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Original article

The effects of exercise on self-rated sleep among adults with chronic sleep complaints

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Abstract

Purpose: The purpose of this study was to evaluate whether and to what extent the observed effects on self-rated sleep in a previous study using a combined treatment program with physical exercise and sleep education can be attributed by the physical activity (PA) component.
Methods: The present study reports supplementary analysis of an already described and published study. Data were provided by a nonclinical sample of 98 normal-active adults with chronic initiating and the maintaining of sleep complaints. The additional analysis included sleep log, exercise log, and daily pedometer data which were collected during a baseline week and 6-week of a combined intervention.
Results: The results indicate that the number of steps ($p = 0.02$) and the duration of PA ($p = 0.01$) is significantly related to the improvement in subjective sleep measures and therefore reveal an independent effect within this combined sleep program. Sleep diary data (recuperation of sleep, number of awakenings after sleep onset, and wake time after sleep onset time) improved significant (all $p < 0.01$) over the intervention program. About 50% of the participants stated that the PA had an effect on their improvement.
Conclusion: Improvements on subjective sleep quality after a combined intervention cannot be attributed to the cognitive component alone, but PA has an independent effect. Adults with chronic sleep complaints benefit from exercise. Therefore structured PA should be implemented in any sleep management programs.

Keywords: Adults; Insomnia; Non-pharmacological treatment; Physical exercise; Sleep problems

1. Introduction

Epidemiological studies suggests that physical activity (PA) might be one of the most effective daytime behaviors associate with a good night of sleep.[1] The frequently cited study by Urponen et al.[1] demonstrates nicely the notion of sleep-promoting effects due to exercise. In this survey, 1190 middle-aged adults in Finland were asked to name factors promoting and disturbing sleep. Every third respondent for both gender in all age groups listed exercise as the most sleep-promoting activity. Another epidemiological study by Loprinzi and Cardinal[2] analyzed the data of 3081 adults (age: 18–85 years) who wore an accelerometer for 7 days. Results showed an association between the objectively measured PA and self-reported sleeping-related parameters.

Furthermore, field studies have shown that physically active individuals sleep better than less active individuals do. For example, Brand et al.[3] analyzed sleep diaries from adolescent athletes ($n = 258$) with a training volume of about 18 h per week and adolescents ($n = 176$) with only about 5 h of sport per week. Results showed that frequent sporting activities related to subjectively reported shorter sleep onset, less sleep

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interruptions and a generally better mental health. For objective sleep data, a good example is the study by Edinger and colleagues[4] who showed that the sleep profile of 12 older fit men compared to inactive men of the same age revealed shorter sleep latency and shorter sleep interruptions, more deeper sleep and increased sleep efficiency. In another study, PA was measured by accelerometer for three consecutive days in 56 adolescent vocational school students.[5] Additionally, sleep was monitored for one night with a sleep-EEG. Results showed that both subjectively and objectively assessed PA predicted both subjective and objective sleep among adolescents. In a study by Kalak et al.,[6] 51 healthy adolescents were randomly assigned either to a running or to a control group. The running group went running every morning for 30 min at moderate intensity during weekdays for 3 consecutive weeks. Results showed that a relative short intervention improved both subjective and objective sleep among healthy adolescents.

In contrast, Youngstedt and colleagues[7] conducted two prospective home assessment studies to investigate correlations between sleep and total daily PA. In the first study, 31 participants kept a dairy for 105 consecutive days about their total exercise duration and sleep. In the second study, 71 participants wore a wrist-mounted Actillume measuring activity and kept a sleep log for 7 consecutive days. In both studies, no correlations between PA and sleep parameters were found. From a methodological point of view, the mixed results from the studies so far might be explained by the different assessment of PA and sleep, e.g., the measure of PA ranged from not validated questionnaire items to objectively measures by pedometers and from subjective sleep data (thus assessing the psychological, but not the physiologic part of sleep) to sleep measures via actigraphy or sleep-EEG. Youngstedt et al.[8] highlighted another important issue: in this study participants were normal sleepers with no potential to improve (ceiling effects), or the other way around: “The greater the initial impairment in sleep, the greater the potential for improvement”.

So far, experimental studies that examined the effects of PA on sleep in individuals with sleep problems are limited but show promising results. Small to moderate improvements in sleep quality were found after different exercise interventions like walking,[9] Yoga,[10] Tai Chi,[11] Baduanjin,[12] or resistance training[13] but also for worksite interventions.[14] Most of the studies focused on moderate activity respectively on the current PA health recommendation for adults and older adults worldwide.[15] In an own intervention study, we investigated the efficacy of a combined program that included physical exercise and sleep education on subjective sleep quality in adults with a long history of sleep complaints.[16] Results indicate that the combined program is effective in improving self-reported sleep quality. During the intervention, participants were required to keep a sleep and exercise log starting from a baseline week over the 6-week intervention period.

