Operation early-bird: Investigating altered light exposure in military barracks on sleep and performance - a placebo-controlled study

David T. Edgar[1,2], C. Martyn Beaven[1], Nicholas D. Gill[1], Jennifer L. Zaslona[4], C. & Matthew W. Driller[1,3]

[1] *Faculty* of *Health, University of Waikato, Hamilton, New Zealand*

[2] *New Zealand Defence Force, Wellington, New Zealand*

[3] *Sport and Exercise Science, School of Allied Health, Human Services and Sport, La Trobe University, Melbourne, Australia*

[4] *Sleep/Wake Research Centre, Massey University, Wellington, New Zealand*

ABSTRACT

Background: The manipulation of light exposure in the evening has been shown to modulate sleep, and may be beneficial in a military setting where sleep is reported to be problematic. This study investigated the efficacy of low-temperature lighting on objective sleep measures and physical performance in military trainees. **Methods:** 64 officer-trainees (52 male/12 female, mean ± SD age: 25 ± 5y), wore wrist-actigraphs for 6-weeks during military training to quantify sleep metrics. Trainee 2.4km run time and upper-body muscular-endurance were assessed before and after the training course. Participants were randomly assigned to either: low-temperature lighting (LOW, *n*=19), standard-temperature lighting with a placebo 'sleep-enhancing' device (PLA, *n*=17), or standard-temperature lighting (CON, *n*=28) groups in their military barracks for the duration of the course. Repeated-measures ANOVAs were run to identify significant differences with post-hoc analyses and effect size calculations performed where indicated. **Results:** No significant interaction effect was observed for the sleep metrics; however, there was a significant effect of time for average sleep duration, and *small* benefits of low temperature lighting when compared to CON (*d*=0.41 to 0.44). A significant interaction was observed for the 2.4km run, with the improvement in LOW (Δ92.3s) associated with a *large* improvement when compared to CON (Δ35.9s; *p*=0.003; *d*=0.95 ±0.60), but not PLA (Δ68.6s). Similarly, curl-up improvement resulted in a *moderate* effect in favour of LOW (Δ14 repetitions) compared to CON (Δ6; *p*=0.063; *d*=0.68 ±0.72). **Conclusion:** Chronic exposure to low-temperature lighting was associated with benefits to aerobic fitness across a 6-week training period, with minimal effects on sleep measures.

Introduction

Sleep is requisite for human health and well-being, and is crucial to physiological and cognitive functioning (O'Donnell, Beaven, & Driller, 2018). It is known that the human circadian timing system is particularly sensitive to ocular short-wave light exposure (Cajochen et al., 2005) and that phototransduction of specific light wavelengths can be manipulated to impact sleep (Figueiro et al., 2014). Chronic exposure to bright lighting environments before bedtime has been shown to have a profound suppressive effect on melatonin levels, shortening the body's internal representation of night duration (Boyce, 2010; Chellappa, 2020; Gooley et al., 2011; Munch et al., 2006). Wavelength-specific impacts of light extend to eliciting changes in sleep architecture and decreases in slow-wave sleep (Chellappa, et al., 2013). In contrast, chronic reductions in bright light and short-wavelength blue-light exposure in the hours before bed have been shown to promote sleep and support the normal circadian biorhythm of melatonin (Kozaki, Koga, Toda, Noguchi, & Yasukouchi, 2008; Rahman, Hilaire, & Lockley, 2017; Vethe et al., 2021). Amber-lens glasses that specifically block short-wavelength light also improve sleep quality and can decrease sleep onset latency in recreational athletes when worn in the evening prior to bed; however, the implications for recovery and performance were identified as key areas to be addressed (Knufinke, Fittkau-Koch, Møst, Kompier, & Nieuwenhuys, 2019; Shechter, Kim, St-Onge, & Westwood, 2018; Van der Lely et al., 2015).

Obtaining sufficient sleep can play an important role in physical recovery (Halson, 2008) as well as in the consolidation of learning (Stickgold, 2005), emotional processing (Simon, Vallat, Barnes, & Walker, 2020) and skill acquisition (Kuriyama, Stickgold, & Walker, 2004). Short sleep duration and decreased sleep efficiency as a result of variability in sleep–wake time, can also have negative ramifications for mood and mental wellbeing (Chellappa, Morris, & Scheer, 2020). With respect to physical performance, longer sleep durations have demonstrated improved training capacity (Cook, Beaven, Kilduff, & Drawer, 2012), and improved aerobic adaptations in athletes (Teece et al., 2021). Similarly, when stratifying military trainees into two quantile groups based on sleep duration, small benefits in aerobic fitness were observed in those who averaged only a modest 36 minutes longer sleep duration than a short sleeping cohort (Edgar, Gill, Beaven, Zaslona, & Driller, 2021).

Military personnel can experience even greater challenges than the general population with sleep, due to the stressful and constantly changing nature of daily training and operational roles (Good, Brager, Capaldi, & Mysliwiec, 2020). Following sleep disruption, there is potential for

neurocognitive and physiological processes to be compromised (Banks & Dinges, 2007; Durmer & Dinges, 2005; Halson, 2008). A lack of sleep in the military context has been shown to have an impact on combat effectiveness by reducing vigilance, alertness, motivation and inability to physically perform (Charest & Grandner, 2020; Good et al., 2020). Poor sleep quality in a military context has also been associated with poorer occupational well-being (Mantua, Pirner et al., 2021), increases in high risk behaviors (Mantua, Bessey et al., 2021), and greater injury risk (Ritland et al., 2921). Sleep was identified as a third highest priority area out of 43 topics for military personnel's health and physical performance in a consensus paper by Lovalekar et al. (2018). Additionally, sleep was ranked as the highest priority area by 99 of the 502 (~20%) of the attendees from 32 countries at the International Congress on Soldiers' Physical Performance. In the military occupational context, five specific sleep modulators (surface, light, air quality, noise, and temperature) have been identified with the potential to improve health, wellness, and operational performance (Mantua et al., 2019).

