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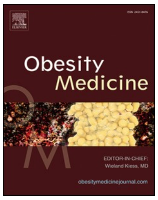

Association between sleep and weight loss in a 12-month digital lifestyle intervention

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ABSTRACT

Objectives: We studied how sleep quality and chronotype relate to weight loss in a 12-month real-world digital lifestyle intervention, the Healthy Weight Coaching.

Methods: Patients self-reported weight and waist circumference and completed a set of customized sleep-related online questionnaires at baseline, 3-, 6-, 9-, and 12-months. Primary outcomes were percent changes in weight and waist circumference, calculated from baseline to each follow-up time point. Using generalized linear regression for repeated measures, we explored associations between sleep variables (individual variables and factor analysis-derived clusters) and changes in measures of obesity across the program. Additionally, we investigated how changes in reported sleep are associated with weight loss outcomes.

Results: Baseline data included 1883 individuals (82.6 % women, median age 52 years, median BMI 39.1 kg/m^2). Reporting sleep apnoea was associated with less successful weight loss across the program [weight, B = 0.760 (95 % CI = 0.446–1.073), $p < 0.001$; waist, B = 1.275 (95 % CI = 0.780–1.771), $p < 0.001$]. *Eveningness* and *Tiredness* factors were associated with poorer weight [B = 0.206 (95 % CI = 0.027–0.385), p = 0.024 and B = 0.613 (95 % CI = 0.371–0.855), $p < 0.001$, respectively] and waist circumference [B = 0.434 (95 % CI = 0.155–0.713), p = 0.002 and B = 0.720 (95 % CI = 0.337–1.102), $p < 0.001$, respectively] reduction over the 12-month program. Increase in reported daytime alertness, over the program, was beneficial for weight loss outcomes.

Conclusions: Addressing evening chronotype and reasons for reduced daytime alertness may be associated with enhanced weight loss; however this study does not establish causality. Additional research is needed to adapt interventions for those with sleep apnoea.

Trial registration: The trial is registered at clinicaltrials.cov (Clinical Trials Identifier NCT04019249).

Abbreviations: BMI, body mass index; HWC, Healthy Weight Coaching.

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1. Introduction

Over the past decades, we have witnessed a significant global rise in the prevalence of obesity, prompting the World Health Organization to recognize it as a major public health challenge (World Health Organization, 2025). According to the recent estimates, by year 2035, 54 % of the population will live with overweight or obesity (World Obesity Federation, 2024). This presents a major public health concern, as excess body weight substantially contributes to increased morbidity and mortality (Guh et al., 2009)(Pischon et al., 2008). Although, once developed, obesity often becomes a chronic condition (World Health Organization, 2025), its treatment yields many benefits including reduced risk of type 2 diabetes, cancer, and hypertension, along with improvements in glucose metabolism, cardiovascular health, osteoarthritis, and health-related quality of life (Tahrani and Morton, 2022).

Obesity results from an imbalance between energy intake and expenditure, but many factors like sleep play a critical role in influencing an individual's ability to regulate this balance (Reutrakul and Van Cauter, 2018). Indeed, disorders of sleep and circadian rhythm are increasingly linked to metabolic dysregulation which may contribute to weight gain and obesity (Depner et al., 2014). Of note, insufficient sleep can result from a range of issues, including abnormal sleep duration, delayed sleep phase, circadian misalignment, irregular sleep-wake rhythm, and sleep apnoea (Sack et al., 2007). These disruptions compromise the body's ability to maintain a healthy sleep cycle, contributing to metabolic and weight regulation challenges.

Several prior studies have explored the associations between various aspects of sleep and intentional weight loss. Regarding sleep duration, some research has linked longer sleep, especially that exceeding 7 h, to improved weight loss outcomes (Chaput and Tremblay, 2012)(Thomson et al., 2012) while other studies have associated both long and short sleep with lower odds of achieving weight loss goals (Elder et al., 2012). In contrast, some studies have reported no evidence of sleep duration and weight loss success (Papandreou et al., 2020; O'Brien et al., 2012).

Beyond sleep duration, chronotype, the individual's circadian preference for behavioural rhythms relative to light-dark cycle (Yu et al., 2015), also plays a role in weight regulation. Evidence indicates that individuals with evening chronotypes ("eveningness") tend to have higher body weight and are less likely to succeed in weight loss compared to those with morning chronotypes ("morningness") (Ekiz Erim and Sert, 2023). However, Altree et al., observed a positive correlation between later bedtime and short-term weight loss and proposed that this association might be explained by individuals with later bedtimes having a higher baseline body mass index (BMI), which confers greater potential for weight loss (Altree et al., 2022).