In the present study we apply supplementary analysis of the above described and published sample.[16] The aim of the present analysis was to investigate the differential effects of PA and general sleep education components on subjective sleep quality. Even though Youngstedt and colleagues[7] did not find correlations between daily PA and sleep quality in healthy young adults, we expected that in persons with sleep complaints the amount of exercise (exercise frequency, duration, intensity, number of daily steps) was positively correlated with the improvement in sleep quality. Thus far, exercise intervention studies in insomnia sufferers have not looked at those relationships.[17] The second aim of the study was to display on a descriptive level the week-to-week variability of sleep quality and PA starting from a baseline week over the 6-week intervention period. We expected an increase of PA and an improvement in sleep quality due to the intervention program. Lastly, we present the responses of the participants to indicate what they judged to be most helpful.

2. Methods

2.1. Study design and procedure

In the present study we perform supplementary analysis of the above described and published study.[16] This study used a waiting-list-controlled design. Participants were assigned either to the intervention group or a waiting-list control group. General sleep measurements were collected at baseline, after the intervention, and at follow-up after 3 months. All participants received a combined 6-week intervention consisting of sleep education and physical exercise, however, participants of the control group received the same treatment after a 6-week waiting period. The program included 6 weekly sessions in groups of 8−12 individuals. Each session started with 60 min sleep education followed by 60 min of instructed moderate physical exercise (Nordic walking). Twice a week, participants were instructed to engage by themselves in Nordic walking or equivalent sports (endurance sports outside). During the 6 weeks, further data provided by sleep log, exercise log as well as by pedometer were collected in a diary. For further details see Gebhart et al.[16]

Participants were recruited by advertisements in local print media. In an initial telephone interview the eligibility criteria (sleep problems, e.g., initiating sleep and/or maintaining sleep) were checked. Participation was not limited to primary insomnia symptoms, but persons with sleep problems who suffered from either coexistent physical or psychological disorders, or hypnotic medication consumption were also included.[16]

Participants provided written informed consent. The study has been carried out at the Institute for Sport and Sports Science in Heidelberg and at the Central Institute of Mental Health in Mannheim.

2.2. Participants

Overall 125 eligible participants were included in the study, whereas 81 were assigned to the intervention group and 44 to the waiting-list control group.[16] In total 27 persons (11 from the intervention and 16 from the waiting list group) did not

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finish the treatment ($n = 20$) or did not provide a sufficient data in the sleep or exercise log or pedometer ($n = 7$). Therefore, suitable data were available for 98 volunteers (72 women and 26 men). Participant characteristics are described in Table 1. The mean age of 57 years indicates that the sample consists in the majority older adults. Looking at the body mass index (BMI, kg/m^2) the weight ranged from normal to obesity. The habitual PA status of $M_{\text{Baecke}} = 8.85$ indicates normal active participants.

2.3. Subjective sleep measures

The Pittsburgh Sleep Quality Index (PSQI) is a self-report questionnaire that evaluates sleep quality and assesses sleep disturbances over the previous month.[18] Nineteen items, each weighted equally from 0 to 3, add up to seven component scores (e.g., subjective sleep quality). The sum of scores for these seven subscales yields one global score of overall sleep quality and ranges from 0 to 21, whereby greater scores indicate higher levels of sleep related symptoms. German adaptation was offered by the German Sleep Society (DGSM).

Furthermore, the subjective sleep quality of the previous 2 weeks was elicited by a validated self-rating scale of the German sleep questionnaire B (SF-B).[19] The factor sleep quality (SQ) includes 11 items (e.g., sleep latency). The composite scores (averages) ranged from 1 to 5 (1 = never to 5 = very often) because most scales of the sleep questionnaire are constructed as 5-point Likert scales; whereby greater scores indicate better sleep scores.

During a 1-week period at baseline and the 6-week intervention period (overall 49 days), participants were asked to keep a daily sleep log (the Abend-Morgen-Protokoll).[20,21] The sleep log provided an additional source of sleep data with day-to-day variability as well as progress and outcome control. It also enlists participants in taking an active role in treatment. All participants were required to fill in the sleep log with five questions upon awakening in the morning:[21] Recuperation of sleep (ROS; from 1 = very to 5 = not at all), sleep onset latency (SOL; in minutes), number of awakenings after sleep onset (WASO-N, times per night), wake time after sleep onset time (WASO-T; in minutes) and total sleep time (TST; in minutes). The instructor collected the sleep logs weekly to avoid missing data and to increase compliance within the participants.

Table 1
Descriptive statistics of the participants at baseline.

Variable	*n*	Range	Mean ± SD
Age (year)	98	22−77	56.72 ± 11.02
Body mass index (kg/m^2)	98	18.47−36.73	24.14 ± 3.39
Baecke total score	77*	5.38−12.17	8.85 ± 1.40
Physical activity at work	84*	1.14−4.00	2.45 ± 0.66
Sport during leisure time	90*	1.00−4.50	2.96 ± 0.68
Physical activity during leisure time	98	1.67−5.00	3.38 ± 0.82

Note: *lower *n* due to missing values.