The manipulation of environmental light exposure to improve sleep outcomes has been shown to have a range of benefits to performance, wellbeing, and recovery in the general population. However, to our knowledge, no previous research has evaluated the effects of altering night-time light exposure over a six-week period in the living quarters of soldiers during an intense period of training. Therefore, the current study aimed to investigate the effect of reduced temperature lighting on objective sleep measures and physical performance in military recruits over a six-week training course. Specifically, based on the work of Knufinke et al. (2019), w~~W~~e hypothesized that lighting with a lower circadian sensitivity would improve ~~objective~~ sleep quality and decrease sleep latency, and that these improvements would translate into ~~measures and~~ enhanced physical performance assessed via a fitness evaluation that consisted of a 2.4 km time-trial road run, curl-ups, and press-ups.

2. Methods

Participants

A representative ~~total~~ sample of 64 healthy officer trainees (50 male/14 female, age: 25 ± 5 y [mean ± SD]) from a total of 116 officer trainees (91 male/25 female, age 24 ± 6 y) on the Joint Officer Induction course from Army, Navy, and Air Force from the New Zealand Defence Force participated in the current study. An a priori power calculation was informed by minimal detectable change and variability from a closely matched cohort Edgar et al., (2021) With

inputs of a 2-sided alpha of 0.05, 0.8 power, calculations indicated a minimum sample size requirement of 24 (press-ups), 52 (sit-ups), and 54 (2.4 km run), to detect meaningful differences using the website (http://hedwig.mgh.harvard.edu/sample_size/js/js_parallel_quant.html). Participation in the study was voluntary and ethical approval for the study was obtained from an institutional Human Research Ethics Committee (HREC) (Health) #2018-01.

Experimental Design

The current study implemented a pre-post parallel-group study over six weeks, with an intervention group, a placebo group, and a control group. Trainees were assigned to either; LOW; low temperature lighting in living quarters (*n* =19, 7 female/12 male), PLA; standard temperature lighting and a placebo sleep enhancing device (*n* =17, male), or CON; a standard temperature lighting control group (*n* =28, 7 female/21 male) (Table 1). Group assignment was random and dependent on barrack allocation (outside of our control). There was no specific assignment due to occupation specialty, unit, or capability. The only specific split was male / female, where each sex resided in their own gender-pure barrack rooms. All barrack rooms were identical in size with open plan cubical spaces defined by dresser, wardrobe and bed. All participants were tested for physical performance pre and post 6-weeks of officer training and sleep was monitored for the entire 6-weeks using wrist actigraphy. Trainees only had access to electronic devices (e.g. mobile phones) for 30 minutes on one day per week in the morning (Sunday), this protocol was specific to the training course. Trainees were only in their barracks after 6pm and for quick uniform changes during the day. Sleep was confined to a specific window of 'lights out' between 2200-2230 h and 'wakeup' between 0530-0545 h.

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7+7 = 14
12+17+21 =50

Experimental Groups

Control group (CON)

The CON group was exposed to standard barrack ceiling lighting (7000 K, 58 W / 391 ± 58 lx / ~386 nm) and warm-white LED bedside bulbs (7000 K, 8 W / 958 ± 128 lx / ~412 nm, Table 1) for the 6-week duration. Each room contained four ceiling lights (two florescent tubes in each, eight-tubes in total), and eighteen LED individual bedside lamps sitting approximately 1-m from the head of the bed.

Low-circadian light group (LOW)

For the 6-week duration, florescent ceiling tubes and were replaced in the living quarters with warm low temperature lighting tubes (3000 K, 58 W / 316 ± 25 lx / ~698 nm, Table 1). The warm-white LED bulbs in the bedside lamps were also replaced with warm-white incandescent bulbs (60 Watt / 300 ± 31 lx / ~704 nm, Table 1) for the 6-week duration.

Placebo group (PLA)

The PLA group was exposed to standard barrack ceiling lighting for the 6-week duration identical to the CON group (Table 1). A placebo sleep device was also placed in the centre of one barrack room in clear view of all trainees (Figure 1). The device was introduced to trainees in the PLA group through a 15-minute presentation, as a 'novel sleep-promoting device' that is emitting a frequency through antennas within a 20 m radius that will be detected by the brain and enhance sleep. The presentation cited previous research investigating other novel sleep devices, including devices that emit white noise (Forquer, Johnson, & Hypnosis, 2007), low energy emissions (Reite et al., 1994), and mixed-frequency white noise (Stanchina, Abu-Hijleh, Chaudhry, Carlisle, & Millman, 2005). The device was also introduced as being a beta-product testing device that had not yet been studied, and given the nature of the invention, it was highly classified. All beds spaces were within 15 m of the device in the centre of the barrack room. The lid of the device was removed for demonstration to show trainees the internal system, battery packs, 'on-off' and 'frequency level' switches (set to high), and various coloured flashing LED lights to give the impression it was a functioning device. The lid was then replaced and locked (with padlocks) with no flashing lights visible, and no access for trainees.

Figure 1. Placebo 'novel sleep-promoting device' with 'frequency emitting' antennas that was placed in the centre of the room reaching a 20 m radius.

Light Measurement

The lux of each barrack was measured using a calibrated Cabac professional digital light multimeter (T8268, Ecco Pacific Ltd, Cabac NZ). Kelvin and wattage are reported as manufacture ratings, and nm and circadian stimulation were determined from the Mount Sinai Light and Health Research Centre conversion calculator (Figueiro, Gonzales, & PeDLer, 2016). Lux was measured on the second day, in the first week of the course at 9:00 pm at night when standing in the middle of the room approximately 200 cm away from the ceiling light, and sitting on the bed approximately 100 cm from the bed side lamp in similar fashion to Rahman et al. (2017).

