Sleep Health 2 (2016) 63–68

Contents lists available at ScienceDirect

Sleep Health

Journal of the National Sleep Foundation

journal homepage: http://www.elsevier.com/locate/sleh

Short-term moderate sleep restriction decreases insulin sensitivity in young healthy adults

Xuewen Wang, PhD [a,*], Julian Greer, BS [a], Ryan R. Porter, MS [a], Kamaljeet Kaur, MS [a], Shawn D. Youngstedt, PhD [b]

[a] Exercise Science, University of South Carolina, Columbia, SC, USA
[b] College of Nursing and Health Innovation and College of Health Solutions, Arizona State University, Phoenix, AZ, USA

ARTICLE INFO

Article history:
Received 28 August 2015
Received in revised form 28 October 2015
Accepted 18 November 2015

Keywords:
Sleep restriction
Insulin sensitivity
Glucose tolerance
Chronic

ABSTRACT

Context and purpose: The literature suggests that severe sleep loss of more than a few hours a night decreases glucose tolerance and insulin sensitivity. The aim of this study was to determine whether moderate sleep restriction had similar effects.
Methods: Fifteen healthy non-obese (body mass index = 24.5 ± 3.4 kg/m^2) young adults (20.6 ± 1.3 years) completed two 2-hour oral glucose tolerance tests (OGTTs): one was after 3 days of time-in-bed restriction by 1 to 3 hours each night, and the other was after 3 days of ad libitum sleep. Glucose and insulin concentrations during OGTT and fasting glucagon and cortisol concentrations were determined. The homeostasis model of insulin resistance, Matsuda index, and the quantitative insulin sensitivity check index were calculated.
Results: The total time-in-bed during the sleep restriction and the ad libitum phase was 5.98 ± 0.76 and 7.98 ± 0.54 hours/day, and total sleep time was 5.16 ± 0.49 and 6.65 ± 0.64 hours/day, respectively. Glucose concentrations before and 30, 60, 90, and 120 minutes after consumption of glucose and area under the curve were not different for the 2 OGTTs ($P > .10$ for all). Insulin concentration at fasting and area under the curve during the OGTT were significantly higher ($P = .034$ and .038, respectively) after restricted sleep than after ad libitum sleep. Fasting glucagon concentration was also higher ($P = .003$). The homeostasis model of insulin resistance, Matsuda index, and quantitative insulin sensitivity check index all suggested decreased insulin sensitivity after restricted sleep.
Conclusion: Short-term moderate sleep restriction reduced insulin sensitivity compared to ad libitum sleep in this group of healthy young adults.

Introduction

Type 2 diabetes and its complications represent a significant and increasing public health burden. In recent years, there has been an increased interest in the potential role of insufficient sleep in the development of type 2 diabetes. An association between self-reported short sleep (<6 h/day) and impaired glucose tolerance and diabetes has been shown by epidemiological data.[1-9] Type 2 diabetes is characterized by reduced insulin sensitivity, and insulin-resistant individuals have been found to have fewer hours of sleep than insulin-sensitive individuals.[10] Previous experimental studies have also shown that a range of sleep deprivation from one to a few nights of 4 to 5 hours of sleep[11-17] to complete deprivation[18,19] negatively affects glucose metabolism and reduces glucose tolerance or whole-body and adipose tissue insulin sensitivity. The relatively severe sleep restriction limits the generalization of these study findings.

The effects of sleep restriction of smaller degrees on glucose metabolism and insulin sensitivity have been investigated less. Of the few studies that examined a smaller degree of insufficient sleep, 1 study found that 2 weeks of 5.5 hours of sleep reduced glucose tolerance and insulin sensitivity compared to 8.5 hours of sleep.[20] High caloric intake was used in the study, which might confound their results. In another study, sleep restriction of 1.4 hours for 8 weeks did not change glucose tolerance; however, the study was conducted in long sleepers (normal sleep duration >8.5 hours per night).[21] Given the U-shaped curve between sleep duration and diabetes shown in epidemiological studies,[22,23] results from studies of long sleepers likely are different from the effects of sleep restriction in individuals who are not long sleepers but go through periods of insufficient sleep.[24]

In real-life situations, it is not unusual for an individual to adopt shortened sleep during the work week and to sleep more during the weekends. The National Sleep Foundation survey found that 25% of the sample self-reported not getting enough sleep during the weekdays and more than 40% reported sleeping longer during the weekend.[25] A recent study found that 3 nights of sleep extension (10 hours) compared to sustained sleep restriction (6 hours)

* Corresponding author at: University of South Carolina, Department of Exercise Science, PHRC 302, 921 Assembly St, Columbia, SC 29208.
E-mail address: xwang@sc.edu (X. Wang).

http://dx.doi.org/10.1016/j.sleh.2015.11.004
2352-7218/

improved insulin sensitivity in young men.[26] However, the 10-hour sleep duration seems to be longer than normal sleep duration even if it is used to "catch up" on sleep, and sleep extension may have its unique metabolic effects. In fact, 10-hour or more sleep was used as the control condition in a few of the aforementioned sleep restriction studies.[12,13,17] In addition, individuals may require different amounts of optimal sleep duration, and most previous studies used the same amount of time in bed for all participants. Therefore, the purpose of our study was to determine whether moderate sleep restriction of less than 3 hours per night affects glucose metabolism and insulin sensitivity compared to ad libitum sleep, by using oral glucose tolerance tests (OGTTs) after 3 nights of reduced time in bed and 3 nights of ad libitum sleep. The secondary purpose of our study was to explore whether hormones involved in the regulation of glucose metabolism might change with sleep restriction.