2.4. PA measures

A German version of the Baecke Questionnaire of Habitual Physical Activity[22] was used to assess the PA status of the participants at baseline.[23] The questionnaire includes 14 questions comprehending three dimensions relating to the previous 12 months: PA at work (7 items), sport during leisure time (4 items), and PA during leisure time excluding sport (3 items). Questions in each dimension are scored on a 5-point Likert scale (from 1 = never to 5 = always or very often). Each factor could receive a score from 1 to 5 points. For the two most frequently reported sports activities, specific questions regarding the number of months per year and hours per week of participation were addressed. Activities were subdivided into three intensity categories with the help of Ainsworth's compendium of PAs.[24] The sum of the three dimensions gives an indicator of the habitual PA status. A total score from a minimum of 3 to a maximum of 15 was obtained.

Besides the sleep log, participants were asked to maintain an exercise log to describe any daily PA that they may have engaged in 1-week before intervention (baseline) and during the 6-week intervention period (49 days). The exercise log required specifications about frequency of PA (PA-F; times/week), duration of PA (PA-D; in minutes), and intensity of PA (PA-I; assessed by Borg Scale from 6 to 20). The instructor collected the exercise logs weekly to avoid missing data and to increase compliance within the participants.

In addition to the exercise log, participants were asked to wear a digital pedometer (OMRON Walking style Pro HJ-720IT, OMRON Medizintechnik Handelsgesellschaft mbH, Mannheim, Germany) on the body (according to the manufacturer's instructions) during waking hours except being in water. The pedometer estimates the number of steps taken based on acceleration signals (dual-axis). The validity of the pedometer in counting walking steps is ±5%. Patients wore the pedometers for 42 days, starting on the day of their first visit, and then returned them after the last intervention session.

2.5. Evaluation of the combined intervention program

To evaluate the combined intervention program by the participants, a self-made questionnaire was implemented. For the study only two questions regarding the subjective estimated contributions of the physical exercise and sleep education components to the observed effects where evaluated: "Do you think, that your improvements in sleep can be explained by the physical exercise?" (1 = not at all to 5 = extremely); "Do you think, that your improvements in sleep can be explained by the sleep education?" (1 = not at all to 5 = extremely).

2.6. Data analysis

For the first aim of the study, to analyze whether improvements in sleep parameters are dependent on the PA, linear regression analyses were applied. The results from the main analysis of the combined intervention program showed

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statistically significant effects for the two sleep questionnaires: PSQI global score and SQ scale from the SF-B.[16] The differences between post intervention and baseline for those scores were used as dependent variables in two linear regression analyses to investigate possible influencing factors of BMI and sport activity status at baseline as well as PA-F, PA-D, and PA-I (physical log data) and number of steps (pedometer data) during intervention. Because severity of sleep symptoms at baseline, age, and gender is related to sleep quality and might be possible confounders for the relationship between PA and sleep, those variables were included into the linear regression.

For the second aim of the study, descriptive data of the week-to-week variability of sleep quality and the PA starting from baseline week over the 6-week intervention period were calculated. To test for statistically significant differences repeated measures analysis of variance (ANOVA) was applied for each sleep log (ROS, SOL, WASO-N, WASO-T, and TST) and exercise log (PA-F, PA-D, PA-I, and number of steps) parameter. *Post-hoc* analysis included *t* tests for dependent variables comparing each intervention week against baseline (e.g. baseline *vs.* first intervention week, baseline *vs.* second intervention week, and so on) and each intervention week with the following one (e.g., first *vs.* second intervention week, second *vs.* third intervention week, and so on).

For the last aim of the study, descriptive data of the ratings from the participants about estimated contributions of the physical exercise and sleep education components were presented.

Data were analyzed for all the 98 participants, however, because of the analysis of dependent variables, the number of participants might be reduced in some calculation due to missing values. Statistical analyses were carried out using the SPSS version 21.0 (SPSS Inc., Armonk, NY, USA) for Windows software. The level of significance was set at $p < 0.05$ for all analyses.

3. Results

3.1. Factors predicting improvements in sleep quality

For the linear regression analysis with the improvements of PSQI global score (higher negative values indicate more improvement) as the dependent variable, all independent variables were entered simultaneously (Table 2). The severity of sleep symptoms at baseline and number of steps are the only two statistically significant predictors. Therefore, participants with higher sleep severity symptoms at baseline were more likely to experience improvements in their sleep quality in comparison to participants with lower symptoms at baseline. Furthermore, the more steps are made during intervention, the more benefits on sleep quality are reported. The other variables (age, gender, BMI, previous sport activity level, PA-F, PA-D, and PA-I) had no effect on the improvement in subjective sleep quality measured by the PSQI total score.

