 11 lucid dreams, the participants succeeded in completing the lucid dream task 14 times, verified by the EOG recordings. In 5 lucid dreams, the participants failed to complete the lucid dream task (see next section). For the further analysis of the 14 successful performed lucid dream tasks, we determined heart rate and respiration rate values from the raw data (peak to peak data). Next, we calculated mean values for heart rate and respiration rate for the preexercise and postexercise counting period and for the performance of 10 squats. Because of the short preexercise and postexercise interval, we calculated mean values for respiration rate over 10 s before and after the counting period, respectively (see Figure 2). For statistical analysis, we computed one-sided *t* tests for dependent samples to compare the cardiovascular parameters of the three different periods. To test for possible effects of non-normal distribution that might be present in the physiological parameter, we also computed nonparametric tests (one-sided Wilcoxon's tests). Effect sizes were determined along formulas given by Cohen (1988).

Problems in Lucid Dreams

In five lucid dreams, the participants failed to complete the lucid dream task because of problems specific to lucid dreams. In sum, those problems include mistakes in the sequence of the lucid dream task, premature awakening, false awakening, loss of lucidity, and unpredic problems caused by the lucid dream. One of these dream reports clarifies two of the aforementioned problems:

> I realize that this is a dream, I give a LR eye signal. . . . I stand up and give the second LRLR. I count 21, 22, 23, 24, 25, and give another LRLR. I start to perform the squats. About the second or third squat I couldn't see anything; my eyes were closed. I slip and fall quickly on the floor. I have no idea how this happened, but I give three LRLR eye movements to start

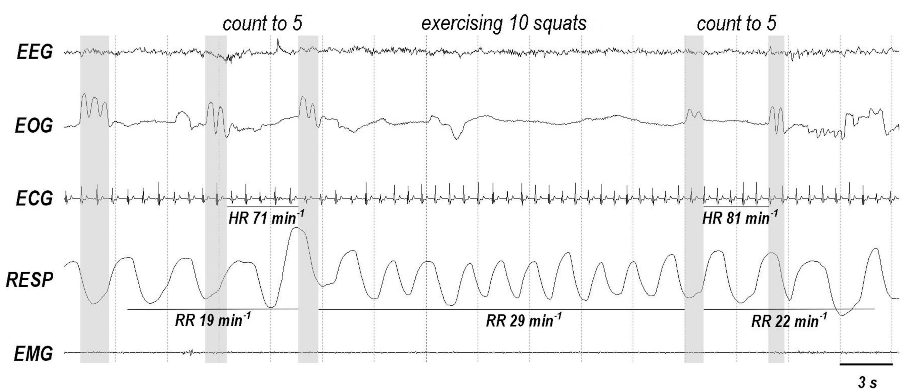

Figure 2. Recording of a signaled lucid dream: Five clear left–right–left–right eye movement signals are shown in the electrooculogram (EOG) channel (left eye, A1). Typically for REM sleep, the electroencephalography (EEG) channel (C3-A2) shows low-voltage mixed frequency, and the muscle tone in the submental electromyography (EMG) channel is very low. See text for the corresponding dream report. Obviously, the respiration rate (RR) and heart rate (HR) increase while the participant performed squats in the lucid dreams. The gain and filter settings were EMG 24 μV and EEG, 85 μV (Bandpass filter 0.53–35 Hz); EOG 366 μV and nResp 915 μV (DC recording); Notch filter on. ECG = electrocardiogram; RESP = respiration.

> the task from the beginning. I stand up and try to concentrate on the experiment. After the first counting, I woke up.

RESULTS

Sample Lucid Dream

Figure 2 depicts one signaled lucid dream task with remarkable changes in heart rate and respiration rate. In the corresponding dream report, the participant described his experience with the lucid dream exercise as follows:

> A young girl was standing in front of me, and she starred at me with a strange gaze. I'm not sure if it was her strange gaze, but in that moment it occurred to me that this is a dream. I signaled immediately with a LRLR eye movement, whereas I actually made three LR movements. I concentrated on the task and gave the next LRLR to start with the task. I started counting from 21 to 25, LRLR, and then I performed the 10 squats, LRLR, and again counting and a final LRLR. I then stared at my hands and recognized that the dream started to dissolve and I woke up. I forgot to give the four LR eye signals for being awake.

