Sleep duration and physical performance during a 6-week military training course

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Summary

Sleep is vital in influencing effective training adaptations in the military. This study aimed to assess the relationship between sleep and changes in physical performance over 6-weeks of military training. A total of 22 officer-trainees (age: 24 ± 5 y) from the New Zealand Defence Force were used for this observational longitudinal cohort study. Participants wore wrist actigraphs to monitor sleep, completed subjective wellbeing questionnaires weekly, and were tested for: 2.4 km run time-trial, maximum press-up and curl-ups before and after 6-weeks of training. Average sleep duration was calculated over 36-nights (6:10 ± 0:28 h:min), and sleep duration at the mid-point (6:15 h:min) was used to stratify the trainees into two quantile groups (UNDERS: 5:51 ± 0:29 h:min, *n* =11) and (OVERS: 6:27 ± 0:09 h:min, *n* =11). There were no significant group x time interactions for 2.4 km run, press-ups, or curl-ups (*p* >0.05); however, *small* effects were observed in favour of OVERS for 2.4 km run (59.8 vs 44.9 s; *d* =0.26) and press-ups (4.7 vs 3.2 reps; *d* = 0.45). Subjective wellbeing scores resulted in a significant group x time interaction (*p* <0.05), with *large* effect sizes in favour of the OVERS group for Fatigue in Week 1 (*d* =0.90) and Week 3 (*d* =0.87), and Soreness in Week 3 (*d* =1.09) and Week 4 (*d* =0.95). Sleeping more than 6:15 h:min per night over 6-weeks was associated with *small* benefits to aspects of physical performance and *moderate* to *large* benefits on subjective wellbeing measures when compared to sleeping less than 6:15 h:min.

Keywords: *exercise recovery, armed forces, sleep restriction, actigraphy*

1. Introduction

An estimated 75% of young adults sleep less than eight hours per night (Owens, 2014). Sleep deficiency is of growing concern for the general public (Brown, Berry, & Schmidt, 2013), and for the military with the recruitment of young adults (Good, Brager, Capaldi, & Mysliwiec, 2020; Miller & Shattuck, 2005). Military personnel can experience even greater challenges with sleep due to the stressful and constantly changing nature of daily training and operation (Good et al., 2020). Sleep management in the military can be complicated due to the need to undertake tasks both day and night at very short notice (Williams, Collen, Wickwire, Lettieri, & Mysliwiec, 2014). In a consensus paper by Lovalekar et al. (2018), sleep was identified as an emerging research priority area at the International Congress on Soldiers Physical Performance, ranking third out of 43 topics identified by 502 attendees from 32 countries at the congress.

It has been established that sleep can be negatively affected during military training (Williams, Collen, Wickwire, Lettieri, & Mysliwiec, 2014), and further impacts physical performance when deployed (Brown et al., 2013), especially when below the recommendation of 7 to 9 h per night for adults stated in the joint consensus of the American Academy of Sleep Medicine and Sleep Research Society (Watson et al., 2015). A review paper by Miller, Matsangas, and Kenney (2012), discussed the effects of sleep deprivation on human performance and outlined research showing that short sleep duration has a negative effect on operational physical performance tasks in the military such as; carrying and lifting, patrolling over distance, weapons handling, and equipment control. It has also been suggested that a lack of sleep may contribute to reduced gains in physical performance and increased injury occurrence in the military (Lentino, Purvis, Murphy, & Deuster, 2013; Miller et al., 2012). Consecutive days of reactive operation can also diminish task effectiveness due to an adverse effect on sleep quality (Miller, Shattuck, & Matsangas, 2011; Williams et al., 2014). Chronically sleeping less than the recommended 7-9 h per night has also been reported to negatively impact physical performance and can contribute to fatalities during military operations (Williams et al., 2014).

Therefore, the importance of sleep and its role in recovery and enhancing physical performance in the military is of the utmost importance (Brown et al., 2013). Williams et al. (2014) determined that insufficient sleep occurs during both basic training and during academic phases of study at military academies and identified that United States (U.S) Military Academy cadets had an average weekday sleep duration of less than five hours per night, and average weekend sleep duration of ~6.5 h (Williams et al., 2014). Previous research supports how the recommended duration of sleep generally does not occur in the military environment (Good et al., 2020; Lentino et al., 2013; Moore et al., 2020). The need for further research on the long term effect of lack of sleep on adaptation to training and physical development in military personal has also been highlighted (Miller, Shattuck, & Mateangas, 2010). Lentino et al. (2013) found that short sleepers were less likely to have a healthy body composition, meet physical training recommendations, and pass their Army physical fitness tests.