For the linear regression analysis with the improvements of SQ (higher values indicate more improvements) as the dependent variable, all the variables described above were entered simultaneously. Table 3 shows that severity of sleep symptoms at baseline and duration of PA are the only two statistically significant predictors. Again, participants with higher sleep severity symptoms at baseline had more improvements in sleep quality after intervention. In contrast, participants with a higher amount of PA duration were more likely to experience positive changes in sleep quality in comparison to participants with a lower amount of PA duration. Again, other variables (age, gender, BMI, previous sport activity level, PA-F, PA-I, and number of steps) had no effect on the improvement in subjective sleep quality measured by the sleep questionnaire B.

Table 2
Summary of regression analysis for variables predicting the improvements in sleep quality (PSQI global score).

Independent variable	Standardized estimate	*T*	*p*
Age	−0.02	−0.23	0.82
Gender	−0.05	−0.45	0.65
BMI	0.06	0.56	0.58
Sleep symptoms severity (PSQI)	**−0.46**	**−4.54**	**0**
Previous sport activity level	0.02	0.14	0.89
PA-F	0	−0.01	0.99
PA-D	0.09	0.64	0.52
PA-I	−0.15	−1.52	0.13
Number of steps	**−0.26**	**−2.35**	**0.02**

Note: $F = 3.59$; $R^2 = 0.30$; Adjusted $R^2 = 0.22$; $df = 84$; bold data mark statistical significant findings.
Abbreviations: BMI = body mass index; PA-F = frequency of physical activity; PA-D = duration of physical activity; PA-I = intensity of physical activity.

3.2. Course of PA and sleep over intervention

Fig. 1 shows the course of PA-F, PA-D, and PA-I from the baseline week over 6 weeks of intervention. Data for number of steps at baseline is missing, because the pedometer was handed out in the first intervention week. The ANOVA showed

Table 3
Summary of regression analysis for variables predicting the improvements in SF-B subscale sleep quality (SQ).

Independent variable	Standardized estimate	*T*	*p*
Age	−1.53	−1.53	0.13
Gender	0.06	0.06	0.96
BMI	−0.74	−0.74	0.46
Sleep symptoms severity (SF-B)	**−0.32**	**−2.71**	**0.01**
Previous sport activity level	−0.18	−1.42	0.16
PA-F	−0.05	−0.26	0.80
PA-D	**0.42**	**2.51**	**0.01**
PA-I	−0.06	−0.55	0.58
Number of steps	−0.02	−0.16	0.87

Note: $F = 2.36$; $R^2 = 0.24$; Adjusted $R^2 = 0.14$; $df = 75$; bold data mark statistical significant finding.
Abbreviations: BMI = body mass index; PA-F = frequency of physical activity; PA-D = duration of physical activity; PA-I = intensity of physical activity.

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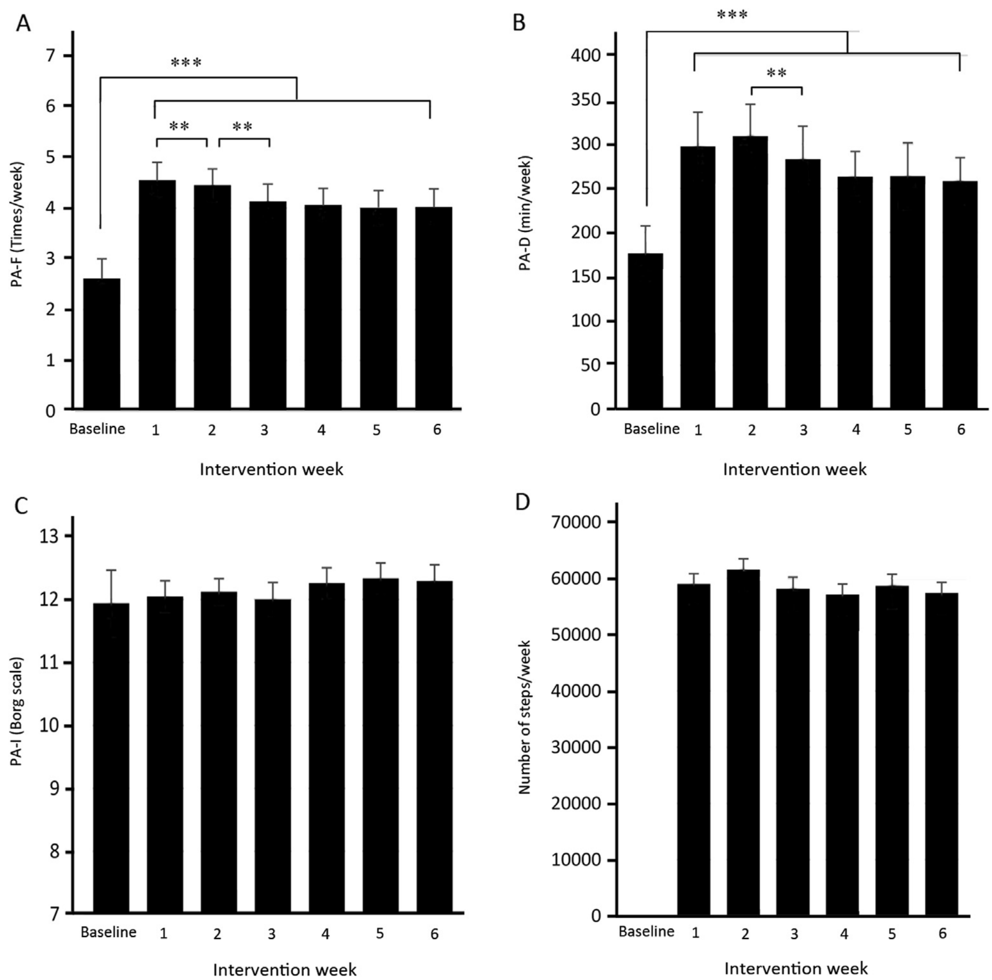