The five reported LRLR eye movement signals can be seen in the EOG recording. For this participant, heart rate increased from 71 min^{-1} during the preexercise counting period to 81 min^{-1} during the postexercise counting period. At the same time, the respiration rate increased immediately from 19 min^{-1} in the preexercise counting period to a mean value of 29 min^{-1} for the period in which the lucid dreamer performed the 10 squats and decreased abruptly after the exercise to 22 min^{-1} in the postexercise counting period.

Comparison of the Different Periods

Table 1 depicts all preexercise, exercise, and postexercise values for each participant. The mean heart rate value (see Table 2) was significantly higher in the

Table 1. Mean Values and Standard Deviations for Heart Rate and Respiration Rate During Preexercise and Postexercise Counting Period and the Period With Exercise

		Heart rate			Respiration rate		
Participant	Dream	Preexercise	Exercise	Postexercise	Preexercise	Exercise	Postexercise
1	1	65.54	68.13	64.04	23.04	20.07	19.33
1	2	62.71	69.28	72.81	20.45	23.10	19.60
2	1	65.46	66.50	72.25	22.29	25.92	24.06
2	2	70.14	78.58	78.94	22.34	26.52	24.82
2	3	63.10	66.08	67.33	21.47	24.26	23.88
2	4	68.33	67.62	65.63	23.42	25.85	19.96
2	5	69.51	68.08	70.43	25.55	24.36	18.92
2	6	55.45	54.94	63.21	24.90	25.91	14.42
2	7	60.51	68.50	68.55	23.46	20.02	20.11
2	8	68.50	68.05	63.30	20.48	19.78	18.76
3	1	71.02	77.02	81.20	18.72	29.39	21.70
3	2	61.85	64.12	64.11	19.34	25.29	16.03
4	1	66.04	68.71	74.34	24.10	17.68	24.89
5	1	77.77	71.35	68.51	—	—	—

Table 2. Mean Values and Standard Deviations for Heart Rate and Respiration Rate During Preexercise and Postexercise Counting Period and the Period With Exercise

	Preexercise		Exercise		Postexercise	
Rate	*M*	*SD*	*M*	*SD*	*M*	*SD*
Heart rate[a]	66.14_a	5.43	68.35_b	5.53	69.62_b	5.73
Respiration rate[b]	22.27	2.09	23.70_c	3.37	20.50_d	3.27

Note. Means with different subscripts within a row are significantly different.
[a] n = 14 lucid dreams. [b] n = 13 lucid dreams.

exercise period than in the preexercise period, $d = 0.54$, $t(13) = 2.02$, $p = .03$ (Wilcoxon test: $Z = 1{,}915$, $p = .03$). In addition, heart rate was significantly different between the preexercise and the postexercise counting period, $d = 0.56$, $t(13) = 2.10$, $p = .03$ (Wilcoxon test: $Z = 1{,}789$, $p = .04$). The respiration data from 1 participant had to be excluded because of incorrect recording of the nasal airflow sensor. The mean value of the respiration rate increased during the exercise period, but the increase from preexercise to exercise period was not significant, $d = 0.32$, $t(12) = 1.16$, $p = .14$ (Wilcoxon test: $Z = 1{,}013$, $p = .16$), whereas the abrupt decrease from the exercise period to the postexercise period was significant, $d = -0.66$, $t(12) = -2.39$, $p = .02$ (Wilcoxon test: $Z = 2{,}411$, $p = .01$).

DISCUSSION

Overall, the results support the hypothesis that performing a physical activity in a lucid dream is accompanied by increased cardiovascular parameters (with moderate effect sizes). Statistically significant higher heart rates were measured during the exercise period in comparison to the preexercise and postexercise periods. Statistical significance was not affected by the distribution of the variables; nonparametric tests yielded similar results. The results for respiration rate were less clear. Even though respiration rate during the exercise period was higher than during the pre- and postexercise periods, statistical significance was found only for the second comparison.

Before we discuss the results in detail, we consider two methodological issues concerning lucid dream studies: small sample size and problems in performing the lucid dream task. First, in a recent study, Schredl and Erlacher (2004) found in a student sample that 36.9% of the 439 participants were frequent lucid dreamers (frequency equal to or higher than once per month) in the terminology of T. J. Snyder and Gackenbach (1988). Only 2.5% of the participants stated that they had several lucid dreams a week. Even though LaBerge (1980) demonstrated that lucid dreaming is a learnable skill, recruiting proficient lucid dreamers is still a problem in experimental lucid dream studies. In the future, it would be helpful to improve lucid dream induction techniques to conduct experimental sleep laboratory studies with bigger sample sizes. Second, although we tried to keep the lucid dream task as simple as possible, in five cases the participants were confronted with problems caused by specific features of lucid dreaming. This might be seen as an interaction between task complexity and participants' experience, but it seems that lucid dreams still have some inherent dynamics that cannot be mastered by even very good trained lucid dreamers. Nevertheless, in the majority of lucid dreams, the participants were successful in accomplishing the lucid dream task.