The current body of literature is limited when assessing the effect of sleep on long term physical performance adaptation in the military. There is also limited information on the use of objective sleep measures (e.g. wrist actigraphy) in military settings. Therefore, the purpose of this study was to investigate the relationship between sleep (via wrist actigraphy), physical performance, and the subjective wellbeing of officer trainees during 6-weeks of initial military training.

2. Methods

Participants

A total of 22 healthy officer trainees (n = 19 male, n = 3 female, age: 24 ± 5 y; height: 180 ±18 cm; body weight: 81 ± 28 kg [mean ±SD]) from the New Zealand Defence Force (NZDF), Joint Officer Induction Course (JOIC) participated in the current study. The participants were a randomly selected, representative sample from an overall cohort size of n = 94. We were unable to test all 94 participants due to equipment and personnel constraints. Participation in the study was voluntary with inclusion dependent on passing the pre-course medical examination. Trainee’s data was to be excluded if they withdrew voluntarily from the course, or were medically removed, however no trainees withdrew from the course or the study. Ethical approval for the study was obtained from the University if Waikato Human Research Ethics Committee (HREC) (Health) #2018-01.

Study Design

The study design was an observational, longitudinal cohort study, whereby sleep was monitored via wrist actigraphy in all trainees over a 6-week JOIC with physical performance assessed pre and post training. The group was stratified into two quantile groups based on the sleep duration, (UNDERS; less than 6:15 h:min sleep on average, n = 11) and (OVERS; more than 6:25 h:min sleep on average, n = 11). This split was selected as all participants in this cohort fell below the recommended sleep duration of 7 to 9 h per night (Watson et al., 2015). Fitness and performance data were collected in Week 1 and 6 of the JOIC across two 90-minute sessions, with subjective wellness questionnaires collected weekly. The sleep of trainees was monitored via wrist actigraphy for the entire duration of the 6-week course in order to assess the relationship between sleep and changes in physical performance.

Wrist-Actigraphy

Wrist-actigraphy has previously been used as a practical sleep assessment method in a military environment (Kushida et al., 2001). A Micro Motionlogger® (Ambulatory Monitoring Inc, Ardsley NY, USA) Sleep Watch was allocated to every trainee, data were collected using the device's zero-crossing mode and recorded in 1-min epochs with individual devices worn continuously for the full duration of the course during both wake and sleep on whichever wrist felt comfortable (Driller, O'Donnell, & Tavares, 2017). The validity and reliability of the Micro Motionlogger has previously been reported and deemed acceptable (Tryon, 2008). Sleep and wakefulness were inferred based on activity count using the Cole-Kripke software algorithm for sleep estimation using the methods described by Quante (2018). This technique using the AMI software analysis has previously been compared to polysomnography and shown to correctly distinguish sleep from wakefulness approximately 88% of the time (Morgenthaler, 2007). The device was removed for any water submersion activities and placed back on the wrist immediately post activity. Double scoring by two trained members of the research team was undertaken on 33% of randomly selected sleep files to assess the reliability of manual selection of sleep intervals. Any discrepancies of more than 15 minutes for either ‘start time’ or ‘end time’ of the sleep interval were flagged and re-analysed. A good interrater reliability agreement rate of 88% was achieved (McHugh, 2012).

Subjective Wellbeing Monitoring

During the study period, trainees completed a psychological wellbeing questionnaire at the end of each week that was based on the recommendations of Hooper and Mackinnon (1995). The questionnaire assessed each trainee’s fatigue, sleep quality, general muscle soreness, stress levels, and mood on a five-point scale of 1 to 5 with 0.5 point increments (5 = very-good, 4 = good , 3 = normal, 2 = poor, 1 = very-poor).

Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In Weeks 3 and 4, the intensity of PT was increased and Weeks 5 and 6 then focused on functional fitness and conditioning, including increased load carriage with field packs and weapons. A total of 18 90-minute sessions, including warm-up and cool-down, 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 (Table 1). The full detail of the JOIC training programme has been described previously (Edgar, Gill, & Driller, 2020).

