Effects of a 12-month lifestyle intervention on sleep among children with overweight

Lærke Ulrikke Jeppesen, 10100, kandidat idræt 4. semester

Department of health science and technology, Aalborg University, Selma Lagerløfs vej 249, Aalborg, Denmark

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Abstract

Purpose: Childhood overweight is an increasing global and national issue in Denmark and is associated with an elevated risk of health problems. In Denmark, TCOCT is used as a treatment method for children with overweight, but its effect on sleep parameters remains unclear. The aim of the present study is therefore to examine whether a 12-month lifestyle intervention alone, and in combination with a 3-month HIIT program, has effects on sleep parameters.

Methods: This study uses data from a randomized controlled trial including 173 children with overweight. The children were divided into two groups: one received only the 12-month lifestyle intervention, while the other received the same intervention combined with 3 months of HIIT training. Sleep parameters were collected using a thigh-worn accelerometer worn for 7 consecutive days at baseline, 3-month, and 12-month follow-up.

Results: The results of the present study showed no significant changes in sleep parameters over the 12-month period, except for TST, which significantly decreased from baseline to 3 months. No significant differences were found between the group receiving only the lifestyle intervention and the group that additionally received 3 months of HIIT training. For SPT and SE, girls scored significantly higher than boys, and girls also went to bed significantly earlier than boys.

Conclusion: A 12-month lifestyle intervention had no significant effects on sleep parameters after 12 months. However, TST significantly decreased from baseline to 3 months. The lack of change over time suggests that participants were able to maintain their sleep parameters throughout the intervention. Furthermore, no differences in sleep parameters were found between those who received the lifestyle intervention alone and those who also received HIIT. Finally, it can be concluded that girls had significantly higher SPT and SE and went to bed earlier than boys.

Keywords: training, obese, adolescents, sleep measurement

Preface

This article was written during the period from January to June 2025 as the final project of the Master of Science in Sports Science at Aalborg University. The project uses data collected during a randomized controlled trial, led by Charlotte Eggertsen. The Axivity data were processed by Jan Brønd, who also generated the sleep parameter data using a machine learning-based algorithm he developed.

I was responsible for sorting the dataset and conducting the statistical analyses that form the basis of the results presented. This work has provided me with valuable insight into data handling and analysis within health-related research.

I would like to extend my sincere thanks to my supervisor, Ryan Godsk, for academic guidance, support, and constructive feedback throughout the process. I also wish to thank Charlotte Eggertsen for providing access to the data and Jan Brønd for technical support and generation of the sleep parameter data.

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Resume

Formål: Børn med overvægt er et stigende problem globalt og i Danmark, og øger risikoen for at få helbredsmæssige problemer. I Danmark benyttes TCOCT som behandlingsmetode for børn med overvægt, men om denne behandlingsmetode egentlig har en effekt på søvnparametre, vides ikke. Nærværende studies formål er derfor at undersøge om en 12 måneders livsstilsintervention alene og i kombination med 3 måneders HIIT-træning har effekter på søvnparametre

Metode: Nærværende studie bruger data fra et randomiseret kontrolleret forsøg, hvor der er data fra 173 børn med overvægt. Børnene med overvægt inddeles i 2 grupper, hvor den ene kun gennemgår 12 måneders livsstilsintervention, og den anden får udover 12 måneders livsstilsintervention også 3 måneders HIIT-træning. Data på søvnparametrene blev indsamlet via et accelerometer, der var placeret på låret over 7 dage ved baseline, 3 og 12 måneders follow-up.

Resultater: Resultaterne fra nærværende studie viste, at der ingen signifikante ændringer var over 12 måneder og kun for TST var der et signifikant fald fra baseline til 3 måneder. Der var ingen signifikante forskelle mellem den gruppe der kun fik livsstilsintervention og den gruppe der yderligere fik 3 måneders HIIT-træning. For SPT og SE blev der fundet at piger scorer signifikant højere end drenge og at piger går tidligere i seng end drenge.

Konklusion: En 12 måneders livsstilsintervention havde ikke nogen effekter på søvnparametrene efter 12 måneder. Dog faldt TST signifikant fra baseline til 3 måneder. Det at der ikke ses nogle ændringer over tid betyder at deltagerne var i stand til at bibeholde søvnparametrene over 12 måneder. Derudover var der ingen forskelle på søvnparametrene mellem gruppen der gennemgik 12 måneders livsstilsintervention hverken alene eller i kombination med 3 måneders HIIT-træning. Ydermere kan det konkluderes at piger har en signifikant højere SPT, SE og går signifikant tidligere i seng end drenge.

Introduction

Overweight and obesity are affecting a growing number of people worldwide. Since 1990, the number of adults living with obesity has more than doubled, while the prevalence among adolescents has quadrupled. In 2022, 2.5 billion adults were classified as overweight, including 890 million living with obesity. Among children under the age of five, 37 million were overweight, and among those aged 5 to 19 years, more than 390 million were overweight, of whom 160 million were living with obesity (World Health Organization, 2024). These numbers are expected to rise. According to a report by Lobstein and Brinsen, an estimated 254 million children worldwide will have obesity by 2030, which is an increase of 60.76% since 2020, and in Denmark, it is projected that 86.079 children aged 5–19 years will have obesity by 2030 (Lobstein & Brinsten, 2019).

The increasing prevalence of overweight and obesity is a major concern due to its numerous negative consequences. Overweight among children is associated with an increased risk of type 2 diabetes and hypertension, and childhood overweight often leads to overweight in adulthood, which can result in cardiovascular diseases, stroke, and certain types of cancer (Branca et al., 2007; Chung et al., 2018). Furthermore, there is some evidence indicating that overweight has a negative impact on sleep. Several studies indicate that children with overweight have an increased risk of sleep apnea (Chay et al., 2000; Verhulst et al., 2008). In addition, these children tend to have shorter sleep duration, take longer to fall asleep, and generally experience more disturbed sleep compared to their normal-weight peers (Beebe et al., 2007; Jarrin et al., 2013; Redline et al., 1998). Insufficient sleep is associated with a range of negative outcomes, including poorer academic performance, a heightened risk of anxiety and depressive symptoms, and challenges in emotional and behavioral regulation (Beebe, 2006; Fallone et al., 2002; Paruthi et al., 2016). Moreover, inadequate sleep also negatively affects quality of life, as even a reduction of just 39 minutes of sleep per night over one week was found to significantly reduce quality of life (Taylor et al., 2023).

