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RESEARCH

Can sleep hygiene interventions affect strength and power outcomes for female athletes?

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Abstract

Improved sleep can enhance sprint, endurance, and sports-specific skills; however, it is yet to be investigated whether improved sleep indices could enhance strength and power performance. Sleep hygiene (SH) is growing in popularity as a tool to enhance sleep indices amongst athletic cohorts, yet the optimal delivery strategy of sleep hygiene education is yet to be determined. Using a randomised, controlled design with repeated measures, this study recruited 34 female footballers playing in WSL or WSL academy league. Participants were split into 3 groups: one receiving both group-based and individualised sleep hygiene education, one receiving only group-based SH education and a control group receiving no education. Monitoring of sleep (actigraphy, diaries) and physical performance (countermovement jump, isometric mid-thigh pull) was carried out at week 1, week 4 and week 7. Split-plot ANOVAs were used to assess for differences between groups × weeks, and groups × time. Individualised sleep hygiene education resulted in significantly improved sleep duration ($p=0.005$), latency ($p=0.006$) and efficiency ($p=0.004$) at week 7 compared to controls, whilst also resulting in significantly improved countermovement jump scores ($p=0.001$) compared to control. Results of this study suggest that jump performance may be affected by sleep factors, and that individualised SH may be superior to group-based SH, providing information to coaches regarding training optimisation and the efficacy of SH education methods.

Keywords Sleep · Female athletes · Strength · Sleep hygiene · Countermovement jump

Introduction

Sleep and exercise influence each other in a bidirectional relationship, via multiple physiological and psychological pathways [1]. Alongside physical conditioning, nutrition and psychology, sleep is now considered a key influential variable for physical performance [2, 3], with effects being modulated by factors including age, sex, and current training levels. Maximising sleep factors can be one way to enhance physical performance, with improvement in sleep coinciding with improvements in sports specific skills (basketball free throw percentage improved by 9% [4], improved accuracy of tennis serve, 35.7% vs. 41.8% pre-post, [5]). Conversely, short sleep has been shown to negatively affect jump performance, joint coordination, mood, rating of perceived exertion and injury risk [6–8]. With Sargent et al. [9] reported only 3% of athletes are meeting their self-assessed sleep needs, and 71% falling short of adequate sleep duration by an hour or more, it is evident many athletes are operating in a sleep debt, which could be affecting physical performance.

Sleep hygiene (SH) can be defined as practising habits that facilitate sleep, and avoiding behaviours that inhibit sleep [10]—it is a simple, non-invasive, low-cost strategy which can be used to enhance many sleep indices [11, 12], and as such, may be a useful tool to enhance athletes' sleep and minimise negative effects on performance. Many previous studies have implemented group-based SH delivery: [13] used a single group design to determine whether group-based SH education was effective in improving sleep indices for elite netballers. Results showed a single SH education session significantly improved total sleep time, wake variance, and wake episode duration. Despite the vast inter and intra individual variation of sleep, very few studies have utilised an individualised SH education approach within

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athletic populations, an approach which tailors SH education to the individual based on previous sleep data, current habits, and individual lifestyle. The few studies that have taken an individualised approach have demonstrated positive results—Driller et al. [14] provided 30 min individualised SH education for 9 male cricketers, with participants showing post-education improvement in sleep latency, and sleep efficiency. In a case study of an academy footballer, Edinborough et al. [15] found an individualised SH education intervention, to be effective in improving wakings per night and wakings per hour, coinciding with an improvement in the athletes' self-report of Pittsburgh Sleep Quality Index [16]. Interestingly, Dunican et al. (2020) utilised both group-based education (~2 h) and individualised SH education (~20 min) but found this did not result in a significant increase to total sleep time for female basketball players. The authors hypothesised that this non-significant result may be since many players were already sleeping > 8 h at baseline, thus potentially already fulfilling their sleep needs and demonstrating a ceiling effect for that parameter. Additionally, the intervention contact time may play a role in the aforementioned insignificant findings, with a single individualised SH session of 20 min perhaps of an insufficient duration to promote meaningful change.

Gaps in the literature investigating the interaction between sleep and strength and power performance have already been identified [8, 17]. Due to the potential impact on physical performance, there is a need to understand the interaction between sleep and physical performances focusing on strength and power. Strength performance, defined as the ability to exert force on an external object or resistance (Suchomel et al., 2016), is determined by many factors, including musculotendinous stiffness, motor unit recruitment and synchronisation, rate coding (the rate at which action potentials are discharged), intra and intermuscular coordination and neural drive [18], whilst power can be defined as force × velocity. It has previously been noted that any physical performance requiring motor control can be impaired by insufficient sleep [19], with previous studies reporting sleep restriction to decrease vertical jump height [7, 20], and negatively affect maximal strength performance [21].