Fig. 1. Mean ± SE for the exercise log items: (A) frequency of physical activity (PA-F), (B) duration of physical activity (PA-D), (C) intensity of physical activity (PA-I), and (D) number of steps starting from baseline over 6 weeks of intervention. $^{**}p < 0.01$, $^{***}p < 0.001$.

a statistically significant difference for PA-F ($F(6, 384) = 7.4$, $p < 0.001$, $eta^2 = 0.10$) and PA-D ($F(6, 390) = 4.2$, $p < 0.001$, $eta^2 = 0.06$). The *post-hoc* analysis revealed that PA-F increased from baseline to each intervention week (all $p < 0.001$) and decreased from first to second intervention week as well as from second to third intervention week (both $p < 0.01$). For the PA-D, the *post-hoc* analysis revealed an increase from baseline to each intervention week (all $p < 0.001$) and a decrease from second to third intervention week ($p < 0.01$). No statistically significant differences were found for PA-I ($F(6, 246) = 0.3$, $p = 0.96$) and number of steps over the 6 weeks of intervention ($F(5, 450) = 1.8$, $p = 0.12$).

Fig. 2 shows the course of ROS, SOL, WASO-N, and WASO-T from the baseline week over 6 weeks of intervention. The ANOVA showed a statistically significant difference ($p < 0.05$) for ROS ($F(6, 528) = 6.5$, $p < 0.001$, $eta^2 = 0.07$), WASO-N ($F(6, 492) = 2.3$, $p = 0.04$, $eta^2 = 0.03$), and WASO-T ($F(6, 456) = 4.1$, $p < 0.001$, $eta^2 = 0.05$). The *post-hoc* analysis revealed that ROS and WASO-T decreased from baseline to each intervention week ($p < 0.001$ and $p < 0.01$, respectively). Decrease for WASO-N was statistically significant different starting from the second intervention week compared to baseline ($p < 0.01$). No statistically significant differences were found for SOL ($F(6, 510) = 1.3$, $p = 0.28$) and for TST (not depicted) over the 6 weeks of intervention ($F(6, 522) = 0.4$, $p = 0.88$).

3.3. Participants evaluations

Fig. 3 shows the estimated contributions from the participants ($n = 98$) of the component PA respectively sleep education to the observed effects on subjective sleep quality. 53.6% of the participants share the opinion that their improvements in sleep quality can be explained by the component physical exercise and respectively 71.1% by the component sleep education (only ratings of 3 = somewhat to 5 = extremely were included).

4. Discussion

The results of the study indicate that PA has an independent effect on the improvement of subjective sleep quality in this combined sleep program. In line with the previous analysis, the diary data also reflect the effectiveness of the intervention program.[16] Finally, about 50% of the

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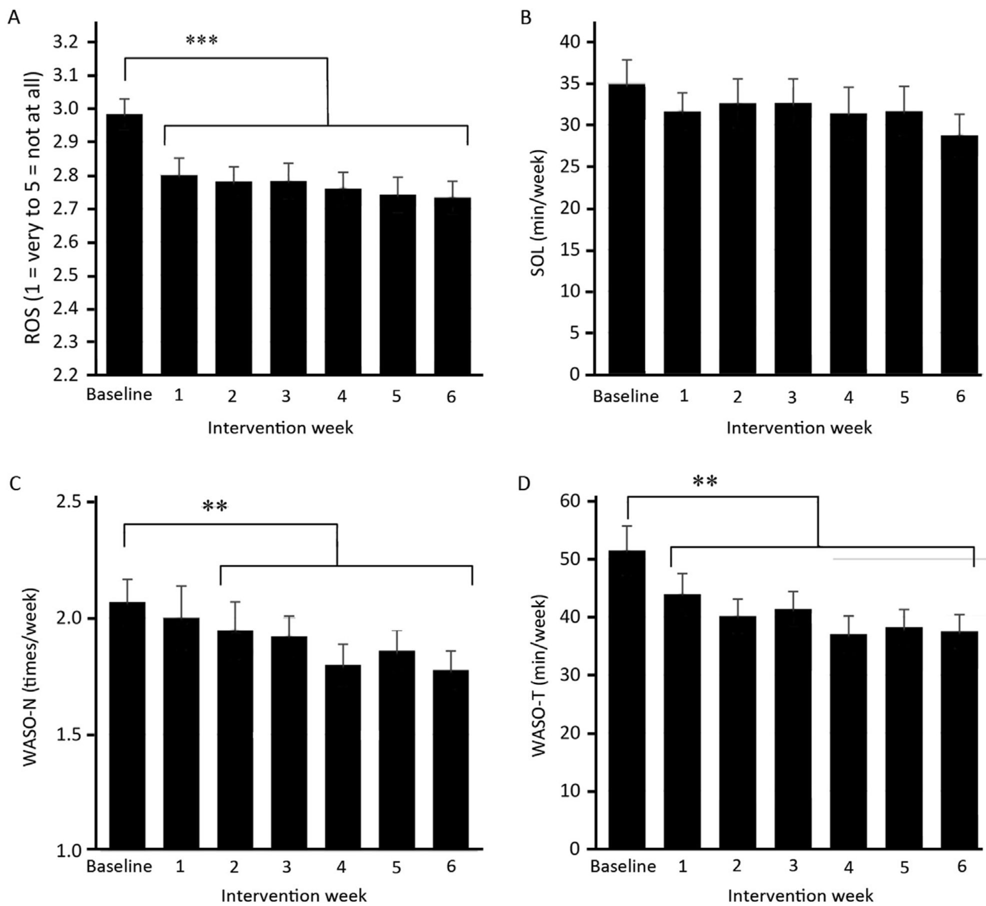