Among children with obesity, lifestyle interventions focusing on food intake and physical activity have been frequently used (Liu, R. et al., 2024; Reinehr, 2013; Vlaev et al., 2021). Physical activity has been shown to have a positive effect on health-related problems and quality of life among children with obesity. Regarding health benefits, aerobic exercise has a positive effect on glucose metabolism, reduces body fat (García-Hermoso, Antonio et al., 2014; Kelley & Kelley, 2013) and lowers resting blood pressure (García-Hermoso, A. et al., 2013), which may help prevent type 2 diabetes (Marson et al., 2016). High-intensity interval training and moderate-intensity exercise have been shown to reduce blood lipids, decrease body fat, and improve cardiovascular fitness, with moderate-intensity exercise leading to the greatest improvement in cardiovascular fitness (Fisher et al., 2015). Studies also conclude that physical activity contributes to a reduction in body fat and enhances quality of life in children with obesity (Aguilar-Cordero et al., 2021; Knöpfli et al., 2008). Furthermore, a study by Petty et al. found that aerobic exercise is effective in reducing depressive symptoms and increasing self-esteem in children with obesity (Petty et al., 2009).

However, the extent to which physical activity has a positive effect on sleep among children with obesity remains limited. A study by Ekstedt et al. found that high levels of physical activity during the day improved sleep efficiency the following night in normal-weight children aged 6–10 years (Ekstedt et al., 2013). Sleep efficiency is a measure of the ratio between the time from going to bed to waking up (sleep period time) and this time with any awakenings subtracted (total sleep time), expressed as a percentage. Additionally, a study by Brand et al. compared athletes to controls with an average age of 17.2 years and found that athletes with increased physical activity reported longer and better sleep (Brand et al., 2010). However, a conflicting study by Pesonen et al. found that higher levels of physical activity during the day led to shorter sleep duration and poorer sleep efficiency the following night in normal weight 8-year-old children (Pesonen et al., 2011). However, one study has examined children with obesity (Mendelson et al., 2016). This study included 20 children with obesity and 20 children with normal weight, with an average age of 14.5 years. The children participated in a 12-week supervised exercise program, where the results showed that children with obesity increased their total sleep time by +64.4 minutes and their sleep efficiency by +7.6% after training.

In Denmark, in addition to focusing on diet and physical activity, there is also an emphasis on sleep recommendations in lifestyle interventions for children and adolescents with obesity. The TCOCT model is used in Denmark as a treatment method for children with obesity, addressing multiple aspects of daily life, including recommendations on diet, physical activity, sleep patterns, and psychosocial factors (Holm et al., 2011; Mollerup et al., 2017). However, whether there are effects on sleep parameters when using the TCOCT model has not been investigated, and whether sleep recommendations alone are sufficient to produce an effect remains unclear. Evidence from the systematic review by Vlaev et al. indicates that it is still uncertain whether sleep is an effective component of a lifestyle intervention or a standalone intervention for overweight or obesity in children aged 5–17 years (Vlaev et al., 2021). This review includes eight studies, of which only one reports improvements in sleep, emphasizing that sleep recommendations alone are not enough to induce behavioural changes related to sleep. Several studies suggest that increased sleep leads to reduced calorie intake, weight reduction (Hart et al., 2013), and positive effects on children's BMI, nutrition, and physical activity levels (Yoong et al., 2016). Since children with overweight tend to have poorer sleep, it is important to determine whether exercise can further improve sleep quality. If exercise proves to enhance sleep quality, it could contribute to a positive cycle where better sleep supports weight regulation, energy levels, and overall well-being. Additionally, understanding this relationship could help optimize treatment strategies, such as the TCOCT model, by integrating targeted recommendations for physical activity to improve both sleep and weight loss in children with overweight. Therefore, the aim of this study is to examine whether a 12-month lifestyle intervention alone, and in combination with a 3-month HIIT program, has effects on sleep parameters in children with overweight. The hypothesis that children and adolescents receiving HIIT in addition to TCOCT would experience greater improvements in the sleep parameters sleep period time, total sleep time, sleep efficiency, time in bed, and time out of bed compared to TCOCT alone will be investigated.

Method

Study design

This study used data from a controlled randomized study by Eggertsen et al. (Eggertsen et al., 2024). The study included 173 children with overweight (BMI z-score > 1), consisting of 60 girls and 84 boys aged 9–16 years. For children with overweight, exclusion criteria included physical limitations (e.g., bone fractures, heart or lung disease, or metabolic disorders) or mental illness, as they needed to be able to participate in a 3-month HIIT intervention.

In the study by Eggertsen et al., the participants with overweight were divided into two groups: one group underwent a 12-month lifestyle intervention (n=83), while the other group participated in the same 12-month lifestyle intervention along with a 3-month HIIT intervention (n=90). There was a continuous enrollment of participants, and therefore participants started the intervention in different months (see table 1). Measurements were conducted at baseline, at the 3-month follow-up, and at the 12-month follow-up. At these three time points, participants were required to wear an accelerometer placed on the thigh with permeable adhesive for seven consecutive days. Sleep elements were detected from the accelerometer data using an algorithm. The algorithm, developed by Associate Professor Jan

Brønd, is based on machine learning and uses data such as temperature and rotational angle. In addition, height and weight were recorded at baseline, 3 months, and 12 months to determine BMI z-score, which indicates how much a child's BMI deviates from the average BMI of children of the same age and sex. Eggertsen et al. found a decrease in BMI z-score from baseline to 12 months of 0.20 SD (Eggertsen et al., 2024).

