Journal of Science and Medicine in Sport xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

Inadequate sleep and muscle strength: Implications for resistance training

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ARTICLE INFO

Article history:
Received 14 November 2017
Received in revised form 14 January 2018
Accepted 23 January 2018
Available online xxx

Keywords:
Sleep restriction
Sleep deprivation
Resistance exercise
Performance
Skeletal muscle health

ABSTRACT

Objectives: Inadequate sleep (e.g., an insufficient duration of sleep per night) can reduce physical performance and has been linked to adverse metabolic health outcomes. Resistance exercise is an effective means to maintain and improve physical capacity and metabolic health, however, the outcomes for populations who may perform resistance exercise during periods of inadequate sleep are unknown. The primary aim of this systematic review was to evaluate the effect of sleep deprivation (i.e. no sleep) and sleep restriction (i.e. a reduced sleep duration) on resistance exercise performance. A secondary aim was to explore the effects on hormonal indicators or markers of muscle protein metabolism.
Methods: A systematic search of five electronic databases was conducted with terms related to three combined concepts: inadequate sleep; resistance exercise; performance and physiological outcomes. Study quality and biases were assessed using the Effective Public Health Practice Project quality assessment tool.
Results: Seventeen studies met the inclusion criteria and were rated as 'moderate' or 'weak' for global quality. Sleep deprivation had little effect on muscle strength during resistance exercise. In contrast, consecutive nights of sleep restriction could reduce the force output of multi-joint, but not single-joint movements. Results were conflicting regarding hormonal responses to resistance training.
Conclusion: Inadequate sleep impairs maximal muscle strength in compound movements when performed without specific interventions designed to increase motivation. Strategies to assist groups facing inadequate sleep to effectively perform resistance training may include supplementing their motivation by training in groups or ingesting caffeine; or training prior to prolonged periods of wakefulness.

1. Introduction

Sleep is essential for physiological and cognitive functioning.[1,2] Inadequate sleep, that is, when an insufficient duration or quality of sleep is obtained per night, is detrimental to health and work productivity.[2,3] As the world continues moving toward a 24-h society, more people are getting less sleep.[4] In recognition of this widespread issue, inadequate sleep has recently been declared as a 'public health problem' by the US Centres for Disease Control and Prevention.[1] It is estimated that inadequate sleep costs up to US$680 billion of economic output across the US, UK, Japan, Germany and Canada annually.[1] Lifestyle factors such as working prolonged or irregular hours, social commitments and family responsibilities can all contribute to inadequate sleep.[1]

Inadequate sleep may occur as a result of sleep deprivation, that is, a sustained state of wakefulness with no sleep, or sleep restriction, that is, a chronically reduced sleep duration.[5] Approximately 40% of adults experience inadequate sleep.[1,3] Athletes, new parents and older adults are particularly susceptible to sleep restriction or sleep deprivation. These groups experience disturbances to their sleep cycle (e.g. through training and competing at night, newborn feeding schedules or age-related sleep impairments) exposing them to frequent inadequate sleep. Shiftworkers, who work outside of a historically typical 7am to 6pm period[6] and experience different feeding patterns and light-exposure schedules compared to day-time workers, are also at risk of inadequate sleep.[2] Shiftworkers may sleep for a short duration or at a time that is mismatched with physiological functions exhibiting a circadian rhythm, a process known as circadian misalignment,[6] which can also result in

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https://doi.org/10.1016/j.jsams.2018.01.012
1440-2440/

inadequate sleep.[2] Inadequate sleep increases fatigue and reduces the physical capacity for daily tasks.[5] Sleeping less than 7 h per night is also associated with an increased risk of cardiovascular disease, type 2 diabetes and obesity by up to 48%.[2]

Physical capacity depends on several factors, including cardiovascular fitness and muscle strength. Muscle strength is critical for daily task capacity in new parents, older adults and shiftworkers, as well as for performance in athletes. Sustained resistance training increases muscle strength and physical capacity[7,8] and reduces risk factors for type 2 diabetes, obesity and cardiovascular disease,[9] which are over-represented in populations facing inadequate sleep. Bi-weekly resistance training is recommended for all adults, for short- and long-term health,[10] but these guidelines do not consider the potential impact of inadequate sleep or daily fluctuations in strength and training capacity,[11] nor how these factors interact with changes in motivation and the optimal times of day[12] or days on which to train.

Resistance exercise has a chronic positive effect on skeletal muscle mass,[13] which underpins muscle strength. Skeletal muscle fibres are made up of almost 90% of proteins.[14] Skeletal muscle mass is regulated by the fine balance between the rate of protein synthesis and the rate of protein degradation occurring in the muscle.[14] When this balance is maintained, muscle mass is preserved.[14] Resistance exercise is a potent way to increase skeletal muscle mass by triggering the molecular pathways that activate protein synthesis in the muscle.[13] Resistance exercise places mechanical load on the muscle, activating pathways that control muscle protein synthesis[13] in the cell. Resistance exercise also stimulates the release of hormones that directly promote protein synthesis (referred to as anabolic hormones), such as testosterone, growth hormone and insulin-like growth factor 1 (IGF-1).[15] At rest, these hormones fluctuate partially due to a circadian rhythm; the peak of their secretion often occurring at the onset of or during sleep.[12] Their secretion in response to resistance exercise positively influences muscle protein turnover,[15,16] allowing for increases in muscle mass and strength.