It is evident that more research is needed with regards to sleep interventions for female athletes and despite female gender being described as a risk factor for poor sleep [8], there is limited research investigating individualised SH education for female athletes. In a recent systematic review, Craven et al. [22] evaluated 77 studies to assess the effects of acute sleep loss on physical performance,within that review, 89% of participants were male, demonstrating the gender gap across this area of research. Similarly, Gwyther et al. [23] conducted a systematic review examining sleep interventions for performance and also noted underrepresentation of female athletes, with representation of male athletes four times as high. Female athletes commonly have a worse sleep status than male counterparts, reporting a variety of negatively impacted sleep indices compared to males. Kawasaki et al. [24] found female athletes were more likely to report subjectively poor sleep quality (48.8% females,31.4% males) than male athletes. The reason for such male–female discrepancy in sleep indices could be attributed to hormonal changes across the menstrual cycle (MC), yet research conclusions are mixed regarding the impact of MC phases on sleep factors, likely due to the high intra- and inter-individual variation of the MC.

Walsh et al. [8] highlighted the fact there is a lack of research regarding the role of sleep as a tool to enhance strength and power variables, thus this study would endeavour to provide novel insights into this, by investigating the efficacy of two SH education methods, one group-based, and one individualised, alongside two common tests for lower body power and strength. The aims of this study were to investigate whether sleep hygiene interventions affect strength and power outcomes, with a secondary aim to assess whether there are any differences between individualised and group-based SH education on sleep indices in female athletes. Due to the existing knowledge regarding the effectiveness of SH on sleep and physiological pathways of performance, it was hypothesised that sleep hygiene education would be a useful tool to enhance strength and power performance, via improve sleep indices. Due to the high degree of individual variation regarding factors affecting sleep, it was hypothesised individualised SH would be more effective in improving sleep indices than group-based education.

Method

Participants

A-priori power analysis (G*power, version 3.1) was used to establish a minimum sample size ($n = 30$) for the present investigation. Sample size calculations were based on a medium effect size of 0.5 and a type I (α) error rate of 5%. A convenience sample of 36 female football players volunteered to take part; one participant withdrew following baseline data collection and was removed from the study. One further participant withdrew from the study in Week 3; meaning $n = 34$ completed the study. All participants gave informed consent prior to data collection. All participants (subject demographics detailed in Table 1) were part of the U21 or First Team squad at their football clubs in the United Kingdom and had played regularly in the Women's Super League (WSL) or the WSL Academy League in the previous season. Throughout the study, participants slept in their usual, home-based environment.

Table 1 Subject demographics

Subject demographics		
	Mean	SD
Age (years)	20.3	1.4
Height (cm)	164.2	11
Mass (kg)	62.1	10.8
Weekly training hours (football)	10.4	4.1
Weekly training hours (gym based)	4.6	0.9

Across all participants, 15 reported regularly taking hormonal contraceptives (type unspecified), whilst 19 were classified as naturally menstruating women. Prior to the commencement of the study, all participants were informed of study requirements and gave informed consent. Participants were excluded if they reported a pre-existing sleep disorder, had a menstrual cycle outside the range of 21–35 days or did not give informed consent. Institutional ethical approval was issued (approval number 2023-12534) in accordance with the Declaration of Helsinki 1964 (revised 2013).

Experimental design

A randomised, controlled trial with repeated measures was used to assess whether sleep hygiene interventions could affect strength and power performance, and whether the method of SH delivery (individualised education vs. group) has any effect on sleep indices and performance. Given the potential for seasonal adjustment of sleep patterns [25] and the potential variability of sleep patterns throughout a football season, it should be noted that data was collected during pre-season in July and August.

A random number generator (www.randomizer.org) was used to allocate participants into one of three groups: Control, Group SH, Individualised SH with $n = 12$ in each. A schematic of the study protocol is detailed below in Fig. 1.

Sleep monitoring – Week 1, Week 4 and Week 7

All participants completed the Athlete Sleep Behaviour Questionnaire (ASBQ) [26] to determine current sleep behaviours and sleep hygiene. The survey asked participants to rate on a Likert scale how frequently they engage in specific behaviours (never = 1, rarely = 2, sometimes = 3, frequently = 4, always = 5). Scores were summed to provide an ASBQ global score,higher scores were considered indicative of worse sleep habits and sleep hygiene. Participants also completed the reduced morningness:eveningness questionnaire (rMEQ, [27]), with scores summed to determine chronotype classification as reported in Adan and Almirall [27]: definitely morning type (22–25), moderate morning type (18–21), neither type (12–17), moderate evening type (8–11), definitely evening type (4–7).