Table 1: The table indicates the timing of participants' baseline measurements.

Table 1

	Participant enrollments
January	10
February	26
March	14
April	1
May	0
June	0
July	0
August	11
September	20
October	26
November	4
December	12

Data collection and processing

Data were collected using the Axivity AX3 accelerometer (Axivity, Newcastle, UK), which weighs 11g and measures movement in three dimensions (see figure 1). A requirement was set that data had to be available from at least three weekdays and one weekend day before inclusion in the data processing. A valid day required the accelerometer to be worn for at least 10 hours of waking time, with a maximum of 2 hours where it was not placed on the thigh (Eggertsen et al., 2024). This requirement was established to provide a more accurate representation of sleep parameters over a full week, ensuring data from at least four days, including one weekend day.

Figure 1: The Axivity AX3 accelerometer, which participants were required to wear on their thigh for seven days to collect data.

Using an algorithm, the following sleep parameters were derived from the accelerometer data: sleep period time (SPT) and total sleep time (TST), both measured in hours; sleep efficiency (SE), measured as a percentage; and the times for going to bed (In Bed) and waking up (Out Bed). SPT is the duration between bedtime and wake-up time, TST is SPT minus any wake periods, and SE is calculated as (TST/SPT) * 100.

To conduct statistical analyses, the bedtime and wake-up time values were converted from hours:minutes:seconds to total hours, and mean values for all five sleep parameters were calculated for each participant. Additionally, statistical tests included information on sex (boy/girl) and which group the participants were allocated to.

Statistical analysis

All statistical tests were conducted in SPSS (IBM SPSS Statistics 28.0.1.1). To test whether the data were normally distributed, a Shapiro-Wilk test was conducted for all mean values of the sleep parameters (SPT, TST, SE, In Bed, and Out Bed). A p-value above 0.05 ($p > 0.05$) indicates that the data are normally distributed. Additionally, normality was assessed using histograms and Q-Q plots, examining whether the data followed the expected distribution. Several of the results from the Shapiro-Wilk tests showed a Sig-value below 0.05, indicating non-normally distributed data. However, based on histograms and Q-Q plots, the data roughly followed the expected distribution and were assessed to be approximately normally distributed. ANOVA tests were used, as they are highly robust to non-normally distributed data.

To examine whether a 12-month exercise intervention affects multiple sleep parameters in children with overweight, both immediately after the HIIT intervention and at a 12-month follow-up, a mixed model ANOVA was conducted, including participants who had data from all three measurement time points. Additionally, two mixed effects model ANOVAs were performed: one model including participants with only one measurement time point and another model including data from participants who had at least two measurement time points. For the mixed model ANOVA, the five sleep parameters were the dependent variables, while group and sex were fixed factors, and time (baseline, 3 months, and 12 months) was the repeated measures factor. For the mixed effects model ANOVA, the five sleep parameters were again the dependent variables, with group, sex, and time as fixed factors. In total, five mixed model ANOVA tests and ten mixed effects model ANOVAs were conducted. In this article, the results from the mixed effects model ANOVA, where the requirement is a minimum of two measurements, will be presented, while the remaining results will be described in the appendix.

In the case of a significant interaction, a pairwise comparison with bonferroni correction was applied to identify where the interaction occurred. Likewise, pairwise comparisons with bonferroni correction were used if there was a main effect of time. The significance level was set at an alpha value of $\alpha = 0.05$.

Furthermore, to investigate whether there was an association between BMI z-score and the five sleep parameters, regression analyses were conducted. The regression analyses were conducted based on the difference between baseline and 12-month data. The significance level was set at an alpha value of $\alpha=0.05$.

Results

Based on the requirement of a minimum of 3 weekdays and 1 weekend day for each participant, a total of 124 participants with overweight were included in the analysis. In the analysis, there was an average of 6.77 days of data at baseline, 6.81 days at 3 months and 6.78 days at 12 months.

Table 2: The table illustrates the baseline characteristics of the participants, with values presented as mean ± standard deviation.

Table 2

	Lifestyle intervention		HIIT	
	Boys (n=31)	Girls (n=24)	Boys (n=41)	Girls (n=28)
Age (years)	12.7 ± 1.8	11.7 ± 1.8	12.0 ± 1.8	12.0 ± 1.5
Weight (kg)	73.6 ± 18.9	57.9 ± 11.6	73.2 ± 20.9	68.7 ± 16.9
BMI z-score	2.4 ± 0.5	2.1 ± 0.4	2.7 ± 0.6	2.4 ± 0.6

The values for age, weight, and BMI z-score are presented as mean (±SD).

The results from the mixed effects model ANOVA, where the requirement is that there are two measurements, will be described in the following sections for each sleep parameter.