Insert Table 1 here

Fitness Testing

The JOIC fitness evaluation was conducted by NZDF Physical Training Instructors before and after the course. This evaluation consisted of three key components: i) 2.4 km time-trial run; ii) maximum press-ups; and iii) maximum curl-ups. The 2.4 km road run, which has been shown to provide an effective evaluation of aerobic fitness (Booth, Probert, Forbes-Ewan, & Coad, 2006; Burger, Bertram, & Stewart, 1990), was completed on a sealed flat road. The run was conducted in a similar fashion to that described by Knapik et al. (2006), where all participants started together, but individual effort was assessed by participants completing the distance in the quickest time possible. Run times were measured via stopwatch to the nearest second (Edgar et al., 2020).

Curl-ups, as used by Vera-Garcia, Grenier, and McGill (2000), provided an evaluation of local muscular-endurance of the core where repetitions were completed until failure. The curl-up was performed with participants in a supine position with knees bent flexed at 90° and feet flat on the floor. Hands were held in a fist with arms straight. Hands slid up the thigh until the wrist met the apex of the knee. Hands then slid back down the thigh until the shoulder blades and shoulders touched the ground. A repetition was counted by the instructor every time the wrist reached the apex of the knee until failure. There was no time limit on repetitions, but they were completed in a continuous fashion with a pause of only 1 to 2 seconds between attempts (Edgar et al., 2020).

Press-ups were used to assess upper-body muscular-endurance similar to the protocol outlined by Booth et al. (2006) and Knapik et al. (2006) and were performed on a flat wooden gymnasium surface. Hands were placed on a line in the prone press-up position just slightly wider than shoulder width. A 'ready' cue was then given where the body position was adjusted to the start position of arms straight, feet shoulder width apart and the head looking downward. From the start position the body was lowered eccentrically with a straight-line maintained between the shoulders and heels, until the elbows were at 90°. During the concentric phase arms were extended until straight while maintaining the back and head positions. Repetitions were completed to fatigue in a continuous fashion and counted by the instructor every time the full range of motion was completed. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to participants being stopped (Edgar et al., 2020).

Statistical Analysis

Scores are shown as mean ± SD values unless stated otherwise. We calculated the average sleep duration of all 22-participants over the duration of 36-nights and at the mid-point of total sleep, two quantile groups were identified: UNDERS; averaging less than 6:15 h:min of sleep per night, n = 11, and OVERS; averaging more than 6:15 h:min sleep per night, n = 11. The initial intention was to split the sleep groups by those obtaining >7 hours (the recommended sleep duration per night for adults) compared to those obtaining <7 hours per night. However, given all participants obtained less than 7 hours per night, the decision was made to split the group in half for further analysis from the median of 6:15h:m. All statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. To examine whether there were any differences between groups, Group (UNDERS and OVERS) x Time (pre and post or weekly) two-way multivariate analysis of variance (MANOVA's) were performed on the pre to post performance data and weekly subjective wellness data (mood, stress, soreness and fatigue). A Bonferroni adjustment for multiple pairwise comparisons 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 groups were calculated using Cohen's *d,* and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate and large*, respectively (Cohen, 1988). Effects were deemed *unclear* if the 95% confidence intervals overlapped the *small* thresholds for both positive and negative effects (d ±0.2). Correlation coefficients (Pearson's r-values) were determined for the whole group (n=22) to describe associations between sleep and physical performance, and interpreted using thresholds of >0.50: strong, >0.30: moderate, >0.10: weak (Karwowski & Gralewski, 2013).

3. Results

The average sleep duration across the entire group (n=22) for the JOIC 6-week training course was 6:10 ± 0:28 h:m. Total weekly sleep reduced by 6 ± 2% (p = 0.01) from Week 1 to 6, the equivalent of a 22 ± 10 minute per night reduction in total sleep duration. The OVERS group slept on average 6:27 ± 9.0 h:min, compared to the UNDERS group averaging 5:51 ± 28.5 min, with the OVERS group accumulating 22:20 h:min more sleep than the UNDERS group over the 6-week period (p < 0.01).

The MANOVA detected a significant time effect across all trainees pre-post, regardless of group for 2.4 km run time, press-ups, and curl-ups (all $p \leq 0.01$), but no significant group x time interactions were detected (p >0.05). However, effect size analysis identified an overall performance improvement favouring OVERS in the 2.4 km run (d = 0.29, *small*) and press-ups (d = -0.30, *small*), with a *trivial* difference in the curl-ups (d = -0.12). The OVERS group improved 14.9 s more than the UNDERS group (59.8 vs 44.9 s) in the 2.4 km run and by 1.5 more repetitions (4.7 vs 3.2 rep) in the press-ups (Table 2, Figure 1).