Circadian misalignment, a mismatch between endogenous circadian rhythm and behaviour, is another critical factor. It has shown to reduce energy expenditure and alter the levels of appetite-regulating hormones, thereby promoting hunger and energy intake (Chaput et al., 2023). A notable example of individuals frequently experiencing circadian misalignment is those working in shifts, in whom the risk of overweight/obesity is also significantly increased (Zhao et al., 2011). Irregular sleep-wake cycles, characterized by variability in sleep duration and onset, have also been linked to a higher risk of obesity (Zuraikat et al., 2020). Finally, sleep apnoea, a condition for which obesity is a known risk factor, also contributes to disturbed sleep and may hinder weight loss efforts (Depner et al., 2014)(Gami et al., 2003)(Whited et al., 2016).

Given the growing demand for obesity management, traditional face-to-face treatment may not be available to all those in need. To improve accessibility, various online weight loss programs have been developed, demonstrating outcomes comparable to in-person interventions (Kupila et al., 2023). However, to our knowledge, the role of sleep in weight loss has not been investigated within the context of digital weight loss interventions. Therefore, we aimed to examine the associations between baseline sleep-related variables and weight loss over the 12-month real-world digital lifestyle intervention. In our primary analysis, using factor analysis-derived sleep factors, we hypothesized that baseline sleep factors characterized by high loadings for sleep apnoea, eveningness, and reduced daytime alertness would predict poorer weight loss outcomes. Furthermore, we investigated whether program participation is associated with improvements in sleep-related variables, and if such improvements are reflected in weight loss outcomes within the program.

2. Participants and methods

2.1. Intervention

Data were obtained from an ongoing real-life single arm digital lifestyle intervention, the Healthy Weight Coaching (HWC) (Suojanen et al., 2020)(Kupila et al., 2022). The program is delivered through HealthyWeightHub.fi ("Healthvillage," 2025), a non-commercial eHealth platform developed at Helsinki University Hospital. The program, funded by the patient's municipality, is available to all adult (≥18 years) Finnish citizens with a BMI ≥25 kg/m^2 upon referral by any licenced physician. Participation requires access to a computer or smartphone with an internet connection. Individuals whose health condition necessitates specialist evaluation at an obesity care centre are excluded on a case-by-case basis. The HWC emphasizes teaching coping skills, fostering healthy self-reflection and self-compassion, and supporting concrete lifestyle changes as part of a healthy, gradual weight loss process and subsequent weight maintenance.

This 12-month automated program includes weekly training sessions—each taking approximately 1 h to complete—covering a broad range of lifestyle and behavioural modification topics, including rest and recovery, diet, physical activity, and mental well-being. Of relevance to the current topic, the program includes modules focusing on the role of sleep and rest in weight management, addressing the physiological and behavioural links between sleep, appetite, and eating behaviours. Participants receive evidence-based guidance on improving sleep quality and routines, such as regular sleep schedules, sleep-promoting evening snacks, physical activity recommendations, and relaxation practices, and are encouraged to monitor and address their own sleep habits as part of the program's behavioural change strategies. This comprehensive integration of sleep as a modifiable target is reinforced throughout the intervention, with repeated emphasis in multiple sessions.

In addition to the structured program, each participant is assigned a personal coach, either a nurse, nutritionist, physiotherapist, or psychologist, who supports them throughout the program. Coach assignment takes into account the participant's individual needs and preferences (for example, explicitly requesting support in physical activity or dietary guidance), as well as coach availability. Importantly, all coaches participated in extensive training in behavioural therapy, and the coaching was delivered according to a standardized protocol designed to ensure consistency across participants. This standardized approach helps maintain uniformity in the content and structure of support, regardless of coach background. Moreover, although each participant had one designated coach, the coaches worked collaboratively and consulted one another when needed. This interdisciplinary approach ensured high-quality, coherent support across different coaching domains.

The Ethics Committee of Helsinki and Uusimaa Hospital District approved the study protocol (327/13/03/00/2015, GDPR update 587/2019), and all participants provided web-based written informed consent for the use of their data in research. The data collection schedule, as relevant to the current paper, including variables, their time points, and collection methods, is presented in Supplementary Table 1.