All participants were allocated an actigraph (GeneActiv Original, Activinsights, Cambridge UK) which they were instructed to wear continuously, only removing them for pre-season matches. The device contains a triaxial MEMS-accelerometer with a range of ± 8 g and a sensitivity of ≥ 0.004 g (te [28]). It recorded both motion-related and gravitational

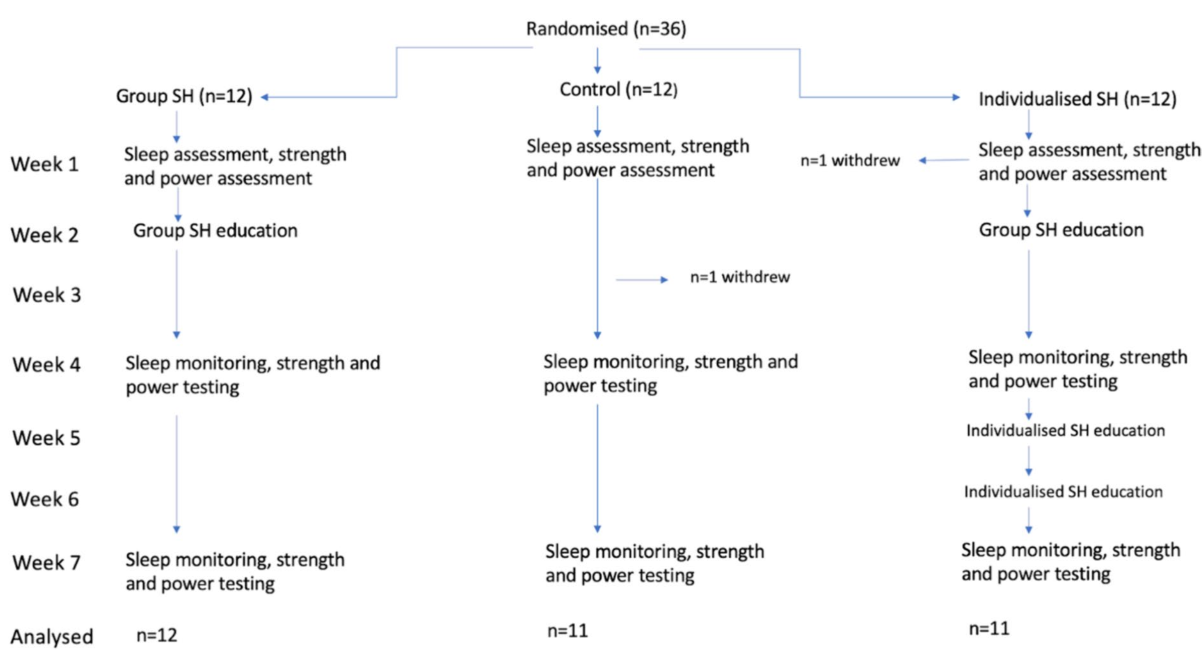

Fig. 1 Participant flow diagram

acceleration and has a linear and equal sensitivity along the three axes. Devices were set with a sampling rate of 50 Hz and participants were instructed to wear the device on whichever wrist they felt more comfortable with [29]. Every week where sleep data was collected, each morning participants were asked to provide self-reported sleep quality (Likert scale response) and "lights out" time and wake up time via a Microsoft Forms questionnaire, sent by email to each participant. Participants were sent a daily reminder to complete this via a text message from coaches. If a missing data set was detected, participants were reminded again to submit their data at lunchtime and received an additional reminder from coaches to submit their data the following day—there was a 6% occurrence rate of this throughout the testing period. Actigraphy-derived sleep parameters are detailed in Table 2 below:

Strength and power assessment – Week 1, Week 4 and Week 7

In Week 1, 4 and 7 of the study, all participants completed testing of countermovement jump (CMJ), and isometric mid-thigh pull (IMTP). All athletes had prior experience of both tests as part of physical testing requirements from their club and had completed the test regularly throughout the previous season. Week 1 was considered as baseline data. Participants followed a standard 15 min warm up following a RAMP protocol [30] led by a strength and conditioning coach, after which warm up repetitions of each test were carried out (detailed below). Strength and power tests were conducted by the same tester throughout the study. Given the potential for circadian influence on performance [31], performance testing was carried out at the same time of the day throughout the study.

Countermovement jump (CMJ)

The CMJ test was conducted prior to the isometric mid-thigh pull and was performed on VALD ForceDecks (Force Decks, VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. Participants were instructed to keep their hands on their hips to eliminate arm swing and perform a fast downward motion to around 90° knee flexion, followed by an immediate upward vertical jump as high as possible, all in one sequence [32]. Prior to the test attempts, participants performed 2 jumps at 75% maximal effort, each separated by 2 min,this was designed to act as an extended warm up, additional familiarisation, and reinforce test technique [33]. For the test attempts, participants were instructed to deliver a maximal attempt and performed the test 3 times, each attempt separated by 2 min. Jump height (cm) was calculated from impulse momentum [34, 35] computed by the VALD ForceDecks software (VALD Performance, FD4000, Queensland, Australia). Software detected the initiation of movement as a 30 N deviation from the initial body weight calculation, eccentric to concentric phase moment as the lowest centre of mass displacement, and take-off as the moment the vertical forces fell 30 N below body mass [36]. [37] stated the importance of defining and using a consistent threshold to identify take off and the importance of using a consistent threshold to enable comparisons between trials and testing sessions. The best of the 3 trials was used for analysis.