Table 1. Lighting descriptors for the three light interventions: LOW (low-temperature light), PLA (standard-temperature light combined with a placebo 'sleep-enhancing' device), and CON (standard lighting). W: Watt, K: Kelvin temperature rating, Lux: Luminous flux, nm: wavelength in nanometer, and CS: circadian stimulation rating derived from Mount Sinai Light and Health Research Centre conversion calculator. LOW (low-temperature light), PLA (standard-temperature light + placebo 'sleep-enhancing device') and CON (standard-temperature lighting).

GROUP	**Fluorescent Ceiling Tube** (58 W)				**Bedside Incandescent Bulb** (60 W)				**Bedside LED Bulb** (8 W)			
	K	lx	nm	CS	K	lx	nm	CS	K	lx	nm	CS
LOW (n=19)	3000	316 ± 25	~698	~0.298	2700	300 ± 31	~704	~0.267	-	-	-	-
PLA (n=17)	7000	433 ± 57	~387	~0.614	-	-	-	-	7000	916 ± 76	~427	~0.646
CON (n=28)	7000	391 ± 58	~386	~0.605	-	-	-	-	7000	958 ± 128	~412	~0.649

Wrist-Actigraphy

An actigraphy device was worn on the wrist continuously for the full duration of the course during both wake and sleep on whichever wrist the individual felt comfortable with (Driller, O'Donnell, & Tavares, 2017), to assess average night-time total sleep time (TST), sleep efficiency (SE), sleep onset latency (SOL), and wake after sleep onset duration (WASO). A combination of both Readiband™ (Fatigue Science, Vancouver, BC, Canada, n = 20) and Micro Motionlogger® (Ambulatory Monitoring Inc, Ardsley NY, USA, n = 44) actigraphy devices were used. Pilot work from our laboratory showed that when these two devices were

compared for inter-device reliability, there were no significant differences for TST, SE, SOL, and WASO (all (p >0.05); and *high* to *very high* intraclass correlation coefficients were observed for all variables (0.81-0.97). The Readiband actigraph is automatically scored and records data at a sample rate of 16 Hz (Dennis, Dawson, Heasman, Rogalski, & Robey, 2016). When validated against lab-based polysomnography (PSG), accuracies of ~90% have been determined for TST (Dunican et al., 2018). The Micro Motionlogger actigraph uses a tri-axial accelerometer which has also been validated against PSG, and distinguishes sleep from wakefulness 88-90% of the time (Gotoh, 2006). As the Micro Motionlogger was manually scored, double scoring by two trained members of the research team was undertaken on 33% of randomly selected sleep files to assess the reliability of manually selected sleep intervals as performed previously (Edgar et al., 2021). Any discrepancies of more than 15 minutes for either 'start time' or 'end time' of the sleep interval were flagged and re-analysed. An accuracy rate of 87.9% was achieved between the two researchers, which is deemed acceptable (McHugh, 2012).

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In weeks three and four, the intensity of PT increased to challenge individuals. Weeks five and six then focused on functional fitness and conditioning. A total of 18, 90-minute exercise sessions were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals. The recruit training course has been detailed previously in Edgar, Gill, and Driller (2020).

Fitness Testing

The standard NZDF JOIC fitness evaluation was conducted by Physical Training Instructors (PTIs) pre and post the course. This evaluation consisted of three key components: 1) 2.4 km time-trial road run, 2) maximum curl-ups (also known as sit-ups), and 3) maximum press-ups conducted on a wooden gym floor. Fitness testing was conducted at 9:00 am with identical morning routines prior to each testing session. Run times were measured via stopwatch to the nearest second by a designated PTI. Press-ups and curl-ups repetitions were counted by a PTI every time the full range of motion was completed, maintaining a consistent tempo, until

failure. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to fatigue or participants being stopped by the PTI (Edgar et al., 2020).

Statistical Analysis

Descriptive statistics are shown as mean ± SD values, while Cohen's *d* effect sizes are represented as mean ±95% confidence intervals. All statistical analyses were performed using the Statistical Package for Social Science (V. 27.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. To examine whether there were any sleep and performance differences between groups, two-way repeated-measures analysis of variance (ANOVA) were performed for Group (LOW, PLA & CON) and Time (pre and post) on the performance data, and weekly sleep data: (TST, SE, SOL, and WASO). A Bonferroni adjustment was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms and also using the Shapiro-Wilk test of normality. Magnitudes of the standardized effects between pre and post physical tests were calculated using Cohen's *d* and interpreted using thresholds of <0.2, 0.2, 0.5, and 0.8 for *trivial*, *small*, *moderate and large*, respectively (Cohen, 1988). Effects were deemed unclear if the 95% confidence intervals overlapped the thresholds for both *small* positive and negative effects (*d* ± 0.2).

3. Results

All participants (*n* =64) completed the entire training program. All participant sleep data from each night was included (*n* =2,304 nights), and all participants completed the pre and post physical performance testing. There was no significant difference between groups for physical performance at baseline (all $p > 0.05$). The repeated-measures ANOVA revealed no significant Group x Time interaction for TST ($p = 0.186$); although there was a significant effect of time ($p < 0.001$) and ~~a tendency towards a~~the main effect of group ~~effect (~~was $p = 0.090$; Figure 1). Effect size analysis revealed *small* differences in sleep duration between the LOW and CON groups at Week 3 (15.4 min; $d = 0.44 \pm 0.58$) and Week 6 (21.2 min; $d = 0.41 \pm 0.57$), and *moderate* differences between PLA and CON in Week 3 (18.9 min; $d = 0.58 \pm 0.58$; Figure 2). The rebound (increase in sleep duration) from Week 5 to Week 6 was also greater in the LOW compared to the CON group (20.6 min; $d = 0.42 \pm 0.59$; Figure 2). There were no significant differences between LOW and PLA for TST at any time point; however, the significant decrease in TST seen in the PLA (-28.4 min; $p = 0.026$) and CON groups (-26.5 min; $p = 0.028$)