2.2. *Participants*

For the current analyses, we considered data from all consenting patients enrolled in the program between October 2016 and September 2020 who completed a 2-week trial period. Participants were excluded if they self-reportedly used other weight loss methods, at any point of the 12-month program, beyond the HWC program or if they did not respond to any sleep-related questions. Information on participants' age and sex was obtained from a national register.

2.3. *Weight-related variables*

At baseline, patients reported their height, weight, and waist circumference on an internet-based questionnaire. Patients were instructed to conduct the weight measurements using domestic scales in the morning immediately after using the restroom. For height, patients reported their previously recorded height, but if they were unsure, they were instructed to conduct the measurement standing barefoot straight against a wall. Waist circumference was to be measured at the narrowest point between the ribs and hips using a flexible, non-stretchable tape measure available at home, with a visual aid provided to guide correct placement. Due to the nature of the study as a fully digital, real-life intervention, all data were self-reported, and there was no physical contact with participants, nor any materials (e.g., tape measures or scales) provided by the research team. Following baseline, patients were encouraged to report their weight at least on a weekly basis. Self-reported weights were interpolated at 3, 6, 9, and 12 months. From these data, we calculated BMI (kg/m^2) and percentage of weight change from baseline at 3, 6, 9, and 12 months. Waist circumference was reported online every three months, and percentage change in waist circumference was similarly calculated.

2.4. *Sleep-related variables*

The sleep-related questions (Supplementary Table 1) were designed to assess key aspects of sleep quality, including sleep quantity, sleep regularity, sleep apnoea, circadian preference, and daytime fatigue. To improve response rates, most items were presented using a dichotomous (yes/no) response format. The questions were adapted from established sleep questionnaires (Horne and Ostberg, 1976; Paavonen et al., 2016; Partinen and Gislason, 1995).

Sleep duration. At baseline, 3, 6, 9, and 12 months, patients reported their habitual times of falling asleep and waking up separately for weekdays and weekends. From these reports, we calculated the weighted average daily sleep duration in hours [(weekday sleep duration x 5) + (weekend sleep duration x 2)/7]. Individuals were classified into three groups based on sleep duration: less than 7 h, 7–9 h, and more than 9 h, with the 7–9 h category serving as a reference group in multivariable analyses.

Sleep apnoea. Sleep apnoea was self-reported (yes/no) on a digital questionnaire at baseline and 12 months.

Shift work. At baseline, using free text format, patients reported whether they worked in shifts. For the current analyses, shift work was defined as any type of shift schedule, including two-shift work, three-shift work, or predominantly night work.

Daytime alertness. At baseline, 3, 6, 9, and 12 months, patients reported their level of daytime alertness on a 4-level scale (1, always tired; 2, tired most of the time; 3, occasionally tired; 4, alert). Over the program, a score ranging from 1 to 4 was calculated from these responses to assess changes in the reported levels of alertness, with a higher score indicating greater alertness.

Statements about regularity of the sleep and chronotype. At baseline, 3, 6, 9, and 12 months, patients were presented with six statements related to the sleep and circadian rhythm: "I have a regular sleep rhythm", "I have an irregular sleep rhythm", "I am an evening person", "I am not an evening person", "I am an early bird", and "I am a late riser". For each statement, patients responded with "yes" or "no". These responses were used as dichotomised variables in the analyses.

2.5. *Statistical analyses*

The basic characteristics are reported as frequencies and percentages for categorical variables, and as medians (interquartile ranges) for continuous variables with skewed distributions. To compare those included and excluded from the analyses, we used the Chi-squared test for categorical variables (e.g., sex) and the Mann-Whitney *U* test for continuous variables (e.g., weight, BMI, and waist circumference).

To assess changes over time in the sleep-related variables, we modeled the data with time (baseline, 3, 6, 9, 12 months) as a within-subject factor. Continuous variables (sleep duration and daytime alertness) were analysed using repeated measures ANOVA, while dichotomous variables (sleep apnoea, regular/irregular sleep rhythm, morning/evening type) were analysed using Generalized Estimating Equations with a binomial distribution and logit link function. Estimated marginal means were calculated for continuous variables at each time point, and percentages of "yes" responses were calculated for dichotomous variables.

Exploratory factor analysis (maximum likelihood and varimax rotation) was used to identify distinct factors from the sleep variables (sleep duration, sleep apnoea, shift work, daytime alertness, regular sleep rhythm, irregular sleep rhythm, evening person, not an evening person, early bird, and late riser). An eigenvalue >1.0 was used as the cutoff for factor selection. Factor scores, calculated using the regression method, represent the sum of all items multiplied by their corresponding factor loadings and were used as continuous variables in the analyses. The analyses with these factor analysis-derived sleep factors as predictors and weight loss (percentage weight change and percentage waist circumference change) as an outcome form the primary analysis. All secondary outcomes were considered exploratory, thus no correction for multiple testing was performed.