Fig. 2. Mean ± SE for the sleep log items: (A) recuperation of sleep (ROS), (B) sleep onset latency (SOL), (C) number of awakenings after sleep onset (WASO-N), and (D) wake time after sleep onset time (WASO-T) starting from baseline over the 6 weeks of intervention. $**p < 0.01$, $***p < 0.001$.

participants stated that physical exercise had an effect on their improvement, even though the cognitive component was more important to them.

4.1. Effect of exercise on sleep quality improvement

The first linear regression analysis showed that the number of steps was related to the improvement in PSQI global score; in contrast, the second linear regression analysis showed that the PA-D was linked to the better scores in sleep quality measured by the sleep questionnaire B. Because we controlled for possible confounders (e.g., age, gender, and previous sport activity level), PA in this combined sleep program has an independent effect on the improvement of subjective sleep quality. The different results for number of steps and PA-D might be explained by the different questionnaires and the different weighting of quantitative and qualitative aspects of sleep: whereas the SQ comprises questions related to sleep quantity (e.g., sleep latency) and items about sleep quality (e.g., deep, undisturbed); the PSQI summarizes seven subscales with focus on sleep quantity (e.g., sleep duration) but also sleep disturbances and daytime drowsiness and only one question on sleep quality. However, future research is needed to establish these differences in the findings.

We geared our PA intervention on current recommendations for adults and older adults with at least 150 min per week of moderate-intensity aerobic physical exercise.[15] There are clinical trials in which exercise volume rise above the national

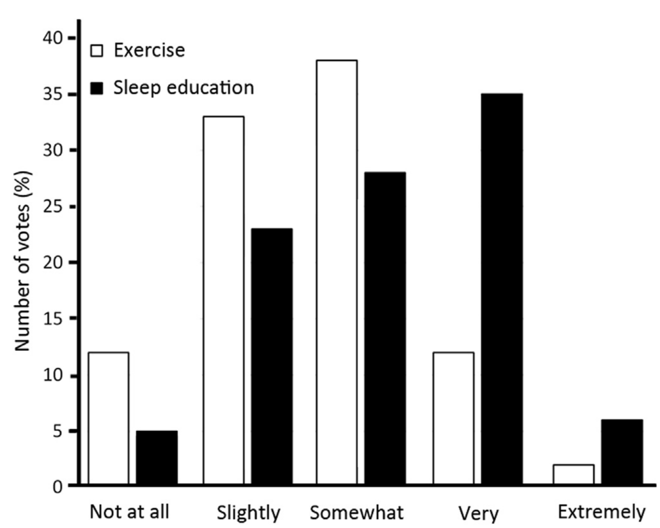

Fig. 3. Participants estimated contributions of the component exercise respectively sleep education on the observed effects on subjective sleep quality ($n = 98$).

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recommendations showing greater sleep improvements.[25] The mean PA-D per week of our participants were 282 min of moderate-intensity. Looking at the results of the second regression analyses the suggested dose–response effect of the predictor PA-D on sleep quality can be confirmed.[17] On the other side, the participant took on average 8382 steps per week which is below the recommended 10,000 steps a day,[26] however, the first regression analyses also suggested a dose–response effect to general daily activity. It seems plausible that sedentary people have more benefit on their sleep after joining an exercise event than active people do.[27] The participants of our study had a normal PA level at baseline. Therefore, it can be assumed that PA of longer duration, above the national recommendations, is needed for this activity level to improve in sleep quality, but also the higher general activity during the day reveals sleep-promoting effects. Furthermore, the Baecke sport index from baseline did not correspond to improvements in sleep quality and therefore the program seems to be effective for both unfit and fit participants.

