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A multi-component intervention to affect physical activity, sleep length and stress levels in office workers

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ABSTRACT

Physical inactivity, insufficient sleep and prolonged high stress levels are well documented risk factors for premature death. Yet, modern lifestyle is associated with high prevalence of these risk factors. This multi-component intervention aims to enhance and support healthy behaviors in office-workers. Sixty-three participants (28 males, with a mean age of 42 years, SD 11, range: 24–68 years) were included at three workplaces. A control period (four weeks) was followed by an intervention period (eight weeks). The intervention included a personal approach to enhance physical activity, restrictions on the use of bedtime technology and the application of a wrist-worn device tracking physical activity, sleep, and stress. After the intervention period, an increase of aerobic capacity was observed with 2.05 mL/kg/min ($P < 0.001$). Total sleep time was unchanged while sleep onset was postponed 10 min ($P < 0.001$) in the intervention period compared to the control period. Lower stress levels based on heart rate variability were observed in the intervention period compared to the control period ($P = 0.001$). Our results suggest that a multi-component intervention can increase physical activity resulting in an improved maximal oxygen uptake in office-workers. Stress levels may decrease especially for those with an initially low VO_2max while restricting use of technology use in the bedroom has no effect on sleep length. The results suggest that increasing PA through an individual approach supported by a WTD is accompanied by noteworthy health benefits while restricting bedtime technology use has limited effect on sleep measures.

1. Introduction

Personal behavior is the single most important factor to improve health and decrease premature death (Schroeder, 2007). Physical inactivity is one of the leading behavioral causes of premature death. It is estimated that 37% of the adult population in high-income countries are insufficiently physically active (Guthold et al., 2018) and that between four and five million deaths per year could be avoided if the global population was more active ("WHO Guidelines on Physical Activity and Sedentary Behaviour," 2020). Regular physical activity (PA) contributes to preventing and managing heart disease, stroke, cancer, diabetes and hypertension ("WHO

Abbreviations: BP, blood pressure; HR, heart rate; HRV, heart rate variability; PA, physical activity; PSS, Perceived Stress Scale; TST, total sleep time; SO, sleep onset; WTD, wearable tracking device.

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Guidelines on Physical Activity and Sedentary Behaviour," 2020). In addition, physical activity is proven to enhance brain function, cognition, and psychological well-being, including decreasing job stress (Conn et al., 2009; Kramer & Erickson, 2007; Thøgersen-Ntoumani et al., 2015).

Insufficient sleep constitutes another risk behavior in modern society. Sleeping on average less than 6 or 7 h increases the risk of mortality by up to 13 and 7 per cent respectively (Hafner et al., 2017). A survey conducted by the National Sleep Foundation found that in the U.S., 21% report that they sleep less than 6 h on a typical workday, while 32% report they sleep between 6 and 7 h. Insufficient sleep can have multiple negative consequences, such as cognitive impairment, obesity, hypertension and insulin resistance (diabetes) and is associated with increased stress levels and substantial economic losses (V. Chattu, Manzar, et al., 2018; V. K. Chattu, Manzar, et al., 2018). Unfortunately, recent evidence demonstrates that the proportion of people getting less sleep than recommended is rising. This unhealthy behavior is associated with lifestyle factors related to a modern 24/7 society, such as psychosocial stress, lack of physical activity and excessive electronic media use, among others (Roenneberg, 2013).

Prolonged psychosocial stress has been shown to increase risk of premature mortality (Keller et al., 2012) and constitutes a risk factor for several conditions and diseases, including high blood pressure (Liu et al., 2017), cardiovascular disease (Kivimäki et al., 2012; Nabi et al., 2013; Rosengren et al., 2004) and depression (Rugulies et al., 2006), just as quality of life and general well-being can be negatively affected by stress (Cohen et al., 2007). Stress occurs when a person perceives the demands of an environmental stimuli to be greater than their ability to meet, mitigate, or alter those demands (Lazarus et al., 1985). According to a national survey, 25% of Danes report they suffer from high stress levels (Jensen et al., 2018). An annually national survey from US attempts to separate the prevalence of different personal stressors. Job strain has been reported as a significant source of stress by 64% of employed Americans in recent years, making work-related stress one of the most commonly mentioned personal stressors (APA, 2020).

Most health promotion focus on a single intervention. However, evidence indicates that lifestyle factors such as PA, sleep and stress are interrelated (Dolezal et al., 2017; Garde et al., 2011; Stults-Kolehmainen & Sinha, 2014). Interventions targeting multiple behaviors simultaneously might be more effective to promote healthy behaviors (Prochaska & Prochaska, 2011). The aim of this study was to enhance and support healthy behaviors in office-workers with a focus on PA, sleep and stress. Based on evidence from previous research we designed an intervention combining four components. Firstly, a personal approach to enhance PA was applied to ensure motivation for obtaining an active lifestyle. Starting and maintaining a physically active life is a great challenge for many people. A study by Gavin et al. suggests that personality should be paired with PA in order to meet inactivity challenges (Gavin, 2004). For example, an extroverted personality type may be drawn to team sports or group fitness whereas an introverted personality type complies better with activities that can be performed independently of others such as running or swimming. Thus, an individual approach inspired by Gavin et al. was implemented to ensure motivation. Secondly, restrictions on excessive bedtime technology were applied to ensure sufficient sleep. Since smartphones entered the market about a decade ago, they have become an important part of everyday life. This small computer is used everywhere and is often not switch off during nighttime. The vast majority of studies on mobile phone use and sleep have quite consistently shown adverse effects of bedtime technology use on sleep length and sleep quality (Thomée, 2018). However, the effect of bedtime technology use has mainly been investigated based on cross-sectional design with self-reported outcome measures meaning that the causality is difficult to ascertain and the results may be prone to misclassification and recall bias (Thomée, 2018). Furthermore, the majority of studies have been conducted in adolescents which compromises generalizability of the results to the population above 18 years. Thirdly, a wearable tracking device (WTD) to measure sleep, stress and PA was handed out to all participants. In recent years, there have been an exponential development of preventive initiatives using digital solutions for implementing lifestyle changes and tracking different types of health data. These devices have the opportunity to incorporate behavior change techniques to help people enhance their PA as well as other aspects of a healthy lifestyle (Mercer et al., 2016; Michie et al., 2011). Finally, the last component involved the use of a workplace setting. Workplaces present a good setting for health promotion. They have been shown to directly influence the physical, mental, economic and social well-being of employees and as a result, the health of their families (Abdin et al., 2018). Interventions at workplaces can access groups of participants in their daily lives, and provide opportunities for the individual to share health challenges and achievements with coworkers and thereby reinforce participation in interventions (Freak-Poli et al., 2020).