over the six weeks training was not observed in the LOW group (-3.3 min; p = 0.693; Figure 1). Regarding the remaining sleep metrics, no significant differences or substantial differences were observed for sleep efficiency or SOL; however, there was a significant group difference for WASO (p = 0.039) and ~~a tendency towards a~~the main effect of time ~~effect (~~was p =0.092~~)~~. The WASO was consistently lower in the LOW compared to the CON and PLA groups, and was substantially lower than CON in Week 2 (8.7 min; d = 0.44 ±0.59) and Week 3 (8.7 min; d = 0.48 ±0.58; Figure 3). Data for all sleep metrics are presented in Table 2.

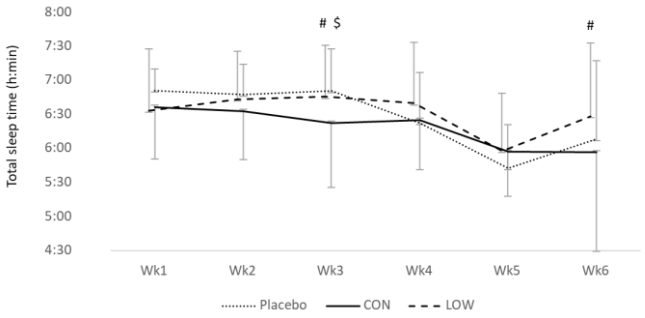


Figure 2. Average total sleep time data across the 6-week training course. Dashed line: LOW (low-temperature light), dotted line; PLA (standard-temperature light + placebo 'sleep-enhancing device') and solid line; CON (standard-temperature lighting) over 6-weeks of military training. [#]significant difference between LOW and CON, [$]*moderate* difference between PLA and CON.

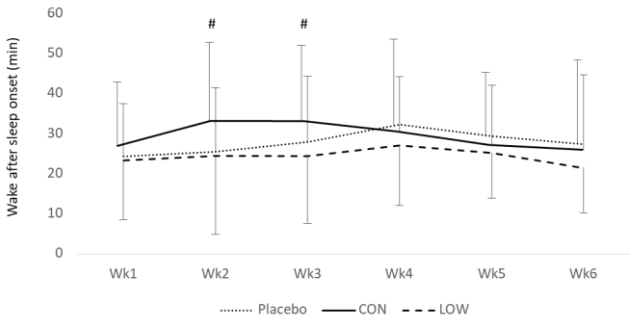


Figure 3. Wake after sleep onset data across the 6-week training course. Dashed line: LOW (low-temperature light); dotted line: PLA (standard-temperature light + placebo 'sleep-enhancing device'); and solid line: CON (standard-temperature lighting) over 6-weeks of military training. #Significant difference between LOW and CON.

Group	Time in Bed (h:m)	TST (h:m)	SE (%)	SOL (min)	WASO (min)
LOW					
Week 1	7:18 ± 0:08	6:22 ± 0:36	91 ± 6	16 ± 7	23 ± 15
Week 2	7:22 ± 0:10	6:28 ± 0:28	91 ± 6	14 ± 4	25 ± 20
Week 3	7:26 ± 0:13	6:30 ± 0:30	91 ± 6	14 ± 5	24 ± 17
Week 4	7:22 ± 0:31	6:26 ± 0:36	91 ± 5	15 ± 6	27 ± 15
Week 5	6:51 ± 0:26	5:58 ± 0:34	91 ± 5	16 ± 4	25 ± 11
Week 6	7:17 ± 0:29	6:18 ± 0:43	91 ± 6	17 ± 9	22 ± 11
Overall Mean	**7:16 ± 0:16**	**6:20 ± 0:34**	**91 ± 6**	**15 ± 6**	**24 ± 15**
PLA					
Week 1	7:22 ± 0:09	6:34 ± 0:13	92 ± 4	15 ± 4	24 ± 13
Week 2	7:19 ± 0:16	6:31 ± 0:18	92 ± 4	14 ± 4	25 ± 16
Week 3	7:21 ± 0:20	6:33 ± 0:25	92 ± 4	14 ± 4	28 ± 17
Week 4	7:20 ± 0:10	6:14 ± 0:30	90 ± 4	16 ± 6	32 ± 21
Week 5	6:46 ± 0:34	5:48 ± 0:26	92 ± 4	14 ± 4	29 ± 16
Week 6	7:01 ± 0:54	6:05 ± 0:46	90 ± 8	17 ± 10	27 ± 21
Overall Mean	**7:24 ± 0:26**	**6:18 ± 0:26**	**90 ± 5**	**15 ± 5**	**28 ± 17**
CON					
Week 1	7:18 ± 0:18	6:24 ± 0:31	92 ± 5	15 ± 7	27 ± 16
Week 2	7:19 ± 0:19	6:21 ± 0:29	91 ± 5	15 ± 4	33 ± 20
Week 3	7:16 ± 0:34	6:14 ± 0:38	91 ± 4	17 ± 10	33 ± 19
Week 4	7:12 ± 0:27	6:16 ± 0:29	91 ± 4	16 ± 5	31 ± 14
Week 5	6:50 ± 0:29	5:58 ± 0:26	92 ± 4	16 ± 6	27 ± 15
Week 6	6:58 ± 0:52	5:57 ± 0:58	91 ± 6	18 ± 9	26 ± 19
Overall Mean	**7:09 ± 0:30**	**6:12 ± 0:35**	**91 ± 5**	**16 ± 7**	**30 ± 17**

Table 2. Average sleep metrics (mean ± SD) over the 6-week training course.