Sleep period time

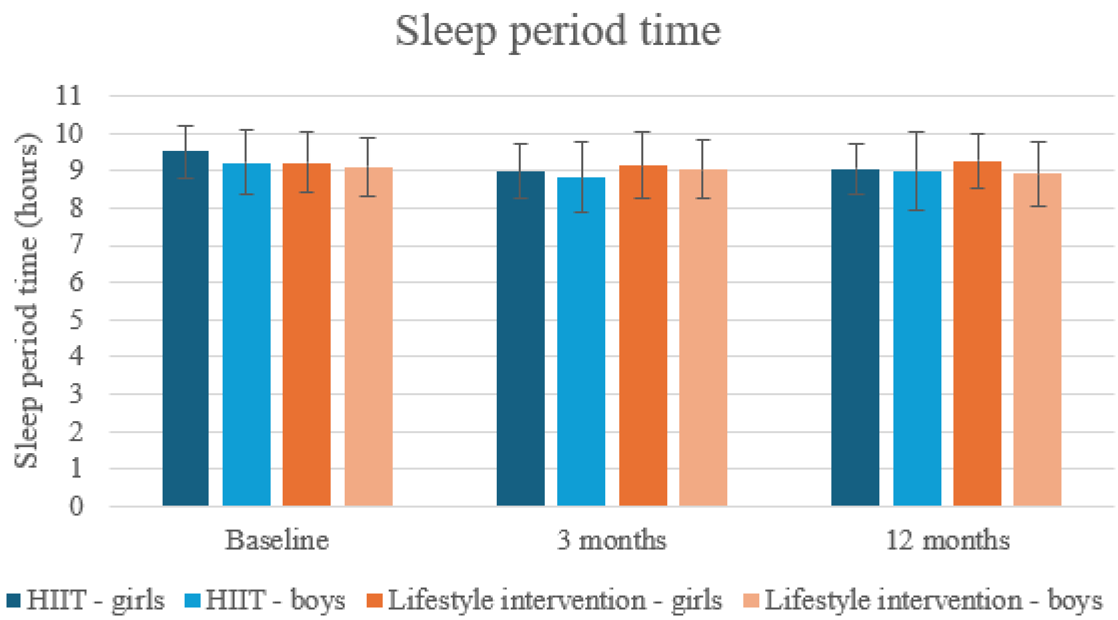

Figure 2: Mean values for SPT in hours for girls and boys in each group at baseline, 3 months, and 12 months, with standard deviations represented by error bars. Blue bars illustrate the HIIT group and orange bars illustrate the lifestyle intervention group, where lighter shades represent boys and darker shades represent girls.

There was no statistically significant difference between the groups (HIIT = 9.09; lifestyle intervention = 9.11, $p = 0.89$), across gender (girls = 9.20; boys = 9.02, $p = 0.073$), or over time (baseline = 9.26; 3 months = 8.97; 12 months = 9.04, $p = 0.05$). No significant interactions were found ($p > 0.23$).

Total sleep time

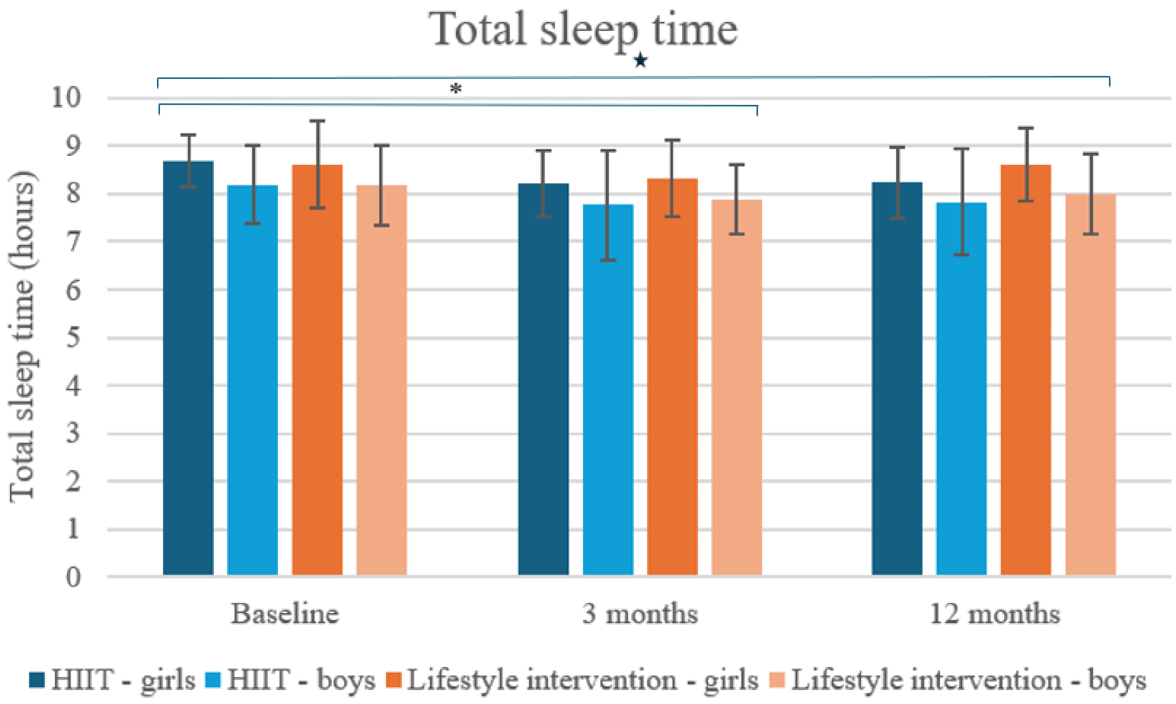

Figure 3: Mean values for TST in hours for girls and boys in each group at baseline, 3 months, and 12 months, with standard deviations represented by error bars. Blue bars illustrate the HIIT group and orange bars illustrate the lifestyle intervention group, where lighter shades represent boys and darker shades represent girls. ★ indicates a significant difference between sexes, and * indicates a significant difference over time.

There was a statistically significant difference between genders (girls = 8.44; boys = 7.97, $p < 0.001$), with TST being higher in girls than in boys. There was also a statistically significant difference over time (baseline = 8.37; 3 months = 8.00; 12 months = 8.09, $p = 0.008$). TST was lower at 3 months compared to baseline ($p = 0.007$). No significant difference was found between groups (HIIT = 8.11; lifestyle intervention = 8.23, $p = 0.23$), and no significant interactions were observed ($p > 0.49$).