2. Material and methods

2.1. Participants

Participants were recruited from three office workplaces in Naestved city, Denmark. Participants were required to own and use a smartphone, and willing to enhance their PA level or for participants already exercising (the recommended 150 min/weekly or more) willing to receive and incorporate new approaches in their training. Sixty-three participants signed up for the study.

The present study was first initiated end of February 2020 but paused shortly after recruiting participants from the first workplace due to a national lockdown because of the COVID-19 pandemic. We resumed the data collection by end of August 2020 from the first workplace followed by recruitment of participants from the other two workplaces. The data collection ended in the first week of December 2020, shortly before a second lockdown of the Danish society. The incidence of COVID-19 increased during the fall 2020 which led to gradual restrictions on physical training facilities and size of participation in teams sport and group exercising during the intervention.

The primary outcome was aerobic capacity, and the minimal difference of interest was 2 O_2/kg/min. With a significance level of 0.05 (two-sided), a total number of 56 participants had to be included using a standard deviation of 4.5 O_2/kg/min to obtain a 90% power to detect the minimal difference of interest. The standard deviation was based on the difference between two measures for the same participant obtained in a feasibility study (Larsen et al., 2021). Allowing for an attrition rate of 10–15%, 62–64 participants should be included. All participants gave informed consent to the experimental procedure, which was approved by the local ethics committee (SJ-780). The study was performed in accordance with the Declaration of Helsinki.

2.2. Experimental protocol

Participants attended three test days. A baseline test day (T1) followed by four weeks of observation. A second test day (T2) followed by eight weeks of intervention and a third test day (T3) at the end of the intervention (Fig. 1). Characteristics of participants were collected from an online survey shortly before T1 and included age, gender, years of education, family status and smoking. The online survey also included four validated questionnaires:

1) The NEO Five Factor Inventory questionnaire (NEO–FFI–3) (McCrae et al., 2005). The questionnaire consists of 60 items and was used to provide a measure of the five domains of personality (neuroticism, extraversion, openness, agreeableness and conscientiousness).
2) The Nordic Physical Activity Questionnaire-short (Danquah et al., 2018). This is a 2-item questionnaire and was used to monitor moderate-to-vigorous PA (MVPA) in minutes per week.
3) The Perceived Stress Scale (PSS) (Cohen et al., 1983). The questionnaire was used to assess subjective stress levels and comprises 10 items on a five-point Likert scale. Scores range from 0 to 40, with higher composite scores indicating greater levels of perceived stress.
4) The Insomnia Severity Index (Bastien et al., 2001). This questionnaire was used to monitor degree of sleep problems and consists of 7-item on a five-point Likert-type scale, and the total score ranges from 0 to 28. A higher score suggests more severe insomnia.

At T1, the above questionnaires were used to qualify the conversation with each participant regarding their health behavior and personal choice of physical activity. The latter three questionnaires were also completed at T2 and T3 to explore changes in self-reported measures. Finally, at T3 the participants were asked to rate the challenges of complying with the intervention and report their primary motivation for completing the study.

Height was measured at T1 with a stadiometer (Leicester portable height measure Tanita HR 001). At all test days, weight, body composition and blood pressure were measured. Body composition, including body weight (kg), fat percentage, and skeletal muscle percentage were measured using the body composition monitor Tanita DC 430 SMA. The device utilizes bioelectrical impedance analysis with current going from the tips of the toes to the heels of both feet. An earlier model has been validated against the criterion method dual-energy X-ray absorptiometry (Boneva-Asiova & Boyanov, 2008). Blood pressure was measured whilst sitting using an automated oscillatory device (Omron M3) after the participant had rested for 5 min and three readings were taken. The mean arterial pressure was calculated as $MAP \cong P_{Dias} + \frac{1}{3}(P_{Sys} - P_{Dias})$ for each reading and the lowest value was used for further analysis. To estimate VO_2max, participants conducted The New Step test (Aadahl et al., 2013). This test is based on the principle that the energy cost of stepping with a known step height and pace is relatively independent of age, gender, and training status. The test starts with a stepping frequency of 0.2 steps/second which increases gradually until a maximal stepping frequency of 0.8 steps/second at 6 min. When the pace no longer can be followed, the VO_2max is estimated based on the stopping time.