A generalized linear model for repeated measures was used to study the independent associations between sleep-related variables (predictors) and outcome variables with multiple observations over the program (i.e., weight loss percentage and percentage of waist circumference change at 3, 6, 9, and 12 months). For participants who did not complete the 12-month program, all available weight measurements (at 3, 6, 9, and/or 12 months) were included in the repeated measures analyses, allowing the use of partial data from these participants. All multivariable models were adjusted for age and sex. Models with relative weight change and relative waist circumference change as outcomes were additionally adjusted for baseline BMI and waist circumference, respectively, while models with individual sleep variables as independent variables were additionally adjusted for sleep duration. In the sensitivity analyses, we controlled for 1) age and sex (sleep duration classes and sleep factors as predictors), 2) age, sex, and baseline measures of obesity (individual sleep variables as predictors), and 3) age, sex, and sleep duration (independent sleep variables as predictors).

All analyses were conducted with IBM SPSS Statistics version 29.0.2.0 (IBM Corp., Armonk, NY, USA), with a significance level set at $p < 0.05$.

3. Results

3.1. Study population

Altogether 2157 individuals were enrolled in the HWC program between October 2016 and September 2020. Of these, 182 individuals using other weight loss methods and 92 individuals who did not respond to any sleep-related questions were excluded from the analyses (Supplementary Fig. 1). Those included (n = 1883, 87.3 %) and excluded had comparable median age (52 and 53 years, respectively, $p = 0.627$), sex distribution (82.6 % vs. 81.4 % women, respectively, $p = 0.610$), and waist circumference (118 vs. 120 cm, respectively, $p = 0.148$) (Supplementary Table 2). However, participants included in the analyses had a lower baseline weight (111 vs. 114 kg, $p = 0.025$) and BMI (39.1 vs. 40.2 kg/m^2, $p = 0.001$) compared to those excluded. In total, 1204 (63.9 %) of the study

Table 1
Baseline characteristics of the 1883 participants.

Continuous variables	Median (interquartile range)	Range
Age, years	52 (42–59)	21–81
Weight, kg	111 (98–126)	60–284
Body mass index, kg/m^2	39.1 (35.3–43.6)	26.5–78.7
Waist circumference, cm	118 (109–129)	83–180
Waist circumference men, cm	130 (122–140)	95–180
Waist circumference women, cm	116 (108–125)	83–180
Sleep duration, h	8.1 (7.6–8.8)	3.5–14.1
Categorical variables	**n**	**%**
Women	1556	82.6
Sleep apnoea	663	36.2
Shift work	64	4.0
Daytime alertness		
Always tired	101	5.8
Tired most of the time	360	20.6
Occasionally tired	1040	59.4
Alert	250	14.3
Regularity of sleep rhythm		
Regular sleep rhythm	864	49.3
Irregular sleep rhythm	685	39.1
Chronotype		
Evening person	797	45.5
Not an evening person	360	20.5
Early bird	490	28.0
Late riser	611	34.9

population completed the program. On average, participants completed 23 weekly sessions. Mean (standard error) weight loss percentages at 3, 6, 9, and 12 months were −1.9 (0.1), −2.8 (0.1), −3.5 (0.2), and −4.7 (0.3), respectively.

3.2. Baseline sleep-related variables

3.2.1. Individual sleep variables

The median reported sleep duration was 8.1 h, ranging from 3.5 h to 14.1 h (Table 1). In all 663 (36.2 %) patients reported sleep apnoea, 64 (4.0 %) reported shift work, 864 (49.3 %) reported a regular sleep rhythm, 797 (45.5 %) identified as evening persons, and 490 (28.0 %) identified as early birds.

3.2.2. Factor analysis-derived sleep patterns

In the exploratory factor analysis, four distinct sleep factors were formed (Table 2). The first factor had an eigenvalue of 2.45 and exhibited high loadings (absolute values) for irregular sleep rhythm (0.922) and regular sleep rhythm (−0.770) and was subsequently named *Irregular Sleep*. The second factor (eigenvalue 1.50) showed high loadings for late riser (0.816) and evening person (0.463) and was named *Eveningness*. The third factor (eigenvalue 1.14) was characterized by not an evening person (0.721) and early bird (0.413) and was named *Morningness*. Finally, the fourth factor (eigenvalue 1.01) had the highest loadings for daytime alertness (−0.549) and sleep apnoea (0.208) and was named *Tiredness*.