Isometric mid-thigh pull (IMTP)

Methodological guidelines from Comfort et al. [38] were followed in the administration of this test, with testing carried out on VALD ForceDecks (VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. Participants were initially asked to self-select a start position that reflected the start of the second pull of a clean (mid-thigh clean pull, see [39]),this allows for athletes' individual anthropometrics to be considered in the adoption of an optimal pulling position [38]. Knee and hip angles were then checked with a hand-held goniometer to ensure knee angles were within the range of 125–145 and hip angles were within the range of 140–150 [38] and straps were used by all athletes to mitigate the risk of grip strength becoming a limiting factor [38]. Prior to testing, single reps were performed at 50% maximal effort for 5 s, and 75% maximal effort for 5 s, each separated by 60 s rest, with the purpose of serving as further warm up, additional familiarisation and reinforcing test technique [40]. For the beginning of the maximal attempts, the tester gave the athlete a countdown of 3,2,1 before the initiation of the test. Participants were instructed to "push their feet into the ground as hard and fast as possible", maintaining the tension for a period of 5 s timed by the tester. This verbal cue has been previously shown to result in greater peak force than focusing on

Table 2 Actigraphy-derived sleep parameters

Sleep variable	Units	Description
Latency	min	Number of minutes from time at lights out to sleep onset
Duration	hh:mm	Time at start of sleep interval to end of sleep interval, minus number of minutes awake (WASO)
Efficiency	%	Sleep duration divided by time in bed × 100

internal cues [41]. Each trial was separated by 2 min rest. The highest force generated was reported as the absolute peak force (PF) with relative PF then calculated by dividing this by the body mass of each participant [42]. The best of the 3 trials was used for analysis.

Group sleep hygiene education – Week 2

A 40 min group sleep hygiene education was delivered to both SH group and Individualised SH group in Week 2 of the study; the session was led by a strength and conditioning coach with specific expertise on athlete sleep. The session took place in a private room in the athletes' training ground, with two technical coaches also present. The focus of the session was to provide athletes with general information regarding SH and provide practical tips on the following areas—maintaining a regular bedtime and wake time [43], maintaining a cool and dark bedroom [44], avoidance of light-emitting screens before bed [14], and implementation of relaxation techniques before bed [45]. The session was delivered in a way that focused on positive reinforcement and potential performance benefits, rather than negative impacts of bad habits. The session concluded with participants writing down 2–3 practical changes to their sleep habits which they would aim to implement following the session.

Individual sleep hygiene education – Week 5 and 6

Participants within the Individualised SH group were each given one one-on-one session per week, delivered via Microsoft Teams, where they were provided with individualised advice on their sleep hygiene, based on week 1 sleep data and self-reported perception of areas they needed to improve. Any areas reported above a "3 = sometimes" on the ASBQ was discussed as an area for improvement with each participant. Discussions aimed to establish and prioritise practical changes participants could implement daily and to overcome any concerns regarding changes. Participants were encouraged to ask questions and to focus on their own specific requirements, and each session concluded with the participant writing down 2–3 key areas of focus for their sleep habits which they would aim to implement. The initial individualised session for each participant lasted 30 min, with the second session lasting 20 min, to include a review of the success of previous action points, discussions of any concerns, and if necessary, amendments of any practical advice based on individual circumstances.

Statistical analysis

Descriptive statistics (mean ± SD) were calculated for all variables. Data was checked for normality using Shapiro–Wilk tests, and inspection of skewness-kurtosis. Between and within session reliability was assessed using two-way mixed intraclass correlation coefficients (ICC) and %CV for all performance outcome variables. ICC values were deemed as poor if ICC < 0.50; moderate 0.50–0.74; good if 0.75–0.90; and excellent if ICC > 0.90 [46],%CV was considered acceptable < 10% [47]. Split-plot ANOVA were used to examine the effects of SH education on strength and power outcomes, by using a 3 (group: Individual SH, group SH, control) by 3 (time: week 1, week 4, week 7) design. Sphericity was verified by Mauchly's test. For each variable, the main effects for group × week were examined, as well as the group × time interaction. To protect for familywise error, statistical significance was set at $p < 0.008$ via Bonferroni correction [48]. Partial eta squared was reported to give an indication of effect size, with values of 0.01, 0.06 and 0.14 considered as small, medium and large effect sizes respectively [49]. For chronotype, data was analysed from raw rMEQ scores rather than classifications. Statistical analyses were performed on SPSS (version 29.0, SPSS, Chicago, Illinois) and Microsoft Excel (Microsoft Office 365, Microsoft Corporation, USA).