At T1, each participant had a conversation with a health professional. Findings suggest that personality dimensions may be used to open a dialogue about PA choices and help individuals identify more satisfying physical activities (Gavin, 2004). Therefore, the conversation was initiated with suggestions for types of physical activities inspired by the idea of pairing personality with physical activities (based on the participants answers on e.g., openness and social preferences). Based on the suggestions, a dialogue was opened where essential elements such as practical circumstances and individual preferences also were covered. Advantages and disadvantages of different physical activities were discussed and finally, the participants were asked to prioritize those activities they found interesting and realistic. Between T1 and T2 participants were instructed to continue their usual lifestyle. They received information of

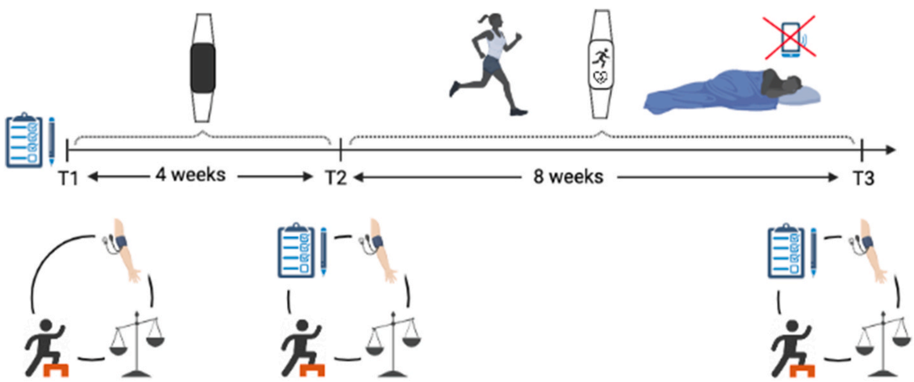

Fig. 1. Experimental protocol (Created with BioRender.com).

which of their prioritized physical activities that could be met in the intervention period. For example, a critical mass of office-workers was needed to establish a weekly session of yoga on-location following a working day. Expenses associated with participants choice of PA were covered by the project. Between T2 and T3 participants were instructed to make several actions: 1) attend their personal choice of PA and increase their PA level to a least 150 intensity minutes per week, 2) register and follow their health behavior (i.e., sleep, stress and physical activity) on a wearable tracking device (WTD) and 3) remove or switch off smartphones/TV/iPad and other electronic devices (including partners) in the bedroom. Several different technologies (such as computers, tablets, and other handheld devices) are used for the same activities as a smartphone and, therefore, use of all electronic devices were restricted. Analog alarm clocks were distributed, and participants were asked not to check their smartphone and other digital screen/devices from bedtime until they get up in the morning.

A WTD (Garmin Vivosmart 4, www.Garmin.com, CE marking) was handed out to all participants at T1. Garmin Vivosmart 4 detects movement and heart rate (HR) via an embedded triaxial accelerometer, optical photoplethysmography signals, and associated algorithms. It automatically records intensity and duration of different activity patterns and estimates active kilocalories. It also attempts to obtain an objective measurement of stress through heart rate variability (HRV) based on root mean square of successive R-R intervals (Firstbeat, 2014) and of sleep measures through a combination of accelerometer and photoplethysmography. Participants were instructed to download an application called Garmin Connect and set up a user account. One participant already used a WTD (Garmin Vivoactive 3), which the participant continued to use instead of Vivosmart 4. Participants were instructed to wear the device on their wrist for the entire period of approximately 12 weeks. During the first four weeks participants were asked to refrain from looking at their data. The screen on the WTD was customized to display only the clock. After 4 weeks of observation participants had an extended introduction to the WTD and the accompanying Garmin Connect mobile app in which they were able to follow their health behaviors (e.g., physical activity, sleep and stress).

2.3. Analyses and statistics

Baseline characteristics were presented by mean ± standard deviation (SD) or proportions (%). All data were imported to Matlab (R2017_b) for analyze. The statistical processing of data was carried out with R statistical program (Rstudio version 1.2.5033, packages: nlme, clubSandwich) and Python (Version 3.9.1, scipy 1.6.0). For analyses of the primary outcome (VO_2max), we used a linear mixed model for repeated measures over time to analyze the difference between the three test days, where time was considered a fixed effect and participant a random effect. A similar procedure was used for secondary outcomes such as weight, blood pressure and self-reported measures. Cluster-robust variance estimators were used for non-normal distributed variables. The linear mixed model prevents listwise deletion due to missing data.

Daily measures obtained with WTD included step, active kcal, resting HR, stress score, total sleep time (TST) and sleep onset (SO). A mean of each WTD measure was calculated for each participant from the control and the intervention period, respectively. The first 7 days in the control period were excluded due to a recommended calibration period. Students' t-test was used to test for differences in the normally distributed variables. Compliance of wearing the WTD was calculated for each participant based on the amount of available HR measures relative to the length of the intervention period. The HR measure was chosen as it is sampled relatively frequently (1 sample per 2 min). More than 10 min of continuous missing HR data were registered as missing data. Thus, the percentage of available HR data was used as a proxy for the percentage of time the participant wore the WTD.

Recordings from the WTD were also used to explore how stress were affected by sleep and physical activity. A mixed linear model was used with mean values of stress scores, TST and active kilocalories for each participant from the control and the intervention period, respectively. The measured VO_2max at T1 and T3 were also included presenting the control and intervention period respectively. Observations were included as a fixed factor variable while participants were included as a random factor variable. Interactions between control/intervention and the parameters were included to allow for different slopes in the control/intervention period.

Stress recordings were further explored in the control and intervention period by dividing the data into business days and weekends, where we defined weekend as Friday after 20:00 to Sunday before 20:00. Each participant's mean stress value was calculated into five-time intervals covering the day ($00{:}00 \le t < 05{:}00$, $05{:}00 \le t < 09{:}00$, $09{:}00 \le t < 16{:}00$, $16{:}00 \le t < 20{:}00$ and $20{:}00 \le t < 24{:}00$). For the statistical analysis, Wilcoxon signed-rank test was used to compare the non-normally distributions of stress. The significance level was adjusted for multiple comparisons by the Bonferroni correction.