3.3. Baseline sleep-related variables and weight loss

3.3.1. Individual sleep variables and relative weight change

Compared to individuals reporting 7–9 h of sleep, those sleeping less than 7 h experienced poorer weight loss across the follow-up timepoints, after adjustments for age, sex, and baseline BMI (Table 3). This result remained when baseline BMI was removed from the model (Supplementary Table 3). When adjusted for age, sex, baseline BMI, and sleep duration, sleep apnoea and being a late riser were both associated with less successful weight loss, whereas higher daytime alertness and being an early bird predicted greater weight loss throughout the program. With the exception of being an early bird, as predictor, which no longer showed significant association with weight loss when model was not adjusted for baseline BMI, these associations remained statistically significant in sensitivity analyses (Supplementary Table 3). Furthermore, in sensitivity analysis excluding sleep duration, irregular sleep rhythm was associated with greater weight loss. Changes observed in the regularity of the sleep likely contribute to these findings (see chapter 3.4., below).

3.3.2. Individual sleep variables and relative waist circumference change

Adjusted for age, sex, and baseline waist circumference, sleeping more than 9 h was associated with a smaller reduction in waist circumference compared to sleeping 7–9 h (Table 3). This observation was attenuated when baseline waist circumference was excluded from the model (Supplementary Table 3). Similarly, in the full models, sleep apnoea and being a late riser were associated with lower success, whereas higher alertness levels, and being an early bird were associated with better success across the program duration (Table 3). All but daytime alertness as predictor, in a model that excluded baseline waist circumference, remained statistically significant (Supplementary Table 3). In sensitivity analysis excluding sleep duration, being classified as an evening person was associated with a slightly greater reduction in waist circumference. However, the effect size was small ($\beta = -0.054$), suggesting that this finding may have limited clinical relevance. Moreover, changes in the reported eveningness could contribute to this observation (see chapter 3.4., below).

Table 2
Exploratory factor analysis-derived sleep factors and sleep variables' factor loadings in each of the factors.

Eigenvalue (% of variance)	Factor 1	Factor 2	Factor 3	Factor 4
	2.45 (24.5)	1.50 (15.0)	1.14 (11.4)	1.01 (10.1)
Factor name	Irregular Sleep	Eveningness	Morningness	Tiredness
Sleep variable				
Irregular sleep rhythm	**0.922**	0.099	−0.040	0.000
Regular sleep rhythm	**−0.770**	0.005	0.139	−0.076
Late riser	0.123	**0.816**	−0.042	0.114
Evening person	0.179	**0.463**	−0.456	−0.061
Not an evening person	−0.069	−0.091	**0.721**	0.050
Early bird	−0.091	−0.442	**0.413**	−0.135
Daytime alertness	−0.253	−0.148	−0.055	**−0.549**
Sleep apnoea	−0.009	0.004	−0.009	**0.208**
Sleep duration	−0.056	0.108	−0.065	−0.053
Shift work	0.069	0.039	−0.012	−0.087

Factor analysis (Maximum likelihood and varimax rotation). For Factor 4, the factor loadings shown in this table and the factor scores used in the analyses, were multiplied by −1 to reflect "Tiredness".

Table 3
Associations between baseline sleep variables and weight change percentage and waist circumference change percentage over the 12-month Healthy Weight Coaching program.