Sleep efficiency

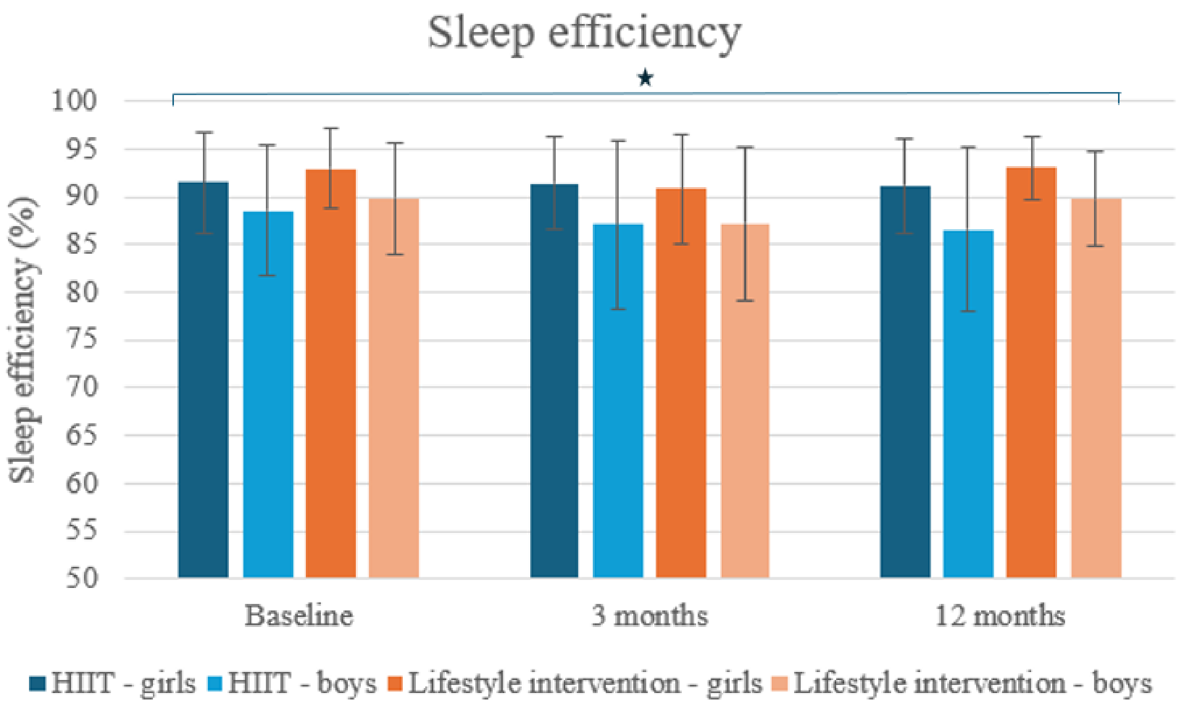

Figure 4: Mean values for SE in procent for girls and boys in each group at baseline, 3 months, and 12 months, with standard deviations represented by error bars. Blue bars illustrate the HIIT group and orange bars illustrate the lifestyle intervention group, where lighter shades represent boys and darker shades represent girls. ★ indicates a significant difference between sexes.

There was a statistically significant difference between genders (girls = 91.73; boys = 88.07, $p < 0.001$), with SE being higher in girls than in boys. There was no statistically significant difference over time (baseline = 90.36; 3 months = 88.75; 12 months = 89.41, $p = 0.2$) or between the groups (HIIT = 88.97; lifestyle intervention = 90.26, $p = 0.113$). No significant interaction was found ($p > 0.35$).

In Bed

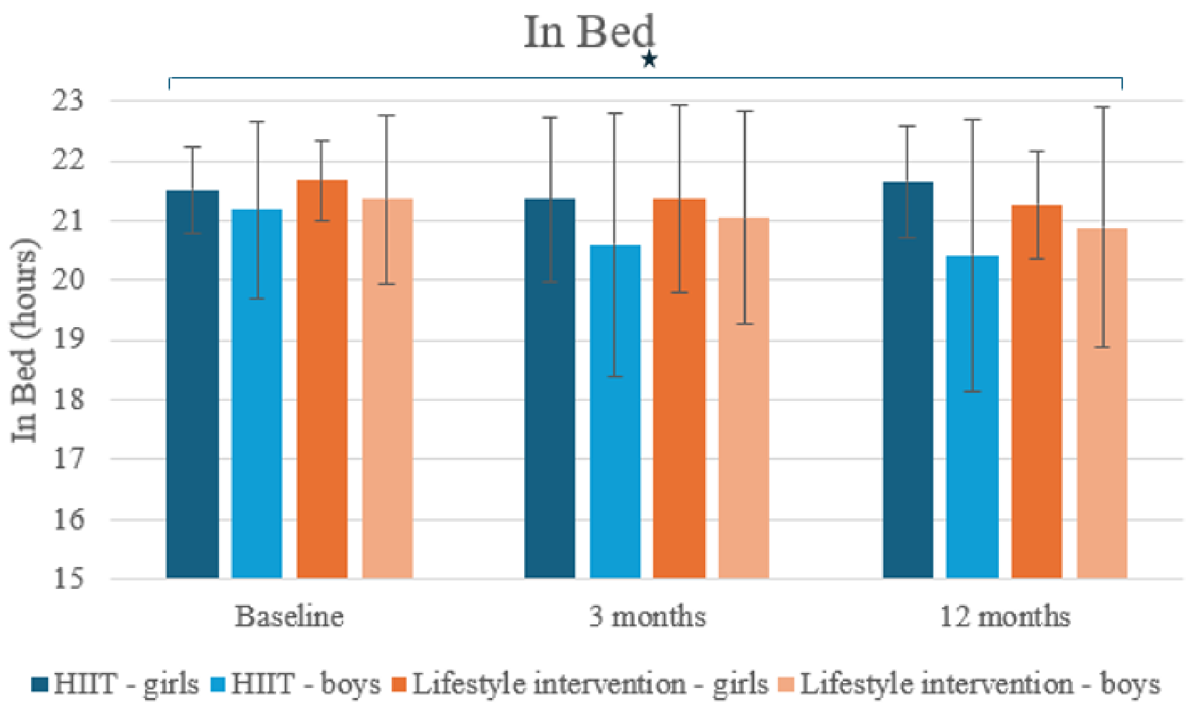

Figure 5: Mean values for In Bed in hours for girls and boys in each group at baseline, 3 months, and 12 months, with standard deviations represented by error bars. Blue bars illustrate the HIIT group and orange bars illustrate the lifestyle intervention group, where lighter shades represent boys and darker shades represent girls. ★ indicates a significant difference between sexes.