3. Results

Participants' characteristics are shown in Table 1. Three participants withdraw during the control period. One participant changed

Table 1
Participants' baseline characteristic.

Baseline characteristic	All participants (n = 63)	Analyzed population (n = 50)
Age, mean (SD) years	42 (11)	44 (10)
Male, % (n)	44 (28)	40 (20)
Education, mean (SD) years	15 (2)	15 (2)
Married/living together, % (n)	81 (51)	82 (41)
Children at home under 16, % (n)	41 (26)	48 (24)
Current smoker, % (n)	13 (8)	12 (6)

job and two participants withdrew due to private circumstances. Sixty participants completed the study of which ten participants were excluded from the data analysis due to a lack of compliance in wearing the WTD (<90% of the time).

Participants' choice of personal PA was distributed between "on-location-activities" with coworkers, fitness center, studio with small classes, self-training with a guided training plan, padel tennis and physical activity within a union. All participants were given either their first or second priority.

The duration of the control and intervention period were 28 days (SD 2 days) and 57 days (SD 4 days) respectively. Results of objective and self-reported health parameters are shown in Table 2. Due to company-specific COVID-19 restrictions, participants at one of the three workplaces were instructed to complete T2 online. Measures of body composition, blood pressure and VO_2max from this workplace (16 participants) at T2 are therefore missing. In addition, two participants did not have their blood pressure measured at any test day. Unfortunately, one participant did not fit the standard cuff and one participant was known with white coat syndrome (the phenomenon of having elevated blood pressure only during a testing consultation). In addition, one participant stopped the use of antihypertensive medication between T1 and T2 (not related to study activities) and was therefore excluded from the BP analysis. Three participants did not conduct the step test at any test day because of chronic knee and back injuries. Moreover, at T3 three participant did not complete the step test due to respectively tooth surgery, virus on the balance nerve and a sore fascia plantaris. Two participants did not have their body composition estimated at any timepoint due to an implanted pacemaker and severe obesity respectively (Boneva-Asiova & Boyanov, 2008).

Compared to T1, the participants increased their estimated VO_2max with 1.35 and 3.39 mL/kg/min ($P < 0.0001$) at T2 and T3 respectively. No change was observed in BMI and muscle mass while the fat percentage decreased from T1 to T3 with 0.47% ($P = 0.02$). Systolic and diastolic BP decreased with 4.32 ($P = 0.001$) and 2.29 ($P = 0.02$) mmHg from T1 to T2 while no further difference was observed between T2 and T3 (see Table 2). In the present study, 18 participants were within the hypertension range (systolic BP $\geq$ 140 mmHg or diastolic BP $\geq$ 90 mmHg) at baseline with an estimated mean of 148/98 mmHg at T1. A decrease of 7.3 in systolic BP ($P = 0.002$) and 4.3 mmHg ($P = 0.002$) in diastolic BP was observed at T3 among these participants. Among normotensive participants with a baseline BP of 119/75 mmHg, we observed a decrease in systolic BP with 3.3 mmHg ($P = 0.02$) and no change in diastolic BP at T3.

Self-reported exercise behavior increased during the intervention period with 55 min/week. Ten participants were omitted because of an incorrect completion of questions relating to MVPA (they reported a higher number of vigorous active min/week than total MVPA

Table 2
Results of linear mixed model on objective and self-reported health parameters.

Parameter *(n)*		Estimated mean	Std. Error	P-value	95% CI Lower	Upper
VO_2max (mL/kg/min)	Intercept T1	31.92	1.07		29.82	34.02
(47)	Diff. T1 to T2	1.35	0.37	<0.001*	0.62	2.08
	Diff. T2 to T3	2.05	0.49	<0.001*	1.09	3.01
	Diff. T1 to T3	3.39	0.62	<0.001*	2.17	4.62
BMI (kg/m^2)	Intercept T1	26.64	0.77		25.11	28.16
(50)	Diff. T1 to T2	−0.05	0.08	0.58	−0.21	0.12
	Diff. T2 to T3	−0.08	0.07	0.29	−0.22	0.07
	Diff. T1 to T3	−0.12	0.08	0.16	−0.30	0.05
Fat (%)	Intercept T1	27.69	0.99		25.73	29.64
(48)	Diff. T1 to T2	−0.16	0.19	0.42	−0.54	0.22
	Diff. T2 to T3	−0.31	0.20	0.12	−0.69	0.07
	Diff. T1 to T3	−0.47	0.19	0.02*	−0.84	−0.10
Muscle mass (kg)	Intercept T1	52.62	1.62		49.43	55.81
(48)	Diff. T1 to T2	−0.11	0.14	0.43	−0.39	0.17
	Diff. T2 to T3	0.14	0.11	0.23	−0.09	0.36
	Diff. T1 to T3	0.03	0.13	0.84	−0.24	0.29
Sys BP (mmHg)	Intercept T1	130.17	2.75		124.76	135.58
(47)	Diff. T1 to T2	−4.32	1.29	0.001*	−6.87	−1.78
	Diff. T2 to T3	−0.50	1.34	0.71	−3.15	2.14
	Diff. T1 to T3	−4.83	1.22	<0.001*	−7.22	−2.44
Dia BP (mmHg)	Intercept T1	82.45	1.69		79.11	85.78
(47)	Diff. T1 to T2	−2.29	0.99	0.02*	−4.24	−0.33
	Diff. T2 to T3	0.86	0.94	0.36	−0.99	2.71
	Diff. T1 to T3	−1.42	0.84	0.09	−3.08	0.23
MVPA (min/week)	Intercept T1	188	28		132	245
(40)	Diff. T1 to T2	27	21	0.21	−16	69
	Diff. T2 to T3	55	26	0.04*	2	107
	Diff. T1 to T3	81	28	0.006*	24	139
PSS (Stress score)	Intercept T1	12.26	0.74		10.77	13.75
(60)	Diff. T1 to T2	−2.42	0.64	<0.001*	−3.71	−1.13
	Diff. T2 to T3	0.7	0.56	0.22	−0.43	1.83
	Diff. T1 to T3	−1.72	0.60	0.007*	−2.94	−0.50
ISI (ISI score)	Intercept T1	6.85	0.96		4.89	8.81
(33)	Diff. T1 to T2	−1.21	1.33	0.37	−3.92	1.50
	Diff. T2 to T3	−1.12	1.13	0.33	−3.42	1.18
	Diff. T1 to T3	−2.33	1.15	0.05*	−4.67	0.01