	Weight change percentage	Waist circumference change percentage
	B (95 % Wald Confidence interval), p	B (95 % Wald Confidence interval), p
Individual sleep variables		
Sleep duration, classes		
<7 h	**0.556 (0.081–1.031), 0.022**	−0.166 (−0.916 – 0.583), 0.663
7–9 h	Reference group	Reference group
>9 h	0.311 (−0.068 – 0.690), 0.108	**0.772 (0.161–1.384), 0.013**
Sleep apnoea, 1 = yes	**0.760 (0.446–1.073), <0.001**	**1.275 (0.780–1.771), <0.001**
Daytime alertness[a]	**−0.398 (-0.600 – -0.196), <0.001**	**−0.331 (-0.650 – -0.012), 0.042**
Regular sleep rhythm, 1 = yes	−0.200 (−0.489 – 0.088), 0.173	−0.104 (−0.557 – 0.350), 0.654
Irregular sleep rhythm, 1 = yes	−0.170 (−0.471 – 0.131), 0.268	−0.017 (−0.493 – 0.459), 0.943
Evening person, 1 = yes	−0.037 (−0.332 – 0.258), 0.805	−0.070 (−0.536 – 0.396), 0.770
Not an evening person, 1 = yes	−0.060 (−0.408 – 0.289), 0.738	−0.176 (−0.698 – 0.347), 0.510
Early bird, 1 = yes	**−0.370 (-0.697 – -0.044), 0.026**	**−0.840 (-1.342 – -0.338), 0.001**
Late riser, 1 = yes	**0.583 (0.269–0.898), <0.001**	**1.076 (0.583–1.569), <0.001**
Sleep factors		
Irregular Sleep	−0.056 (−0.211–0.098), 0.476	−0.029 (−0.270–0.212), 0.814
Eveningness	**0.206 (0.027–0.385), 0.024**	**0.434 (0.155–0.713), 0.002**
Morningness	−0.006 (−0.189–0.177), 0.947	−0.011 (−0.289–0.266), 0.935
Tiredness	**0.613 (0.371–0.855), <0.001**	**0.720 (0.337–1.102), <0.001**

Generalized linear model for repeated measures. All analyses are adjusted for age and sex. The analyses with individual sleep-related variables (excluding sleep duration classes) were additionally adjusted for sleep duration and the analyses with factor-analyses derived sleep factors simultaneously included all sleep factors. The analyses with weight change percentage and waist circumference change percentage, as outcomes, were additionally adjusted for baseline BMI and baseline waist circumference, respectively. [a]Coded as 1, always tired; 2, tired most of the time; 3, occasionally tired; 4, alert.

3.3.3. Factor analysis-derived sleep patterns and weight loss

In two separate generalized linear regression models for repeated measures, adjusted for age, sex, and baseline measure of obesity, higher scores on the *Eveningness* and *Tiredness* factors were associated with less successful weight [B = 0.206 (95 % CI = 0.027–0.385), p = 0.024 and B = 0.613 (95 % CI = 0.371–0.855), p < 0.001, respectively] and waist circumference reduction [B = 0.434 (95 % CI = 0.155–0.713), p = 0.002 and B = 0.720 (95 % CI = 0.337–1.102), p < 0.001, respectively] over the 12-month program (Table 3). In the sensitivity analyses excluding baseline measures of obesity, the results remained statistically significant, except for the association between Eveningness and weight loss (Supplementary Table 3). For this analysis, the direction of the association remained consistent, although the association was attenuated (p = 0.070).

3.4. Changes in sleep variables over the program and weight loss outcomes

While no change in the mean sleep duration was observed over the 12-month program, there was a statistically significant increase in the reported level of daytime alertness (from a mean score of 2.9/4.0 to 3.1/4.0) (Supplementary Table 4). Moreover, the proportion of individuals reporting a regular sleep rhythm increased from 49.3 % to 61.1 %, while reports of irregular sleep rhythm (39.1 %–24.0 %), being an evening person (45.5 %–37.1 %), and being a late riser (34.9 %–23.7 %) decreased (all, p < 0.001 reflecting improvements across the 5 time points). Adjusted for age, sex, baseline sleep duration, and baseline BMI (for weight loss analysis) and baseline waist circumference (for waist circumference change analysis), an increase in reported daytime alertness was associated with greater weight loss [B = −0.558 (95 % CI = −0.844–−0.273), p < 0.001] and reduction in waist circumference [B = −0.462 (95 % CI = −0.867–−0.056), p = 0.026] across the program. Moreover, shifting from being a late riser to not being one was associated with reduced waist circumference [B = −0.870 (95 % CI = −1.519–−0.230), p = 0.008]. In the sensitivity analyses, adjusted for age, sex, and baseline measure of obesity, but no sleep duration, increase in daytime alertness remained significantly associated with both weight loss [B = −0.637 (95 % CI = −0.900–−0.373), p < 0.001] and waist circumference reduction [B = −0.465 (95 % CI = −0.843–−0.088), p = 0.016]. When adjusted for age, sex, and sleep duration, both increase in daytime alertness [weight loss, B = −0.594 (95 % CI = −0.882–−0.306), p < 0.001; waist circumference change, B = −0.626 (95 % CI = −1.035–−0.216), p = 0.003] and change from the late riser status [waist circumference change B = −0.709 (95 % CI = −1.361–−0.058), p = 0.033] remained significant.