Results

Intraclass correlation coefficients (ICC) reliability measures ranged from good to excellent [46] across measured performance variables, and %CV also met pre-defined acceptable thresholds (Table 3).

Table 3 ICC and %CV for performance measures

	Week 1		Week 4		Week 7	
	ICC	%CV	ICC	%CV	ICC	%CV
CMJ						
Jump height (cm)	0.89	7.3	0.86	8.0	0.85	7.6
IMTP						
Absolute PF (N)	0.97	7.1	0.93	7.2	0.94	8.9
Relative PF (N/kg)	0.96	7.5	0.92	8.7	0.92	9.8

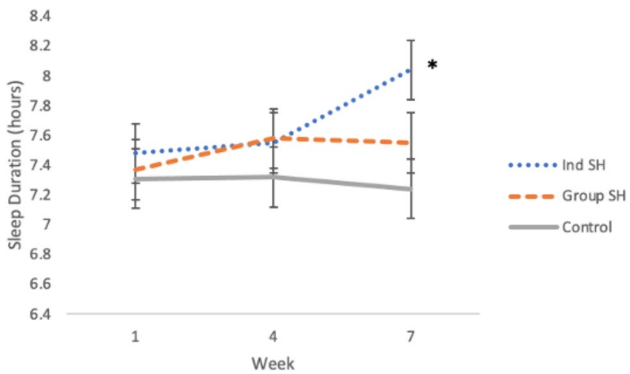

Fig. 2 Changes in mean actigraphy-derived sleep duration across weeks 1–7

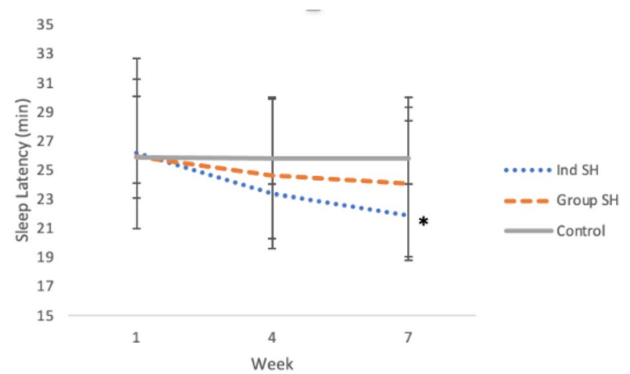

Fig. 4 Changes in mean actigraphy-derived sleep latency across weeks 1–7

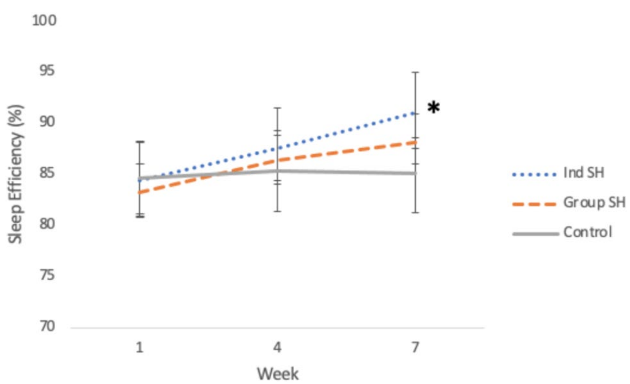

Fig. 3 Changes in mean actigraphy-derived sleep efficiency across measured week 1–7

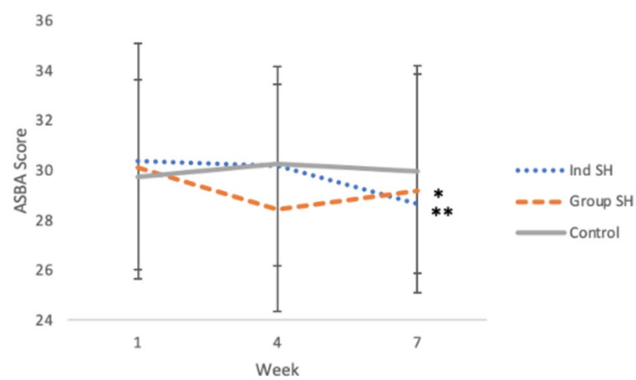

Fig. 5 Changes in mean self-reported ASBQ score

Sleep measures

Pairwise comparisons of sleep duration indicated a significant difference between Ind SH and control at week 7 (F (2, 235) = 6.53, *p = 0.005, $\eta_p^2 = 0.29$) (Fig. 2).