min/week). Perceived stress decreased from T1 to T2 with 2.42 ($P < 0.001$) while no change was observed between T2 and T3. Mild to moderate sleep problems were reported by 23, 19 and 16 participants at respectively T1, T2 and T3. The degree of sleep problems changed from T1 to T3 with a decrease of 2.33 score ($P = 0.05$).

Daily steps increased with 909 steps/day ($P < 0.0001$) from the control to the intervention period and active kcal increased with 96 kcal/day ($P < 0.0001$). One daily active kcal measurement was identified as an outlier within a participant and excluded as the measurement was more than 3 SD above the mean of the participants' daily active kcal. No change was observed in resting HR between the control and intervention period while the stress score based on HRV decreased with 2 ($P = 0.001$). Finally, no change was observed in TST while SO was delayed with 10 min in the intervention compared to the control period ($P < 0.001$) (Table 3).

A significant interaction between control/intervention and VO_2max was observed in the mixed linear model for stress while no interaction was observed for TST and AK (see supplementary material 1). The effect of VO_2max in the control and intervention period was further explored by considering the pairwise comparison of the Least Squares Means (LS-means) within the first, second, and third quintile of VO_2max, denoted Q1, Q2, and Q3, respectively. The results of the pairwise comparison can be found in Table 4 showing a significant difference between the expected stress in the control and intervention period within the lowest two quintiles of VO_2max (Q1 and Q2). Furthermore, the slope of VO_2max in the intervention period was found to be insignificantly different from zero.

We observed that the median stress scores during business days were significantly lower in the intervention period during the morning hours (1.39) and the afternoon hours (2.73) compared to the control period (see Fig. 2). Similar during weekends, the stress scores were observed to have a significantly lower median value during daytime hours (2.35) and afternoon hours (3.16) in the

Table 3
Measures obtained with WTD.

Daily WTD measures	Control period Mean (SD)	Intervention period Mean (SD)	P-value	Mean difference (95% CI)
Step	8545 (2597)	9455 (3070)	<0.0001	909 (499 : 1320)
Active kcal	398 (188)	494 (212)	<0.0001	96 (70 : 122)
Resting HR	58 (8)	58 (8)	0.55	0 (−0.78 : 0.42)
Stress score	32 (7)	30 (6)	≤0.001	−2 (−2.81: 0.75)
TST min	07:56 (40)	07:52 (37)	0.12	−4 (−9 : 1)
SO time	22:56 (38)	23:06 (35)	≤0.001	−10 (−15: 5)

Table 4
The significance levels of contrasts.

Contrast Control – Intervention	Estimate	Std. Error	P-value
Q1 VO_2max = 29.0	2.90	0.737	<0.001*
Q2 VO_2max = 33.0	1.92	0.706	<0.01*
Q3 VO_2max = 38.8	0.51	0.854	0.5526

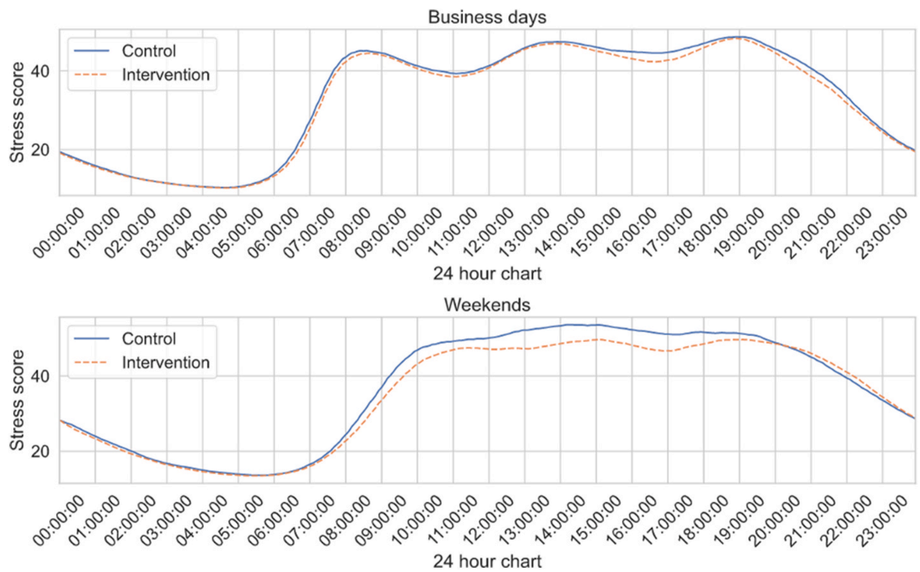

Fig. 2. Stress scores during business days and weekends stratified by control versus intervention period. Average stress values for all participants displayed as rolling mean with at window of +- 1 h.