4. Discussion

In this study of a large cohort of individuals participating in a digital lifestyle intervention, short (<7 h) and long (>9 h) sleep durations were associated with less successful reductions in weight and waist circumference, respectively, compared to sleeping for 7–9 h. Additionally, sleep apnoea and evening chronotype emerged as key factors associated with less successful weight loss over the 12-month program. Instead, morning chronotype and daytime alertness were associated with greater weight loss outcomes. Over the program, we observed beneficial changes in the reported sleep, including increased daytime alertness, greater sleep rhythm regularity, and reduced reports of eveningness and late riser tendencies, albeit all of which may not be of clinical significance. Notably, increased levels of alertness were associated with better weight loss, while increase in morningness associated with greater reduction in waist circumference. These results emphasize the potential of the HWC program to positively influence sleep behaviour alongside weight loss, although their reciprocal relationship makes it challenging to disentangle causal relationships, with improvements in one likely reinforcing the other.

Previous studies on sleep duration and weight loss have yielded mixed results. A recent large study among participants in the PREDIMED-Plus trial reported no significant difference in 12-month weight loss success between those with shorter (<6 h) and longer (7–9 h) sleep durations, although reduction in waist circumference was somewhat greater among those with longer sleeping (Papandreou et al., 2020). Similarly, in a 6-month behavioural weight loss intervention involving 316 women, no association between sleep duration or time in bed and weight loss outcomes were evident (O'Brien et al., 2012). In contrast, some studies have found longer sleep duration to predict greater adipose tissue loss (Chaput and Tremblay, 2012), or increased likelihood of weight loss (Thomson et al., 2012), while others, such as Elder et al., reported that participants with either short (≤6 h) or long (>8 h) sleep durations were less likely to meet the weight loss goals as compared to those with sleep durations within the intermediate range (Elder et al., 2012). The observations made in the current study align most closely with those of Elder et al., as individuals reporting less than 7 h of sleep and those reporting more than 9 h of sleep experienced reduced success in losing weight and waist circumference, respectively, compared to those sleeping 7–9 h.

Obesity is a well-established contributor to obstructive sleep apnoea, and weight loss can significantly alleviate its severity (Peppard, 2000). Research has shown that sleep apnoea can itself make weight loss more difficult. For example, in one study, men with sleep apnoea who participated in a lifestyle intervention lost less weight and achieved fewer metabolic improvements compared to men without sleep apnoea (Borel et al., 2012). Similarly, in another study, individuals at high risk for sleep apnoea lost less weight after a dietary counselling intervention than those at low risk (Whited et al., 2016). Yet in another behavioural weight loss intervention, participants with sleep apnoea lost, on average, 2.2 % less weight than those without (Kline et al., 2018). Given existing evidence and the knowledge that sleep apnoea, through sleep fragmentation and deprivation, may predispose individuals to further weight gain and worsening obesity (Gami et al., 2003), we hypothesized that sleep apnoea would impede weight loss in the current study. Our analyses confirmed that sleep apnoea was indeed linked to less successful weight loss during the intervention. Furthermore, in the factor analysis, sleep apnoea loaded positively on the *Tiredness* factor, which also exhibited a high negative loading with daytime alertness. This factor, indicative of poor sleep quality, was associated with poorer weight loss results, lending support to our hypothesis. Of interest, adding continuous positive airway pressure (CPAP) therapy to weight loss strategies does not appear to provide additional benefits for weight reduction compared to weight loss intervention alone and CPAP therapy by itself does not lead to significant weight loss (Chirinos et al., 2014), suggesting that interventions targeting sleep quality, duration, and circadian alignment may be needed to optimize weight loss outcomes in individuals with sleep apnoea.

Our observation that an evening chronotype is linked to less favorable weight loss outcomes aligns with existing literature. Research indicates that individuals with an evening chronotype tend to have higher BMI and are less likely to follow healthy diets (Ekiz Erim and Sert, 2023). Later sleep timing, captured by a later sleep midpoint, also predicts less successful weight control, as in behavioural weight loss interventions later sleep timing has been associated with weight regain (McNeil et al., 2019) and with blunted weight loss (Kline et al., 2021). While energy and macronutrient intakes may be comparable between the chronotypes, evening types tend to consume most of their energy later in the day (Van Der Merwe et al., 2022). For individuals trying to lose weight, this could be an important challenge, as later eating is well documented to hinder weight loss success (Dashti et al., 2021). Furthermore, in addition to showing that lower sleep efficacy, more awakenings, and higher sleep onset latency were associated with blunted weight loss, Creasy et al. showed that later wake times, characteristic of evening chronotypes, were associated with reduced likelihood of meeting physical activity recommendations (Creasy et al., 2022), potentially adding further challenges to successful weight loss.