LOW: low-temperature light, PLA: standard-temperature light + placebo 'sleep-enhancing' device, CON: standard-temperature lighting, TST: Total sleep time, SE: Sleep efficiency, SOL: Sleep onset latency, WASO: Wake after sleep onset.

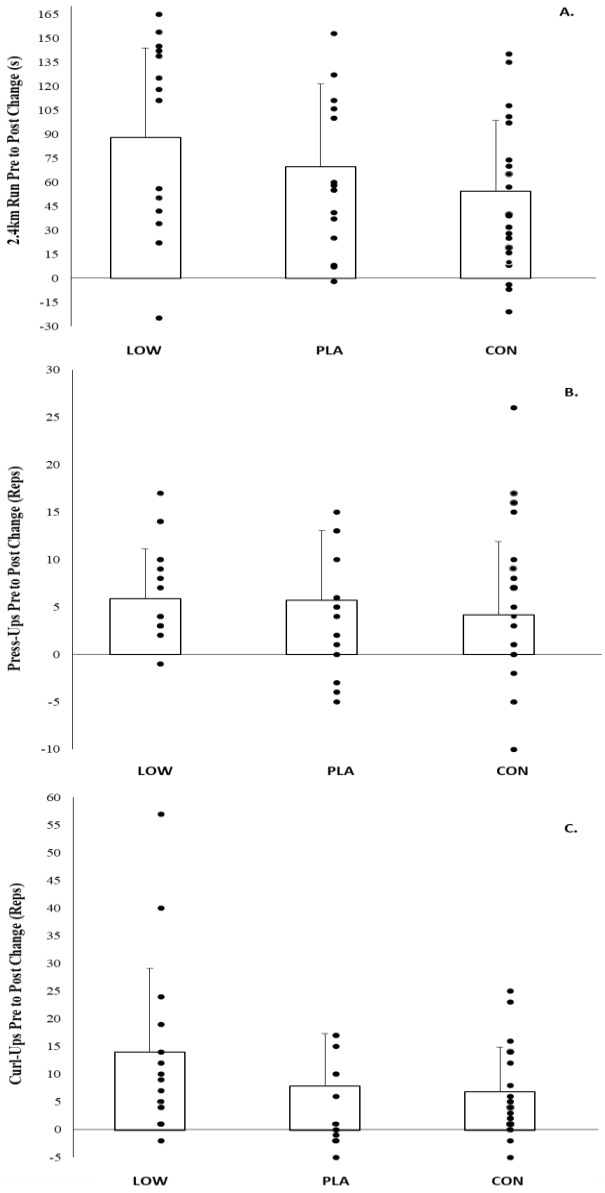
The repeated-measures ANOVA detected a significant Group x Time interaction effect for 2.4 km run (p = 0.009), but not for press-ups (p = 0.808) or curl-ups (p = 0.067). Post-hoc analyses revealed that the *large* improvement in 2.4 km run time in the LOW group was significantly greater than the CON (Δ56.0 s; p = 0.003; d=0.95 ±0.60), but not the PLA group (Δ23.7 s; p = 0.239; d = 0.40 ±0.68; Figure 4A). No significant group differences were seen in press-up performance (Figure 4B). Although not significant, LOW resulted in *moderate* improvements in curl-up performance compared to CON (Δ7.8 repetitions; p = 0.063; d = 0.68 ±0.72), but not the PLA group (Δ6.1 repetitions; p = 0.173; d = 0.50 ±0.73; Figure 4C). All performance data is presented in Table 3.

Table 3. Physical performance changes across a 6-week training program.

		Pre-training	Post-training	%Δ Pre-Post	Effect size vs LOW (*d*)	Effect size vs CON (*d*)
2.4 km Run (s)	**LOW**	711 ± 111	619 ± 66*	13 ± 8 **	-	0.95±0.60** ***Large***
	PLA	624 ± 64	556 ± 31*	11 ± 10	0.40 ±0.68 *Unclear*	0.55±0.63 ***Moderate***
	CON	623 ± 69	587 ± 52*	6 ± 10	-	-
Press-Ups (Reps)	**LOW**	28 ± 9	34 ± 11*	21 ± 18	-	-0.07 ±0.60 *Unclear*
	PLA	32 ± 10	38 ± 10*	21 ± 21	0.20 ±0.72 *Unclear*	-0.19 ±0.67 *Unclear*
	CON	28 ± 9	33 ± 9*	19 ± 30	-	-
Curl-Ups (Reps)	**LOW**	38 ± 15	52 ± 26*	37 ± 39	-	-0.68 ±0.72 ***Moderate***
	PLA	39 ± 19	47 ± 15*	21 ± 23	-0.50 ±0.73 *Unclear*	-0.19 ±0.67 *Unclear*
	CON	40 ± 20	47 ± 20*	15 ± 20	-	-

* Significantly greater than pre-training value (p<0.01). **Significantly greater than CON, p<0.01.
LOW (low-temperature light), PLA (standard-temperature light + placebo 'sleep-enhancing device') and CON (standard-temperature lighting).

Figure 4. Performance improvement over the 6-week training course. A: 2.4 km time-trial run, B: curl-up and C: press-up performance. Bars (Mean + SD), scatter dots (individual participants). LOW: low-temperature light, PLA: standard-temperature light + placebo 'sleep-enhancing' device, CON: standard-temperature lighting, Reps: repetitions



4. Discussion

The main results from this study demonstrate the effectiveness of a chronic modification of the lighting environment on sleep, with *small* improvements in sleep duration relative to a control

group for two of the 6-weeks of the intervention. These improvements were also reflected in less time awake after sleep onset and importantly, in 2.4 km run performance. Other objective sleep metrics measured by actigraphy (sleep efficiency and sleep onset latency) showed no significant differences between the groups. Of note, a placebo sleep device did show a benefit to sleep duration when compared to the control group. Thus, the current study adds novel insight into the impact of low temperature night-time lighting on objective sleep metrics and physical performance over a 6-week intense training program.