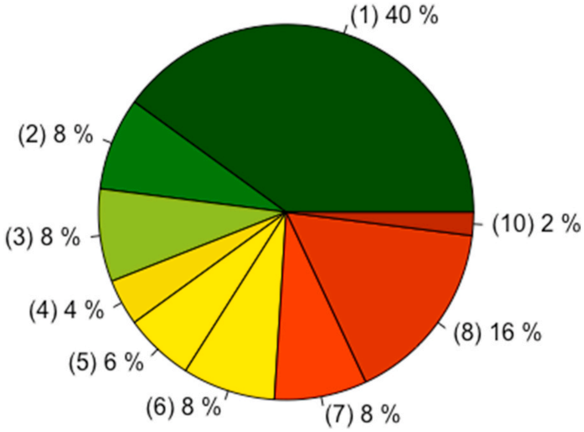

Fig. 3. How challenging was it to remove electronic devices from the bedroom? 1 = No problem, 10 = Impossible.

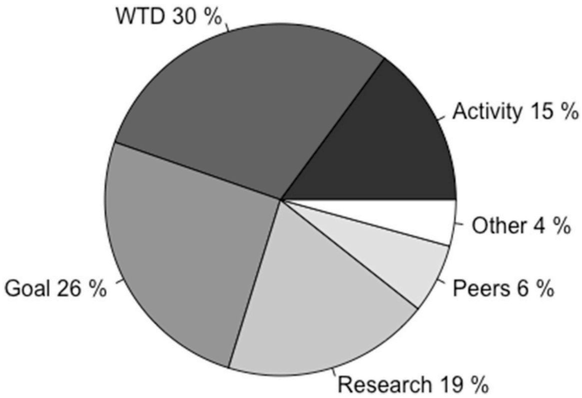

Fig. 4. Primary motivation for obtaining a physical active lifestyle.

intervention compared to the control period (see supplementary material 2). When comparing stress scores between business days and weekends during the intervention period the median stress was higher during weekends except in the morning hours.

Fig. 3 shows a circle graph of how participants perceived the restrictions of bedtime technology. Approximately 56% found it easy (green), 18% found it reasonable (yellow) and 26% found it very difficult (red) to remove all screens and electronic devices from their bedroom. Fig. 4 illustrates participants' primary motivation for meeting their goal of being physical active. Many participants were either motivated by "the use of WTD" (30%) or their "own goal" (26%). Nineteen percentage were primarily motivated by "being part of a research project" and 15% by "their personal guidance and access to PA". Finally, few reported the importance of peers (6%) or answered a combination of options (=other) (4%).

4. Discussion

To our knowledge this is the first study to target physical activity, sleep and stress behaviors simultaneously among a population of office-workers. Results from this study suggest that a multi-component intervention can increase physical activity resulting in an improved maximal oxygen uptake in office-workers. TST were unchanged after removing bedtime technology while objectively measured stress levels were lower in the intervention period compared to the control period.

4.1. PA behaviors

Approximately 50% in the present study had a low or somewhat low VO_2max at T1 according to Astrands classification of aerobic capacity by age and gender (Astrand, 1960). Measurements of VO_2max at baseline were low for men in the present study (32 mL/min/kg for both men and women) compared to reference values obtained in Norwegian adults (39.5 mL/min/kg for men and 32 mL/min/kg for women). A Danish study demonstrates that PA behavior decreased with 16% during the first national shutdown in spring 2020 due to COVID-19 (Schmidt & Pawlowski, 2020), which may partly explain the low value of baseline VO_2max in the present study. However, Schmidt at al. did not report gender differences in the drop of PA and furthermore, data was based on an over-representation of (highly educated) females, which limit the representativeness of the study population (76% of the 1802 participants were females).

It has been demonstrated that a low VO_2max is associated with a 2- to 5-fold increase in cardiovascular disease or all-cause mortality, independent of other cardiovascular disease risk factors (Ross et al., 2016). Importantly, relatively small improvements in aerobic capacity such as 1 metabolic equivalent (3.5 mL/kg/minute) have been associated with 8%–35% reductions in mortality (Ross et al., 2016). From this perspective, an average VO_2max increase of 3.39 mL/kg/minute during the study period of 12 weeks suggest a noteworthy health benefit if the participants maintain the level of PA in the future. An increase of VO_2max was observed between T1 and T2 suggesting that participants commenced enhanced PA behavior already during the control period although not instructed to do so. An increase in PA initiated during the control period could also explain the average decrease of systolic and diastolic BP of respectively 4.32 and 2.29 mmHg at T2 compared to T1. No further change in BP was observed after the intervention period. It is well documented that regular PA prevents hypertension and lower BP (Fagard, 2005). In a meta-analysis of randomized controlled trials, the weighted net decrease of blood pressure averaged 7.4 mmHg for systolic BP and 5.8 mmHg for diastolic BP in response to PA in subjects with baseline blood pressure in the hypertensive range. In normotensive participants the corresponding values were respectively 2.6 mmHg and 1.8 mmHg (Fagard, 2001). This is in accordance with the observed decrease in BP for hypertensive (7.3/4.3 mmHg) and normotensive participants (3.3/0 mmHg) in the present study. Hypertension significantly increases the risks of heart, brain, and other diseases. In a meta-analysis the age-specific relevance of usual BP to vascular mortality was assessed from one million adults in 61 prospective studies (Lewington et al., 2002). The authors found that a reduction in systolic BP of just 2 mmHg reduces apoplexy mortality by 10% and death of ischemic heart disease by 7% among middle-aged people. Considering this, the observed decrease of 7 mmHg in average systolic BP among hypertensive participants is highly relevant.