Group × week comparisons for sleep efficiency indicated significant differences were identified between Ind SH and control at week 7 (F (2, 235) = 8.85, *p = 0.004, $\eta_p^2 = 0.246$) (Fig. 3).

Pairwise comparisons for sleep latency indicated a significant difference between Ind SH and control (F (2, 235) = 10.65, *p = 0.006, $\eta_p^2 = 0.081$) at week 7. Group × time interactions demonstrated a significant difference from week 1 to week 7 within the Individual SH group (− 3.29 min, $p = 0.001$) (Fig. 4).

Group × week comparisons indicated changes in self-reported ASBQ score were significant between Ind SH and control group (F (2, 31) = 14.35, *p = 0.004), and group SH and control (**p = 0.002), $\eta_p^2 = 0.085$ at week 7 (Fig. 5).

Group × week comparisons for sleep quality indicated significant differences between Individual SH and control

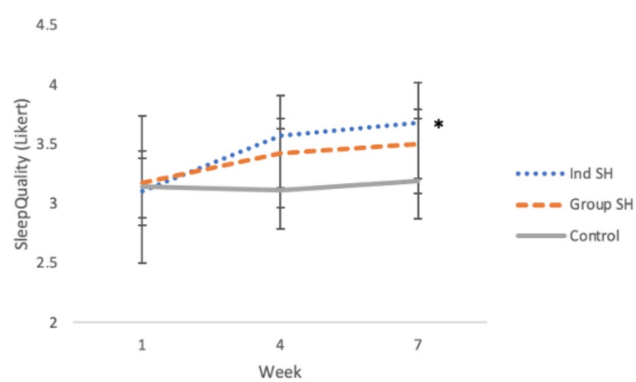

Fig. 6 Changes in self-reported sleep quality across weeks 1–7

(F (2, 235) = 6.22, *p = 0.001) and Individual SH and group SH at week 7 (*p = 0.003), $\eta_p^2 = 0.35$ (Fig. 6).

Individual vs group sleep hygiene delivery

Changes over time between Individual SH and group SH demonstrate no significant differences at week 1 or week

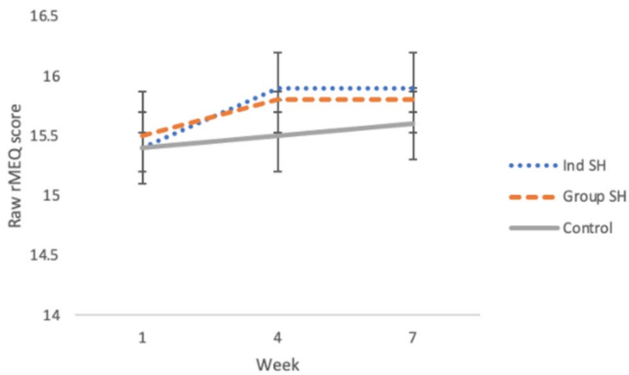

Fig. 7 Change in mean self-reported rMEQ score across weeks 1–7

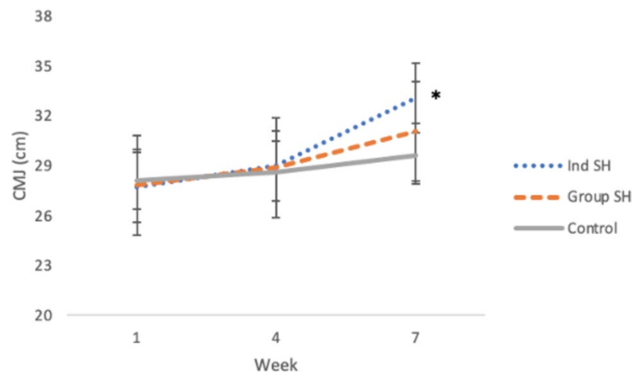

Fig. 8 Changes in CMJ height across weeks 1–7

4 between the two groups across any sleep parameters. At week 7, significant differences were observed between Individual SH and group SH in sleep quality ($p = 0.003$) but no other sleep parameters were significantly different, despite Individual SH presenting better mean values at week 7 for all sleep parameters. Individual SH significantly enhanced sleep efficiency ($p = 0.004$) compared to control group. At week 7, group SH showed a decay in improvements for sleep duration (− 2 min compared to week 4) and ASBQ (+ 0.74 compared to week 4, indicating a worse sleep status).

Chronotype

No significant differences in raw rMEQ scores of self-reported chronotype were identified group × week or group × time (Fig. 7). Chronotype distribution was as follows across all participants: definite morning type 9%, moderate morning type 14%, neither morning nor evening preference 53%, moderate evening type 21% and definite evening type 3%.