The low temperature lighting in the current study led to improvements in aerobic capacity across six weeks of training relative to the standard lighting provided. Earlier research has demonstrated that, when cohorts are dichotomised into high and low durations of sleep, longer sleep durations are associated with improved aerobic performance in both sporting (Teece et al., 2021) and military cohorts (Edgar et al., 2020). The improvements in aerobic fitness relative to the control group are of particular note given the specific negative effects of sleep loss on aerobic capacity reported in military personnel (Grandou, Wallace, Fullagar, Duffield, & Burley, 2019). In a 2017 review, the lack of sleep intervention studies that address real-world issues was cited as an important limitation of the existing sleep literature (Grandner, 2017). Here we present data that takes an important step beyond simply making recommendations, by demonstrating a potentially valuable passive intervention to address the health implications of poor sleep by manipulating the lighting environment.

It is well established that light detected at the retina provides the stimulus for circadian and biological regulation, as well as the release of melatonin (Cajochen et al., 2005; Figueiro, Rea, & Bullough, 2006; Rahman et al., 2017). It is also clear that these physiological outcomes have important implications for sleep (Chellappa, Gordijn, & Cajochen, 2011; Kozaki et al., 2008; Munch et al., 2006; Vethe et al., 2021). As a result, interventions to minimise circadian misalignment including the use of blue light-blocking glasses (Knufinke et al., 2019; Van der Lely et al., 2015) and blue-depleted environmental lighting (Vethe et al., 2021) have been assessed and shown to improve objective and subjective sleep metrics. Here we show that manipulating evening lighting with a lesser circadian stimulation rating of 3000 K led to meaningful improvements in sleep when compared to 7000 K light. Specifically, the LOW group tended to display longer sleep durations across the 6 weeks and less reduction in TST per night from the first to the last week of the training period (difference of ~ 3 min) when compared to the PLA and CON groups where TST was reduced by ~ 29 and ~ 27 min,

respectively over the 6-week period. Of note, previous research has shown acute decreases in slow wave sleep, as a proxy for sleep quality, under similar lighting conditions (Chellappa et al., 2011; Kozaki et al., 2008). The significantly shorter WASO durations observed in the early part of the 6-week training period, can also be interpreted as enhanced sleep quality in the LOW group relative to the CON group (Appleman, Albouy, Doyon, Cronin-Golomb, & King, 2016). Appleman et al. (2016) and colleagues also demonstrated an association between shorter WASO and skill acquisition, and these findings could have far-reaching ramifications across a range of work personnel (e.g. military, aviation, medical).

In a military context, sleep deprivation is common, with less than a third of US service members attaining 7-8 h of sleep (Luxton et al., 2011; Mysliwiec et al., 2013). Of note, short-term sleep extension in military cadets has been shown to improve motivation and performance in cognitive and physical tasks (Ritland, 2019). In addition, the Millennium Cohort Study identified that short sleep duration was associated with greater odds of developing post-traumatic stress disorder and anxiety (Gehrman et al., 2013). Neurological research has determined the potential links between sleep debt and emotional instability via an enhanced response of the amygdala to negative emotional stimuli (Motomura et al., 2013). It is worth noting that actigraphy has been reported to underestimate WASO, and overestimate sleep duration (Dunican et al., 2018) thus, the data presented here likely represent a 'best-case scenario' for sleep duration and fragmentation.

An interesting finding in the current study is the PLA group responding more positively in TST and 2.4 km run than the CON group. In the current study, the PLA group received specific education around potential positive effects of the electromagnetic device placed in their sleeping quarters and, although the device was a sham, this would have created positive expectations regarding efficacy. Therefore, our data support the concept that beliefs and expectations can affect neurophysiological and neurochemical activity (Beauregard, 2007). In a sleep context, placebo pills have previously been shown to improve perceived sleep quality (Yeung, Sharpe, Geers, & Colagiuri, 2020) and decreased wakefulness after sleep onset as assessed by polysomnography (Um et al., 2018). Of note, the LOW group were entirely unaware of the change in the lighting environment; thus, the positive effects observed in this group occurred in the absence of expectation.

As highlighted by Grandner (2017), insufficient sleep is highly prevalent globally and has been associated with "significant morbidity and mortality". Studies of sleep restriction suggest that cognitive deficits accumulate when adults attain less than 7 hours per night (Goel, Rao, Durmer, & Dinges, 2009). Chronic sleep restriction, which is not uncommon in a military environment, can result in cognitive deficits equivalent to those observed after 24-h of wakefulness (Van Dongen, Maislin, Mullington, & Dinges, 2003), and this level of sleep deprivation results in deleterious effects similar to drink-drive limits (Fairclough & Graham, 1999; Lowrie & Brownlow, 2020). Further, emotional, behavioural, and functional dysfunction have all been identified in a military context following poor sleep quality (Mantua, Bassey, & Sowden, 2020; Mantua, Bessey et al., 2021). While we acknowledge the constrained sleep opportunity window, uneven groups size, relatively small sample, lack of control over light exposure outside the barracks, and use of actigraphy as limitations in the current study, we did observe improvements in total sleep time and aerobic fitness from chronic exposure to lower-temperature lighting over 6-weeks when compared to a control group. This passive and readily implementable lighting intervention has the potential to offset some of the negative sequelae of cumulative sleep deficit.

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References

Appleman, E., Albouy, G., Doyon, J., Cronin-Golomb, A., & King, B. (2016). Sleep quality influences subsequent motor skill acquisition. *Behavioral Neuroscience, 130*(3), 290.

Banks, S., & Dinges, D. (2007). Behavioral and physiological consequences of sleep restriction. *Journal of Clinical Sleep Medicine*, *3*(5), 519-528.