We observed no change in BMI and muscle mass and only a small decrease in fat% from T1 to T3. Changes in these parameters depend on baseline values, the duration of the intervention and the type of PA. In general, participants in the current study were not overweight with a body fat% of 23.8(SD 4.6)% and 30.2(SD 7)% for respectively men and women (ACE, 2009) and therefore only minor changes would be expected. An increase of muscle mass is especially associated with strength training and only a few participants focused on this type of training. The majority focused on aerobic capacity which is reflected in the increase of VO_2max. Finally, the duration of the study was rather short and/or the dose too small to measure changes in these parameters considered the baseline values of participants (McTiernan et al., 2007; Schoenfeld et al., 2017). Individuals who are physical active require greater volume of PA to elicit improvements in body composition.

4.2. Motivation for obtaining a physical active lifestyle

Behavioral change to a more physical active lifestyle is a powerful tool to improve public health and motivation is a key factor for success. The participants reported different motivation factors for increasing/obtaining a PA behavior (Fig. 4), which emphasizes the need for an individualized approach. Thirty percentage of the participants rated the use of technology as the most important factor. Well-documented principles for behavior change techniques including feedback, tailored information, gamification, rewards, goal-setting, prompts, social comparison and connectivity have been incorporated in WTD's and can support motivation (Düking et al., 2020; Michie et al., 2011). Furthermore, the WTD allows individuals to gain insight into their own activity level 24-h a day and studies have demonstrated that for some individuals self-monitoring is valued and can prompt further goal-directed behavior, while for other individuals the inability to meet their goals can trigger negative experiences (Carter et al., 2018). Thus, it is not surprising that approximately 25% of participants were primarily motivated by their own goal while 20% of the participants were motivated by being part of a research project. A few participants rated the use of peers/co-workers as the primary motivation factor highlighting that for some individuals, peers may provide an effective method to increase PA (Best et al., 2016). Fifteen percentage of the participants were motivated by the personal approach, guidance and access to PA. Pairing personality with PA is an interesting approach to inspire participants to try new types of PA (Gavin, 2004) although, in practice, the office-workers were often more concerned of logistic and flexible training options. Of note, participation in certain types of physical activities were challenged by the fact that the incidence of COVID-19 raised during the study period with gradually higher levels of restrictions on physical training facilities and number of participants in teams sport and group fitness were introduced. Thus, every third person changed their strategy and spend more time on individual physical activities assisted by the WTD than initial planned. The reported results of primary motivation factors may therefore be affected by limited PA opportunities due to COVID-19. Nevertheless, the increase of PA is robust despite that the intervention was conducted during the COVID-19 pandemic.

4.3. Sleep behaviors

In the present study we observed a 10 min-delay in SO and no change in TST in the intervention period compared to the control period. Furthermore, self-reported sleep problems decreased from T1 to T3 with 2.33. Previously cross-sectional studies have quite consistently shown adverse effects of bedtime technology use on sleep length. However, few existing experimental studies have been conducted and they report contradictory results on sleep measures (Bartel et al., 2019; Harris et al., 2015; He et al., 2020; Hughes & Burke, 2018). Two studies restricting bedtime technology use for 1 week report a positive impact on sleep length (Bartel et al., 2019) and wellbeing, respectively (Hughes & Burke, 2018). Two studies measured the effect of restricting bedtime technology for four weeks. Improvements were reported in both sleep measures and working memory in Japanese university students (He et al., 2020) while no effect on sleep measures was found in Norwegian high school athletes (Harris et al., 2015). Of note, the inclusion criteria differed in these studies: e.g. He et al. only included participants with poor sleep and a habit of using a mobile phone during bedtime, while Harris et al. did not have such inclusion criteria. In the present study, we did not have any inclusion criteria regarding smartphone use meaning that we included both light and heavy smartphone users. According to Fig. 3 it was relatively easy to remove bedtime technology for more than 50% of participants in the present study which is quite different from what Bartel et al. experienced in their attempts to recruit adolescents (Bartel et al., 2019). A recent telephone-based survey showed that 42% of 1225 adults reported using electronic devices in bed after lights out, and 27% of those adults who reported always using electronic devices in bed were spending over an hour per night using them (Lastella et al., 2020). The survey demonstrates a large variance in the habits of bedtime technology among adults, which is important to consider in the attempt to illuminate how the use of smartphones affect sleep measures. Difference in restrictions of bedtime technology may also explain part of the discrepancy in the beforementioned experimental studies. Restrictions varied from removing smartphones from the bedroom to refrain from use of the smartphone after 10.00 p.m. or refrain from use of the smartphone respectively 30 and 60 min before bedtime. In the present study participants, where instructed to remove smartphones and other electronic devices from their bedroom and maintain their usual bedtime. However, it is possible that some participants may still have spent extended times periods on their smartphone prior to bedtime and then delayed going into their bedroom just before sleep. This may explain the delay in SO of 10 min.

Another factor that is known to influence the circadian rhythm is PA. Thus, the increase of PA during the intervention period may also influence the SO. Studies have shown that exercising in the evening may delay SO especially for early chronotypes and most prominent following vigorous PA shortly before bedtime (Barger et al., 2004; Stutz et al., 2019; Thomas et al., 2020). Of note, recordings from the WTD shows that the included participants in the present study do not suffer from severe circadian misalignment or insufficient sleep either in the control or intervention period. The initial good sleep habits among participants seem to represent a ceiling effect, which reduce the potential for improvement. In contrast, in the study conducted by He et al., 2020 participants only slept between 6 and 7 h at baseline (He et al., 2020).