There was a statistically significant difference between genders (girls = 21.49; boys = 20.91, $p = 0.004$), with In Bed being higher in girls than in boys. There was no statistically significant difference over time (baseline = 21.40; 3 months = 21.01; 12 months = 20.96, $p = 0.19$) or between the groups (HIIT = 21.05; lifestyle intervention = 21.27, $p = 0.46$). No significant interaction was found ($p > 0.26$).

Out Bed

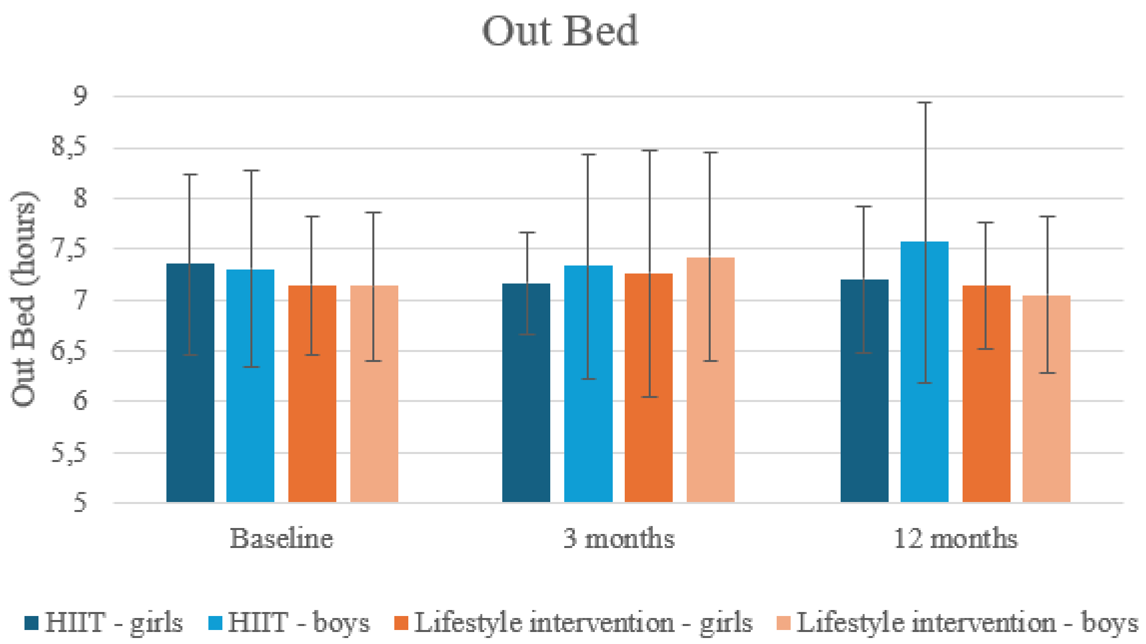

Figure 6: Mean values for Out Bed in hours for girls and boys in each group at baseline, 3 months, and 12 months, with standard deviations represented by error bars. Blue bars illustrate the HIIT group and orange bars illustrate the lifestyle intervention group, where lighter shades represent boys and darker shades represent girls.

There was no statistically significant difference between the groups (HIIT = 7.33; lifestyle intervention = 7.20, p = 0.25), across gender (girls = 7.22; boys = 7.32, p = 0.42), or over time (baseline = 7.24; 3 months = 7.30; 12 months = 7.29, p = 0.88). No significant interactions were found (p > 0.34).

Association with BMI z-score

There was no significant association between the decrease in BMI z-score from baseline to 12 months and the changes in each of the sleep parameters over the same period: SPT (p = 0.31, r = 0.12), TST (p = 0.58, r = 0.07), SE (p = 0.50, r = 0.08), InBed (p = 0.18, r = 0.16), or OutBed (p = 0.77, r = 0.04).

Discussion

Change over time

This study investigates the changes in sleep parameters that occur after 3 and 12 months of intervention in children with overweight. The results showed that TST exhibited a significant decrease from baseline to 3 months across groups. This decrease of 22.2 minutes in TST aligns well with previous literature, which indicates that sleep duration shortens during puberty (Knutson, 2005; Lucien et al., 2021). However, these previous studies were conducted on children with normal weight, which is in contrast to the present study. It may therefore suggest that the decline in sleep duration during puberty is not only observed in children with normal weight, but also in children with overweight. The reduction in TST may potentially be explained by the hormone melatonin, which declines as puberty progresses (Lucien et al., 2021). Melatonin signals to the body when it is time to sleep. Its levels increase in the evening as it gets dark and decrease again in the morning when it becomes light (Foster, 2021). However, it should be emphasized that the decline is only observed from baseline to 3 months, making it uncertain to what extent a progression in pubertal development can explain this change, as it only spans a 3-month period. The observed decrease from baseline to 3 months, but not at 12 months, may possibly be explained by the continuous enrollment of participants. A study by Mattingly et al. shows that sleep patterns vary throughout the year, finding that people wake up earlier and have shorter sleep duration in spring compared to winter (Mattingly et al., 2021). This could therefore be a possible explanation for the observed decrease from baseline to 3 months. However, as shown in table 1, participants were enrolled on a rolling basis with a wide distribution over time, which raises the question of whether seasonal variation may have influenced the present data.