Insert Table 2 here

Insert Figure 1 here

Subjective wellbeing data for the 6-week training period demonstrated significant and *large* effects in favour of the OVERS group for fatigue and soreness at Weeks 1, 3 and 4. While not statistically significant, there were also *moderate* effects favouring the OVERS compared to UNDERS for stress and mood in Weeks 3 and 4 (Figure 2).

Insert Figure 2 here

As a supplementary analysis we looked at the correlation between sleep and performance metrics and sleep and wellbeing measures. Regarding performance variables, a strong relationship was observed between time in bed and faster 2.4 km run time (r = -0.53); however, only weak relationships between time in bed or sleep duration were observed for the Press-up or Curl-up (r = -0.04 to 0.12).

4. Discussion

The main results from this study showed that sleeping on average, more than 6:15 h:min per night lead to *small* gains in physical performance measures and had beneficial effects on aspects of subjective well-being in officer trainees over a 6-week training period when compared to sleeping less than 6:15 h:min per night. The study reinforces previous research and demonstrates that the recommended 7-9 hours of sleep generally does not occur in the international military personnel (Good et al., 2020; Lentino et al., 2013; Moore et al., 2020). Longer sleep duration in the current study correlated strongly to faster 2.4 km run times, improved number of press-ups and a shift toward positive fatigue, mood, soreness, and stress measures. This data indicates that more time in bed will likely support physical performance adaptation and ongoing physical development in individuals with sleep durations below the recommendation of 7 to 9 h (Watson et al., 2015).

Interestingly, the performance improvement observed in the current study was gained in a state similar to that previously described as 'short sleep duration', where military members consistently sleep on or around 6 h per night (Good et al., 2020). While there were no significant differences observed between groups for performance measures, there were *small* effect sizes in favour of the OVERS group for 2.4 km run and press ups.

Previous military research by Ritland (2019) found a positive relationship between sleep extension (1.36 ± 0.7 h) and performance benefits in psychomotor vigilance, executive functioning, standing broad jump distance, and motivation levels in officers under training. In a physically demanding professional rugby environment a ~1 hour sleep extension (from 6:52 to 7:35 h:mm) also showed improved reaction times in a five minute psychomotor vigilance response test (Swinbourne, Miller, Smart, Dulson, & Gill, 2018). Although sleep architecture was not measured in the current study, the aerobic improvement seen in the OVERS group in the current study could potentially be related to an increase of growth hormone release and its relationship to physiological recovery (Dattilo et al., 2011). Growth hormone levels have been shown to effect physical performance, aerobic capacity and specifically, VO_2 max; thus it is plausible that these physiological processes have supported muscle recovery and growth and the observed increase in press-ups and run times (O'Donnell, Beaven, & Driller, 2018; Widdowson, Healy, Sonksen, & Gibney, 2009).

Subjective wellbeing in the current study was affected by the quantity of sleep acquired between groups. The reductions in perceived fatigue and soreness in favor of the OVERS group in Weeks 3 and 4 were recorded during stages of high physical and cognitive demand. These observations highlight the important relationship between sleep and enhanced physical and mental wellbeing (Charest & Grandner, 2020; Lentino et al., 2013). Positive outcomes on Stress and Mood scores were also seen in the OVERS group, with reduced stress in Week 4 corresponding with lower soreness, and improved Mood in Week 1. Our data support previous research from Good et al. (2020), that also outlined the strong association between sleep quality and perception of stress and fatigue in military populations, and the association between sleep quantity, cognitive function and reduced physical capacity. In a similar operational environment, McGillis et al. (2017), found that wildland attack firefighters physical performance could be maintained in the initial stages of extended periods of poor sleep and broken shifts (~5 hours a day over 14 to 18 days), but as days progressed, poor judgment, deflated mood, increased fatigue, muscle soreness, and a decrease in reaction time and physical performance did occur.

Similar to the findings of Moore et al. (2020), the current study observed short sleep duration in this initial stage of military training, due to non-standard shift work schedules and routinely participating in demanding and highly variable daily schedules of greater than 12 hours in duration across several days. A study by Miller and Shattuck (2005), with similar aged officer trainees and sleep to the current study, found that U.S Military Academy Cadets sleep ranged from 5 h and 50 min to 6 h 32 min during initial training and trainees often struggled with intense physical training. It has also been acknowledged that military training, even at academies and officer training schools similar to the JOIC environment, is characterised by highly demanding physical and academic training loads with limited sleep opportunities (Moore et al., 2020). Further to this finding, research conducted by the U.S Naval postgraduate school over the last decade highlights a common trend of soldiers, sailors and Marines world-wide accumulating high levels of sleep debt (Miller et al., 2012), supported by the results of the current study.