Finally, it should be noted that the observed changes of sleep measures in the present study might be affected to alterations during the COVID-19 pandemic (Morin et al., 2020). Daily routines such as arising at a specific time, showing up at work, and engaging in social and leisure activities at relatively fixed times are all important factors to remain synchronized with the day (light) and night (dark) cycles. During the pandemic, the daily routines have been changed for many office-workers due to working (more) from home. In addition, data shows that the use of especially social media has become even more pervasive during social isolation (Altena et al., 2020).

4.4. Stress levels

Stress levels were targeted indirectly by increasing physical activity and restricting excessive electronic media use during nighttime. A decrease in perceived stress was observed after the control period but with no further change during intervention, while stress scores based on HRV decreased from the control to the intervention period. A recent review concludes that HRV is influenced by stress and supports its use for the objective assessment of psychological stress although discrepancy between studies exist (Kim et al., 2018). Part of the discrepancy may be due to the application of different HRV variables and that HRV is influenced by physiological factors (e.g., breathing, circadian rhythms, posture), non-modifiable factors (e.g., sex, age, genetic factors) and modifiable lifestyle factors (e.g., obesity, smoking, drinking) as well as disease and medication (Kim et al., 2018). Moreover, studies differ in duration and outcome measures for subjective stress or focus on specific stressors, such as work-related stress or negative life events. A challenge in this field is the lack of a universal definition of stress. The concept of stress includes both biological and psychological factors which may be difficult to capture in a single assessment. The discrepancy observed in the present study between objective- and subjective measures may also relate to different sensitivity in the two scales and the data collection period. The PSS relies on participants' memory from the last four weeks introducing a recall bias while HRV is recorded continuously.

The initially subjective and objective stress level among participants in the present study was categorized as low, reducing the potential for improvement and which furthermore limits the generalization of results to people with moderate to high stress levels. Nevertheless, we observed a decrease of objectively measured stress in the intervention period compared with the control period among participants with an initial low to moderate VO_2max whereas for participants with an initial high VO_2max, no such difference was observed (Table 4). The positive effect of fitness on HRV is in accordance with previous studies (Sandercock et al., 2005; Santa-Rosa et al., 2020) and emphasize the importance of obtaining a physically active lifestyle. Studies suggest that individuals who maintain higher physical fitness, are more resilient to mental stresses (Hamer, 2012).

Differentiating stress scores based on HRV over a 24-h chart revealed lower stress scores during morning and afternoon hours in the intervention period compared to the control period during business days (Fig. 2). The observed decrease in stress levels may reflect an ability to better cope with transitions between work and leisure time. The rush of getting to and from work may have been less pronounced due to working more from home during the COVID-19 pandemic. We also observed lower stress levels during the weekends in the intervention compared to the control period. Many leisure time and social activities have gradually been restricted during the fall due to the pandemic which may also have affected the result. Nevertheless, in the present study we observe a decrease in stress while a survey of stress in an American report found a profound increase of stress levels due to the COVID-19 pandemic (APA, 2020).

Much effort has been directed towards the effect of job strain on health and stress. However, in the present study, we observed higher stress scores in the weekends compared to business days (except from the morning hours). This topic is not well investigated but a few other studies have found similar results and discuss the possibility that home life reveal higher (objective) stress levels than work life because of e.g. housework, tensions in family life or physical activity (Damaske et al., 2014; Pantzar et al., 2017).

4.5. Limitations

It appears that participants have changed PA behavior during the control period although specifically instructed not to do so. More than three out of four participants report that they have followed their health behavior during the control period via the accompanied WTD application. This information may have affected their behavior. A more realistic picture of the participants behavior would probably have been possible if the participants were completely blinded to their own data. However, by using a commercial activity tracker this was not possible. Moreover, behavioral outcome may also be affected simply by the awareness of being monitored (McCambridge et al., 2014), also known as the Hawthorne effect.

The use of a commercial WTD is challenged by the fact that we as researchers are blinded to applied algorithms used to estimate health parameters and recurrent updates of these algorithms. However, in a recent study, we validated the applied Garmin Vivosmart 4 against the golden standard, polysomnography. The results suggest that this WTD allow for detection of changes in SO, sleep end, and TST on a group level (Mouritzen et al., 2020).

We observed a large variation in compliance of wearing the WTD from 40 to 99% due to skin rash on the wrist, forgetfulness in relation to battery charging and technical issues in relation to phone replacement. This variation introduces a limitation that we have tried to overcome by excluding participants with less than 90% compliance while exploring the interactions between sleep, PA and stress.

5. Conclusion

Results from this study suggest that a multi-component intervention can increase physical activity resulting in an improved maximal oxygen uptake in office-workers. Objectively measured stress levels may decrease especially for those with an initially low VO_2max. Restricting technology use within the bedroom has no effect on sleep length. The results suggest that increasing PA through an individual approach supported by a WTD has positive effect on essential health parameters.

Credit author statement

Lisbeth Højkjær Larsen: Conceptualization, Methodology, Validation, Investigation, Formal analysis, Writing - Original Draft, Funding acquisition. **Maja Hedegaard Lauritzen:** Conceptualization, Investigation, Writing - Review & Editing. **Mikkel Sinkjaer:** Methodology, Validation, Formal analysis, Writing - Review & Editing. **Troels Wesenberg Kjaer:** Conceptualization, Supervision, Writing - Review & Editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhl.2021.100219.

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