For SPT and SE, there were no significant differences over time. When comparing the present study's results with those of Beebe et al., who also examined children with overweight aged between 10 and 16.9 years, it is observed that the mean values for SPT in the present study are higher for both the HIIT and lifestyle intervention groups (HIIT = 9.09, lifestyle intervention = 9.11) than the SPT reported in Beebe et al.'s study (SPT = 7.82) (Beebe et al., 2007). The same trend is observed for SE, where the mean values in the present study for both groups are higher (HIIT = 88.97, lifestyle intervention = 90.26) than the SE in Beebe et al.'s study (SE = 80.2). A study by Mendelson et al., which has a similar design, also reported lower values of SE than those observed in the present study (Mendelson et al., 2016). In the study by Mendelson et al., children with a mean age of 14.5 years completed a 12-week supervised exercise program, and the results showed that children with obesity increased their total sleep time by +64.4 minutes and their sleep efficiency by +7.6% after training. Baseline values for SE in the overweight group in the Mendelson et al. study were lower (SE = 80.4%) than in the present study (HIIT = 89.0%, lifestyle intervention = 90.3%). A possible explanation for discrepancy in absolute levels of SPT and SE between studies may be related to the method of data collection. In both the study by Beebe et al. and Mendelson, polysomnography was used to assess SPT and SE. Polysomnography requires clinical assistance and is typically conducted in a laboratory setting, which can be an unfamiliar environment for participants. Furthermore, measurements are taken over a single night, which has the disadvantage of potential night-to-night variability and may not provide a representative picture of the child's usual sleep. This may influence the collected data and result in findings that do not fully reflect natural sleep patterns. The fact that the measurements are taken in an unfamiliar sleep environment may contribute to more disturbances than usual, which could potentially result in lower values. Another possible explanation for the higher values observed in the present study compared to previous research is that the children may already have been familiar with the TCOCT model, in which sleep has become an integrated component of the treatment strategy for children with overweight. As a result, it is likely that the participants had already been introduced to sleep-related recommendations and practices prior to the start of the study. This increased focus on sleep may have led to improvements in sleep duration and sleep efficiency among children with overweight, which may help explain the values in this study are higher compared to previous studies. The fact that the baseline values in the present study are high may help explain why no change is observed over the 12-month period, as it is difficult to achieve improvement when the values are already high. It could potentially contribute to eliminating the differences previously observed between children with and without overweight (Beebe et al., 2007; Jarrin et al., 2013; Redline et al., 1998).

The lack of change in SPT over time should not necessarily be seen as a negative outcome, as it indicates that the children maintained their already high SPT. Based on the results regarding wake-up times, it appears that they wake up at approximately the same time across all three time points (hh:mm; baseline = 7:14; 3 months = 7:18; 12 months = 7:17), and a similar pattern is observed for bedtime (hh:mm; baseline = 21:24; 3 months = 21:01; 12 months = 20:58). Although the children appear to go to bed slightly earlier over time, this change was not statistically significant. The fact that the children go to bed and wake up at roughly the same times explains why no change in SPT was observed over time. The time difference in SPT from baseline (9.26) to 12 months (9.04) corresponds to a decrease of 13.2 minutes over one year. This aligns well with a study by Campbell et al., which found that sleep time among adolescents decreases by approximately 10 minutes per year (Campbell et al., 2023).

The results from Eggertsen et al. showed a decrease in BMI z-score over 12 months (Eggertsen et al., 2024), but the correlation analyses between BMI z-score and the five sleep parameters showed no significant associations. This may indicate that a decrease in BMI z-score is not necessarily related to changes in the sleep parameters, and that other factors play a greater role in weight loss. It may therefore be relevant for future studies to include additional potential explanatory factors that could help to understand the observed decrease in BMI z-score.

Group differences

The results of the present study show that there are no differences between the HIIT group and the lifestyle intervention group. There is limited literature on whether exercise has an effect on sleep parameters in children with overweight, and even among children with normal weight, the evidence remains mixed. Some studies have investigated how physical activity during the day affects sleep the following night. For example, the study by Ekstedt et al. measured physical activity in 1.231 children aged 6–10 years using an accelerometer placed on the wrist, which categorized activity into sedentary, light, and moderate-to-vigorous levels (Ekstedt et al., 2013). They found that moderate-to-vigorous physical activity led to increased SE the following night after physical activity. Another study by Brand et al. also examined the effect of physical activity on sleep the following night (Brand et al., 2010). The study by Brand et al. compared adolescent athletes with a control group of adolescents. Participants reported their exercise over a 7-day period using a self-completed log, in which they recorded the amount of exercise (in hours). The results, presented as hours over the 7 days, were: female athletes: mean = 17.09, male athletes: mean = 18.39, female controls: mean = 4.68, male controls: mean = 4.73. Sleep data were collected through questionnaires. They concluded that adolescent athletes had better sleep quality and better sleep patterns than the control group and concluded that increased physical activity led to longer and better sleep. These athletes had been training for several years, which distinguishes the study by Brand et al. from the present study, where the training period was only 3 months. Moreover, the training volume was higher among the athletes in the study by Brand et al. compared to the present study. It is therefore possible that the athletes in the study by Brand et al. had achieved more adaptations compared to the participants in the present study. However, it is important to note that the previous studies examine sleep on the night following physical activity and therefore investigate acute effects, whereas the present study investigates more long-term sleep parameters after three and twelve months. The fact that sleep is assessed the following night can be advantageous, as it provides quick feedback on how the body responds to exercise. However, this method has the limitation that there may be day-to-day variations, and one night may not be representative of overall sleep patterns. In contrast, the present study investigates effects after three and twelve months over seven days, which can help determine whether there is a lasting effect of physical activity. In contrast to the study by Brand et al, the study by Pesonen et al. reported that higher levels of physical activity during the day resulted in shorter sleep duration and poorer sleep efficiency the following night (Pesonen et al., 2011). The children were instructed to follow their normal daily routines while wearing an accelerometer on the wrist for seven days to measure physical activity. Sleep was also measured using actigraphy, and parents were asked to keep a sleep diary. The data were analyzed using regression analyses. Both the studies by Brand et al., Ekstedt et al. and Pesonen et al. did not include a structured exercise intervention, which distinguishes them from the present study.