Performance measures

Countermovement jump

There was a significant interaction effect for group × week (F (2, 31) = 3.84, $p = 0.001$; $\eta_p^2 = 0.31$) Pairwise comparisons indicated significant differences across weeks for Ind SH group compared to control (*$p = 0.001$). Group × time interactions were significant from week 1 to week 7 for Ind SH ($p = 0.001$) (Fig. 8).

IMTP No significant differences were observed for groups × week or group × time interactions (Fig. 9).

Changes in IMTP relative peak force was not significant for any group × week or group × time interactions (Fig. 10).

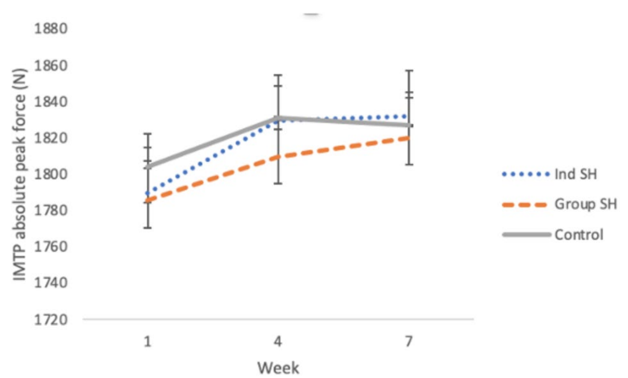

Fig. 9 Changes in IMTP absolute peak force across weeks 1–7

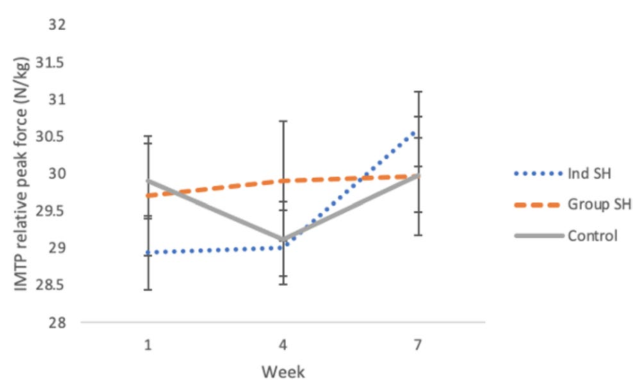

Fig. 10 Changes in IMTP relative peak force across weeks 1–7

Discussion

This study aimed to investigate whether sleep hygiene interventions could positively affect strength and power outcomes for female athletes, via improved sleep indices, and whether the addition of individualised SH education would provide greater benefit to sleep factors, above a single group-based session. Individualised SH education resulted in significant improvements to all measured sleep indices compared to a control group, and significantly improved sleep quality compared to group-based SH. Results suggest that the implementation of SH education could be beneficial to jump performance, with athletes receiving individualised SH demonstrating significantly improved jump performance compared to those exposed to solely group-based education or none. Findings also demonstrate that maximal strength performance was unaffected by sleep indices.

Participants receiving individualised SH demonstrated significantly improved CMJ performance concurrent to significantly improved sleep indices across weeks, suggesting improved sleep to be beneficial in enhancing jump performance. Whilst there is limited comparable previous research, some findings of this study are in agreement with the available literature regarding improved performance following sleep extension. Sleep extension studies on athletic populations have previously demonstrated improved reaction times [50], sprint times [4], tennis serving accuracy [5] and endurance performance [51], thus this study adds to the research body by demonstrating improved jump performance with improved sleep factors. This supports conclusions from earlier work, demonstrating the opposite effect with sleep restriction, where decreases in vertical jump height were evident [52], [20], thus it would appear that jump performance is indeed affected by sleep variables. Although it was beyond the scope of this study to investigate underlying physiological mechanisms, it could be postulated that the observed sleep improvements increased intra and inter-muscular coordination, as well as neural drive, two key variables for successful jump performance. Insufficient sleep has been associated with increased adenosine, a neuromodulator that has a general inhibitory effect on neural activity [53], inhibiting neural drive. Furthermore, a lack of sleep has been shown to reduce joint coordination [7], which may negatively affect jumping biomechanics. By improving sleep indices, it is feasible jump performance may have been enhanced via the optimisation of neural factors and increased joint coordination.

Results from the present study demonstrated improved sleep factors to have no significant effect on strength performance. Previous literature regarding the effects of sleep on strength performance are mixed; [21] showed decreased performance of deadlift, leg press and bench press following sleep restriction, whilst other studies have demonstrated strength performance to be maintained during periods of sleep deprivation [52]. Differences in previous findings could be attributed to methodological differences, with Reilly and [21] utilising strength movements requiring a greater degree of technical ability (deadlift, bench press, leg press) and therefore neurological processing, than maximal tests requiring less technical aspects and less coordinated movements, such as handgrip [52] or IMTP, as used in the present study. Additionally, external motivation has been cited as being an important factor in modulating the effects of sleep variability on performance [54], with differences in verbal motivation potentially contributing to prior conflicting results. In the absence of comparable studies investigating sleep improvements on strength performance, the present study supports the work of Cullen et al. [52] suggesting maximal strength performance may be unaffected by sleep status.