Within the constraints of conducting research in the military environment, we acknowledge a limitation in the current study was that the time available to sleep was confined to a specific window from 'lights out' at 2200 hr to 'to wakeup' at 0545 hr. This narrow window of sleep opportunity led to a relatively minor difference in sleep duration between the OVERS and UNDERS groups. It is possible that if the sleep and wake times were not set, self-selected differences in sleep duration might have been more pronounced, and had a greater impact on the differences in the outcome variables. Future research in military settings should consider comparing groups where different sleep opportunities are set (e.g. <6 hours versus the recommended 7 to 9 h) via manipulating sleep and wake times, while measuring physical, cognitive and wellbeing variables.

In conclusion, results from this study have demonstrated that in two groups of trainees who were grouped by sleep duration derived from wrist-actigraphy, a non-significant but *small* improvement in aerobic fitness and press-up performance were seen in recruits sleeping more than 6:15 h:min compared to those sleeping less than 6:15 h:min per night. The group sleeping approximately 37 min more per night, and thus 22:20 h:min over the duration of the training course, also showed benefits in aspects of perceived well-being (fatigue, soreness, mood and stress). Thus, even a modest increase in sleep duration in a short sleeping cohort may result in enhanced physical performance and perceived wellbeing.

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Figure Legends

Figure 1. Percentage performance improvement by group over the 6-week Joint Officer Induction Course. Black bars: OVERS (>6:15 min per night) and white bars UNDERS (<6:15 min). S: small difference between groups. Error bars represent standard deviations.

Figure 2. Weekly subjective wellbeing monitoring of Fatigue, Stress, Soreness and Mood by group over the 6-week Joint Officer Induction Course. Solid line; OVERS (>6:15 h:min per night) and dashed line; UNDERS (<6:15 min). * Significant difference between groups (p<0.05); L: Large effect; M: Moderate effect. Error bars represent standard deviations.

Table 1. Joint Officer Induction Course Physical and Military Training Program Outline.

Note: A ten minute 6:00 am early morning activity (EMA) was also conducted daily including stretching, mobility and cognitive reaction games.

Variation	**Activity**	**Duration**	**Number of Sessions Per Week**						
	Physical Training		**Wk 1**	**Wk 2**	**Wk 3**	**Wk 4**	**Wk 5**	**Wk 6**	**Total**
1	Aerobic Interval Running	90 min	1	1	1	1	1		5
2	Circuit Training (Strength Endurance)	90 min	1	1	1	1	1		5
3	Swimming / Pool Circuit	90 min	1	1	1	1		1	5
4	Stretch, Mobility & Recovery Flush	90 min	1	1		1		1	4
	Intensity varied between: High / Medium / Low								
	Military Training								
1	Drill (Parade Ground)	30-60 min	3	2	3	2	2	3	15
2	Weapons Training	4hr +	1	4	3	2	2	3	15
3	Land Navigation	3-6 hr		1	2	1			4
4	Sea survival	24 hr					1		1
5	Bush Craft	6hr		1	1	1			3
6	Tactical Field Exercise	5 days						1	1

Table 2. Mean ± SD pre to post performance test values for UNDERS (<6hr 15min sleep per night, *n* = 11) and OVERS (>6hr 15min sleep per night, *n* = 11), and group x time interactions (*p*-value and effect size).

	2.4km Run time (s)				**Press-Ups (Repetitions)**				**Curl-Ups (Repetitions)**			
	Pre	**Post**	***p*-value**	***Effect size (d)***	**Pre**	**Post**	***p*-value**	***Effect size (d)***	**Pre**	**Post**	***p*-value**	***Effect size (d)***
UNDERS	601 ± 75	556 ± 39	<0.01		29 ± 6	32 ± 8	<0.01		40 ± 16	44 ± 17	0.05	
OVERS	629 ± 47	569 ± 42	<0.01		27 ± 8	31 ± 8	<0.01		39 ± 22	43 ± 19	0.09	
Group x Time Interaction			0.37	0.29, *Small*			0.34	-0.30, *Small*			0.79	-0.12, *Trivial*