Methods

Participants

Sixteen young adults, aged 18 to 25 years, volunteered for the study. Each participant completed a medical history form and the Pittsburgh Sleep Quality Index (PSQI) that assesses sleep quality and disturbances during the past month.[27] The exclusion criteria included: self-reported major health issues; taking sleep aid medication; using a sleep device; self-reported sleep problems such as apnea and insomnia; self-reported sleep duration of less than 6.5 hours or greater than 10 hours per day including naps during the day; and travel crossing time zones within 1 month of the study visits. One male had needle-phobia and discontinued. Among the remaining 8 females and 7 males, there were 13 non-Hispanic white, 1 African American, and 1 Hispanic white participants. All participants signed an informed consent approved by the University of South Carolina Institutional Review Board. This study was registered at clinicaltrials.gov (identifier: NCT02583750).

Procedures

Fifteen participants completed 1 OGTT after 3-day sleep restriction and another OGTT after 3-day ad libitum sleep within 2 weeks. The OGTTs were conducted in our research laboratory and, during other time, they maintained their routine in their usual environment. Participants were told that we did not know what the study results would be. They were instructed to be careful to avoid driving and using hazardous things such as heavy machines while participating in the study.

The sequence of the phases was randomized. Six participants completed the sleep restriction phase first, and the other 9 participants completed the ad libitum sleep first. During the sleep restriction phase, participants were prescribed a range of times going to bed later and/or getting up earlier to reduce their time in bed by 1 to 3 hours based on their self-reported information in the PSQI. They were allowed to have various durations of time in bed for the 3 consecutive nights, and they could choose how much to restrict their time in bed for each of the nights but were asked to be in 1- to -3-hour window.

During the ad libitum sleep phase, participants were instructed to sleep as much as they wished for 3 consecutive nights. They were asked to maintain their usual napping habits, diet, caffeine usage, and daily activities during both sleep restriction and ad libitum sleep phases.

The participants wore an actigraph monitor (ActiGraph GT3X+; ActiGraph, Pensacola, FL) on their nondominant wrist throughout the 2 phases. The output from the monitors was analyzed using the manufacturer provided software ActiLife 6.9. The Sadeh algorithm (Sadeh)[28] was used to determine minute-by-minute asleep/awake status. Total sleep time was the total number of minutes scored as "asleep." They also recorded the time they went to bed, got up, and took naps during those days. Total time in bed was the total time from going into bed to getting up plus any naps during the day, as recorded by participants.

During the day after the third night of each phase, after an overnight fast of at least 12 hours, participants arrived at our research laboratory between 0700 and 1000 hour. Height and weight were measured with shoes and outer garments removed, and an OGTT was performed. A 20-gauge polyethylene catheter was placed in an antecubital vein for blood sampling. Blood samples were collected before (0 minutes) and 30, 60, 90, and 120 minutes after consuming a 75-g glucose drink. An Epworth Sleepiness Scale[29] was also completed during this visit. The score for the scale ranges from 0 to 24, with higher scores indicating greater sleepiness.

Plasma glucose was measured immediately using a glucose analyzer (YSI 2300; YSI, Inc, OH). Other blood samples were collected using heparin-treated evacuated tubes. Samples were spun, and plasma was separated and stored at −80°C until final analysis. Plasma insulin concentrations at 0, 30, 60, 90, and 120 minutes during the OGTT, and fasting plasma cortisol concentrations were measured by enzyme-linked immunosorbent assay following manufacturer's instructions (EMD Millipore, St Charles, MO). Fasting plasma glucagon concentrations were measured by chemiluminescent enzyme-linked immunosorbent assay (EMD Millipore).

Calculations

Glucose and insulin areas under the curve (AUC) were calculated using the trapezoid rule: $\frac{1}{2} \times 30 \times (y_{0min} + 2y_{30min} + 2y_{60min} + 2y_{90min} + y_{120min})$, where y represents glucose or insulin concentration at the different time points.[30] Homeostasis model of insulin resistance (HOMA-IR) was calculated as the product of fasting glucose concentration (G(0)) in milligrams per deciliter and fasting insulin concentration (I(0)) in milliunits per liter divided by 405.[31] The quantitative insulin sensitivity check index (QUICKI) was calculated as $1/[\log(I(0)) + \log(G(0))]$.[32] The Matsuda index was calculated as (10,000/square root of $[G(0) \times I(0)] \times$ [mean glucose $\times$ mean insulin during OGTT]).[33]

Statistics

Data were analyzed using IBM SPSS Statistics version 20 (IBM Corp). The outcome variables included concentrations of glucose, insulin, glucagon, and cortisol, and glucose and insulin AUC, as well as calculated insulin resistance/sensitivity indices (HOMA-IR, QUICKI, and Matsuda). Descriptive statistics were calculated. For non-normally distributed variables, data are presented as median and quartiles and transformed to achieve normality of distribution for analysis. Analyses of variance with repeated measures were performed to compare outcome variables obtained from the 2 OGTTs with data from the same individual analyzed as paired observations. Sex was included in the models initially in the analyses to determine whether the comparison of the outcome variables between the 2 OGTTs were different by sex (sex by condition interaction). Because the sex by condition interaction was not significant for any outcome variable, we report combined data of male and female participants. Hedges' *g* effect size of the differences between means of HOMA-IR, QUICKI, and Matsuda index obtained from the 2 OGTTs was calculated. Correlations (Pearson correlations for normally distributed variables and Spearman correlations for non-normally distributed variables) between the changes between the 2 conditions in time in bed and total sleep time, with changes in glucose and insulin AUC and insulin resistance indices, were calculated. $P < .05$ was considered statistically significant.