In the present study, changes in cardiovascular parameters because of physical activity performed in a lucid dream were found to be similar to changes that have been described for mental performance (e.g., Decety, Jeannerod, Germain, & Pastene, 1991). The relative increase of heart rate during lucid dream performance of squats was 13.3%. This is comparable to Decety et al.'s (1991) study, in which the relative mean increase for sportive participants for a mental exercise of 3 min was 19.5%. The high postexercise values for heart rate might be explained by an aftereffect of short-lasting and moderate levels of the activity. For example, McArdle, Foglia, and Patti (1967) found an overshoot of heart rate for participants after finishing a 60-yard dash; these authors speculated that this increase of heart rate with cessation of a short activity may be a the result of a lag of some feedback mechanisms regulating heart rate. Therefore, in further studies the postexercise period should be prolonged to record a decrease of heart rate.

For respiration rate, the relative increase in our study was 8.2%, a figure quite smaller than that reported by Decety et al. (1991) for the relative mean increase for the mentally simulated 3-min exercise (105.3%). The less pronounced increase in this study might be explained by the high baseline rate for respiration rate, which in general is higher in REM sleep compared with relaxed wakefulness (Douglas, White, Pickett, Weil, & Zwillich, 1982; F. Snyder, Hobson, Morrison, & Goldfrank, 1964). For example, the baseline for respiration rate for the rest condition in Decety et al.'s study was 9.5 min^{-1} compared with 22.3 min^{-1} in the present study. The comparatively small relative increase in respiration rate in the present study is therefore likely a result of a ceiling effect. Two further factors might have contributed to the small increase of respiration rate. First, in this study, respiration rate was measured by nasal airflow, but tidal volume—the second parameter contributing to ventilation—was not monitored during the night. For short-lasting exercises, like performing 10 squats, the initial increase in ventilation might be increased by tidal ventilation while respiration rate remains almost the same (Dejours, Kellogg, & Pace, 1963). Therefore, some participants might have used a different breathing strategy that was not detectable by nasal airflow alone. Second, for respiration rate, in contrast to heart rate, the findings regarding increase because of motor imagery are less consistent in nonathletes (Wuyam et al., 1995); in this study, 4 of 5 participants were nonathletes.

In further studies, it might be interesting to investigate whether the perceived exertion while performing a strenuous task in a lucid dream might have any influence on the cardiovascular response. In studies about mental imagery, Wang and Morgan (1992), for example, showed that the instruction to have an external imagery focus instead of an internal imagery focus for a physical activity caused significantly smaller values in perceived exertion and smaller response to ventilation. Therefore, future studies should apply a rating scale (e.g., Borg, 1973) for measuring perceived exertion to study the dependency between perceived exertion and cardiovascular response to lucid dream activity.

In the model by Jeannerod (1994), it was argued that mental simulation of motor actions shares to some extent the same motor representations and central neural mechanisms that are used to execute actual actions. The results from our study support the hypothesis that motor activity in lucid dreams also shares neural mechanisms that are responsive to motor programming, as suggested by the studies on motor imagery (Jeannerod, 2001). Taking into consideration the results from this study and the results from the pilot studies from Erlacher et al. (2003) and LaBerge (1990) showing a relation between lucid dreamed action and actual motor activity leads to the hypothesis that training of motor skills in the simulated environment of dreams is very likely to improve waking performance (Erlacher, 2005; Erlacher & Schredl, 2008). For mental training in wakefulness (for overviews, see Driskell, Copper, & Moran, 1994; Feltz & Landers, 1983), it has been shown that simulation of specific exercises improved performance for a wide variety of motor tasks.

To summarize, in the present study proficient lucid dreamers were able to perform a physical activity during a lucid dream, and this activity increased heart rate. In addition, respiration rate showed greater mean values during the performance of 10 squats than before and after the physical activity. The results of this study support the hypothesis that lucid dreamed motor actions reflect actual motor actions in higher brain areas.

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