Beauregard, M. (2007). Mind does really matter: Evidence from neuroimaging studies of emotional self-regulation, psychotherapy, and placebo effect. *Progress in Neurobiology, 81*(4), 218-236.

Boyce, P. (2010). The impact of light in buildings on human health. *Indoor and Built Environment*, *19*(1), 8-20.

Cajochen, C., Münch, M., Kobialka, S., Krauchi, K., Steiner, R., Oelhafen, P., Orgul, S., & Wirz-Justice, A. (2005). High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light. *The Journal of Clinical Endocrinology & Metabolism*, *90*(3), 1311-1316.

Charest, J., & Grandner, M. A. (2020). Sleep and Athletic Performance: impacts on physical performance, mental performance, injury risk and recovery, and mental health. *Sleep Medicine Clinics*, *15*(1), 41-57.
Chellappa, S. (2020). Individual differences in light sensitivity affect sleep and circadian rhythms. *Sleep*, *44*(2), 1-10.
Chellappa, S., Gordijn, M., & Cajochen, C. (2011). Can light make us bright? Effects of light on cognition and sleep. *Brogress in Brain Research*, *190*, 119-133.
Chellappa, S., Morris, C., & Scheer, F. (2020). Circadian misalignment increases mood vulnerability in simulated shift work. *Scientific Reports*, *10*(1), 18614.
Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York: Routledge.
Cook, C., Beaven, C., Kilduff, L., & Drawer, S. (2012). Acute caffeine ingestion's increase of voluntarily chosen resistance-training load after limited sleep. *International Journal of Sport Nutrition Exercise Metabolism*, *22*(3), 157-164.
Dennis, J., Dawson, B., Heasman, J., Rogalski, B., & Robey, E. (2016). Sleep patterns and injury occurrence in elite Australian footballers. *Journal of Science Medicine in Sport*, *19*(2), 113-116.
Driller, M., O'Donnell, S., & Tavares, F. (2017). What wrist should you wear your actigraphy device on? Analysis of dominant vs. non-dominant wrist actigraphy for measuring sleep in healthy adults. *Sleep Science*, *10*(3), 132-135.
Dunican, I., Murray, K., Slater, J., Maddison, K., Jones, M., Dawson, B., Straker, L., Caldwell, J., Halson, S., & Eastwood, P. (2018). Laboratory and home comparison of wrist-activity monitors and polysomnography in middle-aged adults. *Sleep Biological Rhythms*, *16*(1), 85-97.
Durmer, J., & Dinges, D. (2005). *Neurocognitive consequences of sleep deprivation.* Paper presented at the Seminars in Neurology; Copyright © 2005 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA.
Edgar, D., Gill, N., Beaven, C., Zaslona, J., & Driller, M. (2021). Sleep duration and physical performance during a 6-week military training course. *Journal of sleep research*, e13393.
Edgar, D., Gill, N., & Driller, M. (2020). Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course. *The Journal of Sport and Exercise Science*, *4(2)*.
Fairclough, S., & Graham, R. (1999). Impairment of driving performance caused by sleep deprivation or alcohol: a comparative study. *Human Factors*, *41*(1), 118-128.
Figueiro, M., Gonzales, K., & PeDLer, D. (2016). Designing with circadian stimulus. Retrieved from https://icahn.mssm.edu/research/light-health
Figueiro, M., Plitnick, B., Lok, A., Jones, G., Higgins, P., Hornick, T., & Rea, M. (2014). Tailored lighting intervention improves measures of sleep, depression, and agitation in persons with Alzheimer's disease and related dementia living in long-term care facilities. *Clinical Interventions in Aging*, *9*, 1527-1537.
Figueiro, M., Rea, M., & Bullough, J. (2006). Circadian effectiveness of two polychromatic lights in suppressing human nocturnal melatonin. *Neuroscience Letters*, *406*(3), 293-297.
Forquer, L., Johnson, C., & Hypnosis. (2007). Continuous white noise to reduce sleep latency and night wakings in college students. *Sleep*, *9*(2), 60.
Gehrman, P., Seelig, A., Jacobson, I., Boyko, E., Hooper, T., Gackstetter, G., Ulmer, C., & Smith, T. (2013). Predeployment sleep duration and insomnia symptoms as risk factors for new-onset mental health disorders following military deployment. *Sleep*, *36*(7), 1009-1018.
Goel, N., Rao, H., Durmer, J., & Dinges, D. (2009). Neurocognitive consequences of sleep deprivation. *Seminars in Neurology*, *29(4): 320-339*(04), 320-339.
Good, C. H., Brager, A. J., Capaldi, V. F., & Mysliwiec, V. (2020). Sleep in the United States military. *Journal of Neuropsychopharmacology*, *45*(1), 176-191.
Gooley, J., Chamberlain, K., Smith, K., Khalsa, S., Rajaratnam, S., Van Reen, E., Zeitzer, J., Czeisler, C., & Lockley, S. (2011). Exposure to room light before bedtime suppresses melatonin onset and shortens melatonin duration in humans. *Journal of Clinical Endocrinology & Metabolism, 96(3), E463-E472*.

Gotoh, Y. (2006). The latest model of the mini-motionlogger Actigraph made By Ambulatory Monitoring Inc. USA (AMI)(Session, Motion Iogger: Introduction to activity monitoring, The 22nd Symposium on Life Information Science). *Journal of International Society of Life Information Science*, *24*(2), 429-432.

Grandner, M. (2017). Sleep, health, and society. *Sleep Medicine Clinics*, *12*(1), 1-22.

Grandou, C., Wallace, L., Fullagar, H., Duffield, R., & Burley, S. (2019). The effects of sleep loss on military physical performance. *Spoprts Medicine*, *49*(8), 1159-1172.