The prescription of resistance training may require particular care for groups who are likely to train in conditions of inadequate sleep or misalignment between their sleep time and endogenous circadian rhythm. Our group[17] recently hypothesised that an altered sleep–wake cycle may be detrimental to skeletal muscle health. Indeed, inadequate sleep increases the levels of hormones that directly promote protein degradation (referred to as catabolic hormones), such as cortisol, and decreases the levels of anabolic hormones in the blood.[17] By disturbing baseline muscle protein metabolism,[17] inadequate sleep may blunt skeletal muscle adaptations to resistance exercise. Previous reviews[18,19] have found extended sleep deprivation can reduce muscle strength in athletes, yet have focused on providing recommendations to optimise sleep. While improved sleep outcomes are critical for athletes, the training, work and lifestyle demands of these and other groups could make sleep restriction unavoidable in some circumstances. If resistance exercise is going to be a viable strategy to improve and maintain physical capacity and preserve metabolic health, prescription guidelines specific to groups facing inadequate sleep are imperative. Therefore, the primary aim of this review is to evaluate the literature investigating the impact of inadequate sleep on resistance exercise performance; a secondary aim is to explore the consequences for regulators of muscle protein metabolism.

2. Methodology

2.1. Search strategy

This review was conducted using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement.[20] A systematic search of the electronic databases EBSCOHost (searching Academic Search Complete, Medline Complete, Global Health SPORTdiscus), Embase, Scopus, Web of Science and PubMed was used to identify peer-reviewed, English-language studies of relevance, since inception. The key words for the search were as follows: *sleep deprivation*; *sleep loss*; *sleep restriction*; *circadian*; *diurnal*; *time of day*; *shift work*; *night shift*; *insufficient sleep*; *inadequate sleep*; *sleep fragmentation*; *sleep interruptions*; *sleep restoration*; *sleep extension* and *nocturnal* searched together with *resistance training*; *resistance exercise*; *strength training*; *weight training*; *physical training*; *physical conditioning*; *weight lifting*; *calisthenics*; *concentric*; *eccentric*; *isotonic* and *isometric* searched together with *performance*; *physical performance*; *muscle*; *muscle strength*; *muscle mass*; *hormone*; *cortisol*; *testosterone*; *protein synthesis*; *recovery*; *growth*; *IGF-1*; *insulin* and *metabolism*. Search terms were phrased and truncated as appropriate.

2.2. Eligibility criteria

The eligibility criteria required studies to investigate the effect of inadequate sleep on resistance exercise (e.g. handgrip test) or training performance outcomes. Outcome measures of interest were muscle strength and physiological response mechanisms underlying changes in muscle strength or size e.g. hormonal indicators or markers of protein metabolism. Title/s and abstracts were screened for relevance to sleep and resistance exercise in adults and potentially relevant articles were accessed to assess the full text. Studies were excluded if no nocturnal sleep loss occurred or if the sleep deprivation or restriction period was not defined. Animal studies and conference abstracts were also excluded. Screening, data extraction and quality assessment were performed by two authors (OK, CU). Disagreement on any article or outcome was discussed between authors and resolved by additional authors (ED, SL, BA) where required.

2.3. Quality assessment

The Effective Public Health Practice Project (EPHPP) quality assessment tool for quantitative studies[21] was used to assess the methodological strength of each study. Standard scoring procedures were used to assign global scores based on the accumulation of strong, moderate or weak scores given across domains of selection bias, study design, confounders, blinding, data collection method, and withdrawals and dropout[21] (Table 2).

3. Results

3.1. Literature selection

The original search presented 1702 peer-reviewed, English-language articles, of which 997 were identified as duplicates (Fig. 1). Screening of titles/abstracts excluded 669 articles irrelevant to sleep loss and/or strength parameters. Twelve articles were retrieved from reference lists of relevant articles. Thirty-one articles were excluded where the outcome measures were deemed irrelevant, were conference abstracts or the full text could not be retrieved. Studies investigating jetlag and Ramadan have been previously reviewed[22,23] and were therefore excluded. The final number of studies included in this review was 17. The study characteristics and key findings are presented in Table 1. The quality assessment scores for each paper, based on the EPHPP tool, are shown in Table 2.

3.2. Sleep restriction

Seven studies investigated one night of sleep restriction[24–30] and one study examined repeated nights (three or more) of

Please cite this article in press as: Knowles OE, et al. Inadequate sleep and muscle strength: Implications for resistance training. *J Sci Med Sport* (2018), https://doi.org/10.1016/j.jsams.2018.01.012