In general, the regression analysis did not show any correspondence to the intensity of PA. Even though, the recommendations to the participants to be physically active on a moderate intensity level, there was a range from 7 to 17 in individual data of perceived exertion on the Borg scale. The previous research is ambiguous about whether the dose–response effect is due to increased doses of exercise intensity, duration, or both.[17] At least from our analysis we can conclude that the intensity might be of less importance than the duration of PA. Buman and King[17] suggested that a minimum of 16 weeks of intervention would be needed along with exercise doses that meet or exceed current PA recommendations to answer this question satisfactorily. In our study with an intervention time of 6 weeks we achieved an average 3.1 point reduction in the PSQI global score[16] which is comparable to the findings of King et al.[28] with an average reduction of 3.3 after a 16-week moderate endurance exercise intervention.

As Youngstedt[8] mentioned, an important, but overlooked, consideration in assessing treatment efficacy may be ceiling and floor effects, which dictate that the greater the initial impairment in sleep, the greater the potential for improvement. In the regression analyses severity of sleep symptoms at baseline (PSQI and SF-B) are one of the predictors for the changes in sleep quality. Therefore, it can be assumed that the higher the sleep severity symptoms the more steps and exercise of longer duration has to be done to get improvements in sleep. With respect to PA-F, PA-D, and PA-I but also the length of the treatment, additional research is needed in this area to formally test dose–response effects for chronic exercise on sleep.

4.2. Week-to-week changes

The second aim of the study was to display the week-to-week variability of sleep quality and PA starting from a baseline week over the 6-week intervention period. Our data showed as expected an increase of PA due to the intervention program: PA-F increased from 2.6 times in the baseline week to an average of 4.2 times during the weeks of intervention, PA-D augmented from 176 min in the baseline week to 279 min during the weeks of intervention. In contrast, PA-I showed a slight but statistically not significant increase from 11.9 to 12.3 over time. This was probably due to the general recommendations given to the participants to exercise at a moderate intensity level. On the other side, it is interesting to see that a systematic increase can be found, emphasizing that the physical intervention might had some effect on the cardiorespiratory system.

During the intervention period of 6 weeks participants had an stable average step amount per week ranging from 57,126 to 61,559 which classifies them into "somewhat active" which is below the recommended 10,000 steps a day.[26] Unfortunately, we do not have data for total steps at baseline and therefore we do not know if there was an increase in the number of steps.

With respect to the sleep diary data, the course of sleep diary scores also showed the expected steady improvements of the sleep quality over the intervention period. For ROS the highest improvement was in the first week of the intervention. This effect might have several explanations: on one side, the higher amount of exercise due to the intervention (especially in the first week) lead to the better sleep quality scores, alternatively, the expectations of the participants on the study program improved the ROS, e.g., Constantino et al.[29] showed that treatment expectations had an impact on the outcome of a cognitive-behavioral therapy for insomnia patient. Furthermore, Gerber and colleagues[30] were able to show that the exercise-sleep relation was mediated by cognitive-emotional processes. Despite that, after baseline no further statistically significant difference was found, on a descriptive level a trend for enhanced ROS scores could be identified.

For the descriptive data, a similar trend can be found for SOL, though, the repeated measures ANOVA did not show any statistically significant difference. The reduction of 6 min in SOL from baseline to the last intervention week is, however, comparable to other studies applying moderate aerobic exercise training in a 6-month intervention.

Regarding WASO-N, the participants had statistically significant fewer awakenings starting from the second intervention week compared to baseline. Further, at the end of the intervention they spent 14 min less time awake in bed at night (WASO-T) as before the intervention. With a TST of 379 min at baseline participants are in a normal range within chronic sleep sufferers in this age group.[27,31] TST did not change over the intervention period; however, this result is similar to the effects reported in other exercise studies based on subjective and polysomnographic data.[31]

4.3. Evaluation of the program

The last aim of the study was to present the estimated contributions of the physical exercise and sleep education components by the participants. This subjective view evaluates the study program from the participants' point of view. Results showed that participants judged the cognitive component of the program to be most helpful. The finding

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that sleep education changes dysfunctional beliefs and attitudes was shown and discussed by Morin, Blais, and Savard.[32] However, about 50% of the participants estimated that the physical exercise intervention had also an effect on their sleep quality. This finding might reflect the results on the sleep-promoting effect by exercise from the study by Urponen et al.[1] However, this is an open question for further studies to detangle the effect based on beliefs from the real exercise effects.