In addition to chronic fatigue hindering adherence to the lifestyle changes essential for weight loss, as seen with the increased energy intake in association with disturbed sleeping (Papatriantafyllou et al., 2022), several other mechanisms have been proposed to explain the connection between sleep and weight regulation. For instance, short sleep and sleep deprivation have been linked to elevated circulating ghrelin concentrations and changes in leptin levels, thereby impairing hunger and satiety signals (Lin et al., 2020). Sleep loss also acts as a stressor on the hypothalamic-pituitary-adrenal axis, influencing cortisol secretion and metabolic regulation (Lin et al., 2020). Consistent with hormonal changes, individuals subjected to sleep restriction often report increased hunger and cravings for energy-dense, carbohydrate-rich foods (Spiegel et al., 2004). Beyond hormonal imbalances, sleep deprivation may also trigger alterations in inflammatory responses. During normal sleep the numbers of IL-12 molecules are increased, while those of IL-10 are decreased (Lange, 2006). Conversely, after a night of sleep deprivation, monocyte production of IL-6 and tumour necrosis factor α is increased compared to measurements taken after uninterrupted sleep (Irwin, 2006). These findings suggest that sleep deprivation may contribute to inflammation, potentially linking sleep disturbances with inflammatory conditions like obesity. Nedeltcheva et al. (2010) further demonstrated that sleep restriction alters the metabolic effects of weight loss. In their crossover study, participants experienced similar total weight loss under both sleep conditions, but lost less adipose tissue and showed less favourable substrate utilization when sleep was restricted to 5.5 h versus 8.5 h.

Among the strengths of this study is a large, prospective dataset collected from a nationwide, real-world digital weight loss program. The diverse sample, spanning a broad range of ages and BMIs, enhances the generalizability of the results. However, as the majority of participants were women, caution is needed when extending these results to men. A notable methodological strength is the use of exploratory factor analysis to derive underlying constructs. Given the often high correlations between sleep variables (e.g., eveningness and morningness; irregular and regular sleep patterns; sleep apnoea and daytime alertness), factor analysis allowed us to reduce multicollinearity and distil complex, interrelated dimensions into core factors. This approach may reveal deeper relationships between sleep and weight loss that could be overlooked when analysing individual variables in isolation. However, the study relies on self-reported data, which may introduce inaccuracies, particularly for sensitive measures like sleep time and weight. Additionally, the absence of objective measurements of sleep apnoea and the duration and quality of sleep, the use of unvalidated questionnaires, and the lack of data on sleep disorders other than sleep apnoea are important limitations. Moreover, the lack of data on socioeconomic status is a limitation, as socioeconomic factors can influence both sleep patterns and weight loss outcomes, potentially confounding the observed associations. Nevertheless, this study provides novel insights into sleep's role in digital, real-world health behaviour change programs, an area yet less explored. The findings may have clinical relevance for designing targeted interventions to enhance weight loss outcomes. Future studies employing objective methods to assess sleep are needed to validate our observations.

5. Conclusion

Sleep apnoea and evening chronotype were associated with reduced weight loss, while daytime alertness and morning chronotype were associated with greater weight loss in this 12-month digital lifestyle intervention. The program participation resulted in beneficial changes in sleep, including increased daytime alertness, a higher proportion of participants reporting a regular sleep rhythm, and a reduction in late-riser chronotype, with increased daytime alertness being associated with greater weight loss. Our observations suggest that addressing evening chronotype and reasons for reduced daytime alertness may enhance weight loss. Additional research is warranted to better understand how to tailor lifestyle interventions for individuals with sleep apnoea to improve weight loss outcomes.

CRediT authorship contribution statement

Aila J. Ahola: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Anu Joki:** Writing – review & editing, Data curation. **Mikko S. Venäläinen:** Writing – review & editing, Data curation. **Sakris K.E. Kupila:** Writing – review & editing. **Laura-Unnukka Suojanen:** Writing – review & editing, Project administration. **E. Juulia Paavonen:** Writing – review & editing, Methodology. **Kirsi H. Pietiläinen:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.obmed.2025.100653.

Data availability

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research, supporting data are not available.

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