Additionally, the referenced studies were conducted on children with normal weight, whereas the current study focuses on children with overweight. Furthermore, the present study examines sleep parameters over a longer term, rather than short-term effects as seen in previous literature. Therefore, it is debatable whether the results of the present study can be directly compared to previous findings. Based on the results from the present study, it appears that the 12-month lifestyle intervention with an additional 3-month exercise intervention did not have any further impact on the sleep parameters compared to the group that only underwent the lifestyle intervention.

Difference between genders

The results of the present study showed that girls went to bed significantly later than boys. The finding that girls went to bed significantly later than boys in the present study contrasts with a previous review by Wittert, which pointed out that later bedtimes are typically seen during adolescence, with a more pronounced effect in boys than in girls (Wittert, 2014). The study population in the review by Wittert is not overweight, and therefore it may be difficult to make direct comparisons. This suggests that among children with overweight, girls went to bed later than boys.

Furthermore, the results of the present study showed that TST was higher among girls than boys. The finding that TST was higher among girls than boys aligns well with a study by Crowley et al., who found that boys spend less time in bed than girls (Crowley et al., 2006).

The age group (9–17 years) in that study is very comparable to the present study (9–16 years). However, it is worth noting that the sample in Crowley et al.'s study consisted of children with normal weight, which distinguishes it from the present study and may suggest that this gender difference is independent of weight status, thereby contributing new knowledge to this area. In addition, self-reported bedtimes and wake-up times were used in the study by Crowley et al., and thus the results differ in terms of TST, where any awakenings have been subtracted. Given that self-reported data can be subject to bias and inaccuracies (Choi & Pak, 2005), the reliability of the results from the Crowley et al. study may be questioned, and it may be difficult to directly compare the results from Crowley et al. with those of the present study. The fact that the algorithm used in the present study allows for the subtraction of awakenings may therefore provide a more accurate picture of actual sleep duration and contribute new insights to the field.

The finding that girls in the present study had significantly longer TST compared to boys may potentially be related to differences in melatonin levels. A study by Cain et al. showed that females have higher nocturnal melatonin levels than males, which could contribute to longer sleep duration (Cain et al., 2010). However, it should be noted that this study was conducted in an age group of 18–30 years, and it is therefore uncertain whether the results can be directly applied to children and adolescents as in the present study. Another study by Molina-Carballo et al. examined sex differences in melatonin levels among children aged 6, 11, and 14 years (Molina-Carballo et al., 1996). This study found no significant differences between boys and girls when measured at 9 a.m. However, melatonin is a hormone that increases at night, and therefore it can be difficult to draw conclusions based on melatonin levels at 9 a.m., as it would be expected that the levels have decreased by the time of measurement. The study by Molina-Carballo et al. suggests that there may not be a sex-based difference in melatonin levels in younger age groups, and thus, melatonin may not fully explain the longer sleep duration observed in girls in the present study.

In addition to girls having higher TST than boys, the results also showed that SE was higher in girls. Another possible explanation for the observed gender difference may be the influence of sex-specific hormones, particularly estrogen. Estrogen helps maintain an optimal temperature during sleep because it plays a significant role in regulating body temperature. This can reduce the occurrence of hot flashes, which might otherwise disrupt sleep, as estrogen contributes to a more comfortable sleep environment (Brown & Gervais, 2020). In contrast, the male sex hormone, testosterone, has a more limited impact on sleep quality and duration, but may influence sleep timing, as higher testosterone levels are associated with later bedtimes during adolescence (Wittert, 2014). Based on these hormonal differences, this may help explain why girls in this study had significantly longer TST and higher SE compared to boys. Another hormone that could contribute to the higher TST and SE in girls is cortisol. A study by Liu shows that higher cortisol levels predicted shorter TST and lower SE (Liu, P. Y., 2024). Cortisol has been studied throughout pubertal development in a study by Keulen et al. (van Keulen et al., 2020). They found that during puberty, the activity of A-ring reductases decreases in girls compared to boys. A-ring reductases are enzymes that convert cortisol into less active metabolites and thereby decrease cortisol concentration. Furthermore, they found that there was a decrease in cortisol metabolite excretion between early and late puberty stages in girls. The reduction of cortisol in girls may therefore help explain why TST and SE are higher in girls than in boys, as increased cortisol has a negative impact on TST and SE.

However, it should be emphasized that the present study does not include any hormonal data and therefore cannot confirm or refute these possible explanations.

Perspectives

No previous studies have investigated the effects of the TCOCT protocol on sleep, and the present study addresses a new and important topic in the literature. The study found that sleep parameters were maintained after 12 months; however, it would have been interesting to include a control group that did not receive the TCOCT intervention to examine whether sleep parameters changed differently over time in children who did not receive the intervention. Understanding the effect of the TCOCT protocol is an important focus, as it may help determine whether the current treatment approach for children with overweight should be modified. Furthermore, the present study found that girls had significantly higher SPT and SE and went to bed earlier than boys. This may suggest that different areas of focus should be considered in the treatment of children with overweight, depending on whether the child is a girl or a boy.

In addition, this study used a thigh-worn accelerometer, which has not previously been used. Therefore, further research using similar measurement methods is needed in order to generalize the findings from the present study. The study also examined the sleep parameter TST, which has only been investigated to a limited extent in earlier research. Thus, the present study contributes new knowledge regarding sleep among children with overweight.

Conclusion

The present study concludes that a 12-month lifestyle intervention had no effects on sleep parameters after 12 months. However, TST significantly decreased from baseline to 3 months. The lack of changes over time suggests that participants were able to maintain their sleep parameters throughout the 12-month period. Furthermore, no differences in sleep parameters were observed between the group undergoing the 12-month lifestyle intervention alone and the group receiving it in combination with 3 months of HIIT training. Additionally, it can be concluded that girls had significantly higher SPT and SE and went to bed significantly earlier than boys.

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