4.4. Explanation of the sleep-promoting effects

Amongst health benefits of PA, the idea to use exercise as a treatment method in sleep impaired people appears to come from different theories about the function of sleep, e.g., thermoregulatory, body restoration, or energy conservation.[17] For example, the restorative theory predicts that a correspondence between energy expenditure and more intense sleep (e.g., more slow wave sleep) or longer sleep duration in order to recover.[33] Another theory was provided by Dattilo et al.,[34] the authors hypothesized a decreased activity of protein synthesis pathways and an increased activity of degradation pathways under sleep debt conditions, e.g., damage to the muscles due to exercise requires restoration. Muscle recovery is strongly regulated by the anabolic and catabolic hormones and these hormones are influenced by sleep. Beyond this, exercise is associated with the increased synthesis and release of both neurotransmitters and neurotrophic factors which might mediate sleep from neurophysiological side (e.g., better mental health).[30,35,36] However, up to now, the influence of exercise on physiological as well as on psychological processes is poorly understood and therefore the impact of PA on sleep might be more complex.[37] For example, bright light exposure during outdoor sport has an impact on hormone regulation (e.g., melatonin) and might also have had a positive effect on the sleep-wake circadian rhythm.[38] Furthermore, sleep may be promoted via its anxiolytic or antidepressant effects. The participants in the study by Singh and colleagues[39] diagnosed with depression reported a decrease in depressive symptoms and sleep symptoms after 10 weeks of high-intensity progressive resistance training. Finally, because in some studies and also in this study sleep was assessed with questionnaires and therefore the psychological, but not the physiologic part of sleep. In this context, one might question to what extent subjective sleep and subjective PA might be biased by a common emotional-cognitive process.[40]

4.5. Limitations

The present study has several notable limitations. Our sample was recruited via advertisements in local print media. Participation was not limited to persons with primary insomnia symptoms, but to persons with sleep problems who suffered from either coexistent physical or psychological disorders or hypnotic medication consumption were also included. Therefore the participants covered a non-clinical self-selected sample, which was motivated to participate in the program. Consequently, controlled group exercise intervention trials in patients with different medical or psychiatric histories and impaired sleep should be carried out in future studies.

Furthermore, our sample was heterogeneous in different aspects: based on the baseline mean of 178 min duration of PA and total score of Baecke questionnaire included participants were of normal fitness level, however, the high standard deviation also points out that the sample covers fit and unfit persons. Based on BMI classification of the World Health Organization, participants were classified into normal weight but were close to the borderline of being overweight. Because fitness level[41] and BMI[42] are possible confounders or mediators in sleep we controlled for those variables in our statistical analysis. However, the fitness level and BMI should be included in future studies as independent variable to see whether exercise shows different sleep-promoting effects for fit or unfit and/or for normal or overweighed persons.

The study relied on self-report data, except the pedometer data. From a methodological point of view, the mixed results from the studies so far might be explained by the different assessment of PA and sleep, e.g., the measure of PA ranged from not validated questionnaire items to objectively measures by pedometers and from subjective sleep data (thus assessing the psychological, but not the physiologic part of sleep) to sleep measures via actigraphy or sleep-EEG.

Missing data especially for the baseline week could have been avoided by a preliminary meeting to clarify possible problems with the written informed consent about exercise log and sleep log. Further, we are aware of the missing pedometer data for the baseline week, but we decided to not hand out the pedometer at baseline because of possible motivational effects on PA which might have increased the habitual daily activity amount of the participants.[43] Two further aspects are the kind of sport and the time of day in which exercise is carried out. In our study the focus was on endurance sport (e.g., Nordic walking), however, there is also evidence for improved sleep due to resistance training.[44] It would be interesting to contrast endurance and strength training in an intervention study to see what kind of sport shows better results. Furthermore, in our study the time of day for performing exercise was monitored on the protocol, but because of underrepresentation of morning exercise no statistical analysis was assessed. Therefore from our study no conclusion can be drawn at which time of day exercise should be performed, nevertheless, Passos et al.[31] showed that sleep promoting effects did not vary between morning and late-afternoon exercise.

Our findings on sleep are mainly based on subjective estimates which may not correspond with objective measures.[45] Thus it might be interesting to record also objective measures of sleep by polysomnography or ambulant sleep recording devices (e.g., actigraph). However, for the participants' point of view the subjective sleep data are most important and therefore the present findings are quite important by itself.

4.6. Future directions

While the original paper reported about the efficacy of a combined program that included physical exercise and sleep education on subjective sleep quality on daytime mood, and quality of life in adults with sleep complaints, the present paper focused on the question whether the observed effects on self-rated sleep can be attributed by the PA component *per se*.

The results of this combined intervention showed in the main analysis clinically relevant sleep changes with effect sizes which were comparable to CBT interventions.[16] Furthermore, improvements achieved at the end of the intervention were well maintained over time and even 3 months after the treatment. The analysis in this study showed important influence of the physical exercise component of the intervention. Therefore, this study can be added to the series of positive findings for the beneficial effects of exercise on sleep. This is important because regular PA shows further well-known benefits including improved physical function, a general healthier lifestyle,[46] reduced risk of falls[47] as well as social benefits.[48] On the other side, physical inactivity is one of the risk factors in the development of diseases. Moreover, insufficient sleep is more common in less active and sick people.[49] Research indicates that PA might be a promising component in the management of chronic sleep complaints.

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