Halson, S. (2008). Nutrition, sleep and recovery. *European Journal of Sport Science*, *8*(2), 119-126.

Knufinke, M., Fittkau-Koch, L., Møst, E., Kompier, M., & Nieuwenhuys, A. (2019). Restricting short-wavelength light in the evening to improve sleep in recreational athletes–A pilot study. *European Journal of Sport Science*, *19*(6), 728-735.

Kozaki, T., Koga, S., Toda, N., Noguchi, H., & Yasukouchi, A. (2008). Effects of short wavelength control in polychromatic light sources on nocturnal melatonin secretion. *Neuroscience Letters*, *439*(3), 256-259.

Kuriyama, K., Stickgold, R., & Walker, M. (2004). Sleep-dependent learning and motor-skill complexity. *Learning Memory*, *11*(6), 705-713.

Lovalekar, M., Sharp, M., Billing, D., Drain, J., Nindl, B., & Zambraski, E. (2018). International consensus on military research priorities and gaps-survey results from the 4th International Congress on Soldiers' Physical Performance. *Journal of Science and Medicine in Sport*, *21*, 1125-1130.

Lowrie, J., & Brownlow, H. (2020). The impact of sleep deprivation and alcohol on driving: a comparative study. *BMC Public Health*, *20*(1), 1-9.

Luxton, D. D., Greenburg, D., Ryan, J., Niven, A., Wheeler, G., & Mysliwiec, V. (2011). Prevalence and impact of short sleep duration in redeployed OIF soldiers. *Sleep*, *34*(9), 1189-1195.

McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Journal of Biochemia Medica*, *22*(3), 276-282.

Motomura, Y., Kitamura, S., Oba, K., Terasawa, Y., Enomoto, M., Katayose, Y., Hida, A., Moriguchi, Y., Higuchi, S., & Mishima, K. (2013). Sleep debt elicits negative emotional reaction through diminished amygdala-anterior cingulate functional connectivity. *PLOS ONE*, *8*(2), e56578.

Munch, M., Kobialka, S., Steiner, R., Oelhafen, P., Wirz-Justice, A., & Cajochen, C. (2006). Wavelength-dependent effects of evening light exposure on sleep architecture and sleep EEG power density in men. *American Journal of Physiology-Regulatory, Integrative Comparative Physiology*, *290*(5), R1421-R1428.

Mysliwiec, V., McGraw, L., Pierce, R., Smith, P., Trapp, B., & Roth, B. (2013). Sleep disorders and associated medical comorbidities in active duty military personnel. *Sleep*, *36*(2), 167-174.

O'Donnell, S., Beaven, C., & Driller, M. (2018). From pillow to podium: a review on understanding sleep for elite athletes. *Nature Science of Sleep*, *10*, 243.

Rahman, S. A., Hilaire, M. A. S., & Lockley, S. W. (2017). The effects of spectral tuning of evening ambient light on melatonin suppression, alertness and sleep. *Physiology & Behavior*, *177*, 221-229.

Reite, M., Higgs, L., Lebet, J. P., Barbault, A., Rossel, C., Kuster, N., Dafni, U., Amato, D., & Pasche, B. (1994). Sleep inducing effect of low energy emission therapy. *Bioelectromagnetics:*, *15*(1), 67-75.

Ritland, B., Simonelli, G., Gentili, R., Smith, J., He, X., Mantua, J., Balkin, T., Hatfield, B. (2019). Effects of sleep extension on cognitive/motor performance and motivation in military tactical athletes. *Sleep Medicine*, *58*, 48-55.

Shechter, A., Kim, E., St-Onge, M., & Westwood, A. (2018). Blocking nocturnal blue light for insomnia: A randomized controlled trial. *Journal of Psychiatric Research*, *96*, 196-202.

Simon, E., Vallat, R., Barnes, C., & Walker, M. (2020). Sleep loss and the socio-emotional brain. *Trends in Cognitive Sciences*, *24*(6), 435-450.

Stanchina, M., Abu-Hijleh, M., Chaudhry, B., Carlisle, C., & Millman, R. (2005). The influence of white noise on sleep in subjects exposed to ICU noise. *Sleep Medicine*, *6*(5), 423-428.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature*, *437*(7063), 1272-1278.

Teece, A., Argus, C., Gill, N., Beaven, M., Dunican, I., & Driller, M. (2021). Sleep and performance during a preseason in elite rugby union athletes. *International Journal of Environmental Research & Public Health*, *18*(9), 4612.

Um, M., Kim, J., Han, J., Kim, J., Yang, H., Yoon, M., Kim, J., Kang, S., & Cho, S. (2018). Phlorotannin supplement decreases wake after sleep onset in adults with self-reported sleep disturbance: A randomized, controlled, double-blind clinical and polysomnographic study *Phytotherapy Research*, *32*(4), 698-704.

Van der Lely, S., Frey, S., Garbazza, C., Wirz-Justice, A., Jenni, O., Steiner, R., Wolf, S., Cajochen, C., Bromundt, V., & Schmidt, C. (2015). Blue blocker glasses as a countermeasure for alerting effects of evening light-emitting diode screen exposure in male teenagers. *Journal of Adolescent Health*, *56*(1), 113-119.

Van Dongen, H., Maislin, G., Mullington, J., & Dinges, D. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, *26*(2), 117-126.

Vethe, D., Scott, J., Engstrøm, M., Salvesen, Ø., Sand, T., Olsen, A., Morken, G., Heglum, H., Kjørstad, K., & Faaland, P. (2021). The evening light environment in hospitals can be designed to produce less disruptive effects on the circadian system and improve sleep. *Sleep*, *44*(3), zsaa194.

Yeung, V., Sharpe, L., Geers, A., & Colagiuri, B. (2020). Choice, expectations, and the placebo effect for sleep difficulty. *Annals of Behavioral Medicine*, *54*(2), 94-107.