The present study is novel in its approach, implementing improvement to a variety of sleep variables via sleep hygiene education, rather than focusing on solely extending sleep via napping [50] or instructions to simply stay in bed longer [4]. Results suggest the addition of individualised SH delivery to be superior to solely group-based SH delivery for improving sleep indices. Given the high intra and inter variability of sleep factors, it seems logical that the inclusion of individualised SH would demonstrate greater improvements, and thus results provide key information for coaches when considering optimal strategies to improve athletes' sleep. Group-based SH education demonstrated significant improvements to sleep efficiency compared to controls, but greater improvements may be gained across a wider range of sleep factors by incorporating an individualised approach. Strengths of the present study are the ecological validity, and the relatively short education sessions that were used. Previous research has implemented longer group-based SH education sessions (~2 h, [55], 50 min, [13]), whilst the present study implemented a single group-based session of 40 min and individualised sessions of 30 min and 20 min on consecutive weeks. With time pressures in elite sport high, this study presents a promising, time-efficient method of sleep education to improve both sleep and jump performance. In this study, football performance was not measured, but previous research has demonstrated vertical jump performance may be a strong predictor of football performance [56] with the authors highlighting even small increases in jump performance may make for a significant benefit to football performance [56]. Therefore, improving sleep factors via SH may be one such way to gain additional performance benefits without any additional physical load.

From week 4–7, there is evidence of a small decay effect within those exposed to solely group-based SH for sleep duration and ASBQ score. Previous studies have demonstrated the transient nature of the benefits related to SH education [11], and it would appear the present sample follows a similar pattern, although both aforementioned sleep factors remain enhanced from baseline level and the level of change non-significant. The implementation of individualised SH education is likely to have served as a "top up" to the group-based session, providing individuals with the chance to tailor generic advice to fit with their own lifestyle and habits, plus also reinforcing previous information. Whilst it is unclear whether the improved sleep indices within the Individual SH group were the result of cumulative effects of experiencing both group and individualised sleep education, results highlight the importance of some level of individualised SH education to be included within sleep education for athletes.

The fact that this study was conducted with both naturally menstruating females and those on hormonal contraception may be viewed as another strength of the study, as results are representative of females at varying points of their cycle and throughout various hormonal changes, thus indicative of a wide representation of data. However, it should be considered that MC phase may have influenced sleep parameters [57] which may have skewed results. Loureiro et al. [58] concluded MC phase to have no significant effect on strength performance. Similarly, García-Pinillos et al. [59] found no significant differences in CMJ or sprint performance across different phases of the MC, although interestingly, despite lacking objective verification, self-perception of strength and power performance has been demonstrated to be lower around the time of menstruation [60]. Participants within this study were not asked for self-perceptions of performance alongside objective testing but future research may look to employ this strategy to gain a deeper understanding into the complexities of optimising physical performance.

In conclusion, results suggest that the implementation of SH education can be useful to improve sleep indices and jump performance, with athletes receiving individualised SH demonstrating superior benefits to those exposed to solely group-based education or none. This could provide a novel way of performance enhancement for athletes, whilst also providing coaches with guidance on the optimal delivery method of sleep education in a time-efficient manner.

Limitations and future research

Future research could be directed towards the incorporation of hormonal testing alongside sleep interventions to objectively determine MC phase. Factoring this into the analysis could then determine whether certain cycle phases affect sleep variables or impact the efficacy of the educational component. This was not feasible in the current study due to off-season timings, availability of players and total player numbers. Although the sample size met the a-priori sample size requirements, each comparison group had a maximum of 12 participants in each. As such, the study may benefit from being repeated with a larger sample size to allow greater generalisability. However, with squad sizes in professional female football clubs usually much smaller than male squads, the recruitment of larger sample sizes becomes challenging, and the use of squads from different clubs brings the additional challenge of reducing homogeneity across participants, particularly in regard to training hours and player availability, which is likely to affect the standardisation of interventions.

This study was conducted in pre-season, therefore results may not be generalisable at different timepoints of a competitive season. Further research is required to establish if the application of individualised SH could translate into season-long sleep improvements, particularly given that previous research into SH education has commonly shown effects to be transient, with improvements to sleep indices diminishing over time [11, 12]. Assessing SH interventions across the course of a season could then also translate into determining the optimal duration and frequency of sessions.

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Data availability Data available upon reasonable request from lead author, JG.

Declarations

Conflict of interest The authors declare no competing interests.

Informed consent The authors obtained written consent from all participants.

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