Physiology & Behavior 124 (2014) 33–36

Contents lists available at ScienceDirect

Physiology & Behavior

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

Exercise attenuates the metabolic effects of dim light at night

Laura K. Fonken *[,1], O. Hecmarie Meléndez-Fernández [1], Zachary M. Weil, Randy J. Nelson

Department of Neuroscience, Wexner Medical Center, The Ohio State University, Columbus, OH 43210, USA
Institute for Behavioral Medicine Research, Wexner Medical Center, The Ohio State University, Columbus, OH 43210, USA

HIGHLIGHTS

- Mice exposed to dim, rather than dark nights, increase body mass gain.
- Access to a running wheel prevents weight gain in mice exposed to dimly lit nights.
- Exposure to dim light at night or access to a running wheel increases daytime food intake.
- Dim light at night disrupts the 24 h rhythm in wheel running in a subset of mice.
- Exercise limits weight gain in dLAN mice without rescuing circadian alterations.

ARTICLE INFO

Article history:
Received 31 January 2013
Accepted 22 October 2013

Keywords:
Light at night
Exercise
Circadian rhythm
Obesity

ABSTRACT

Most organisms display circadian rhythms that coordinate complex physiological and behavioral processes to optimize energy acquisition, storage, and expenditure. Disruptions to the circadian system with environmental manipulations such as nighttime light exposure alter metabolic energy homeostasis. Exercise is known to strengthen circadian rhythms and to prevent weight gain. Therefore, we hypothesized providing mice a running wheel for voluntary exercise would buffer against the effects of light at night (LAN) on weight gain. Mice were maintained in either dark (LD) or dim (dLAN) nights and provided either a running wheel or a locked wheel. Mice exposed to dim, rather than dark, nights increased weight gain. Access to a functional running wheel prevented body mass gain in mice exposed to dLAN. Voluntary exercise appeared to limit weight gain independently of rescuing changes to the circadian system caused by dLAN; increases in daytime food intake induced by dLAN were not diminished by increased voluntary exercise. Furthermore, although all of the LD mice displayed a 24 h rhythm in wheel running, nearly half (4 out of 9) of the dLAN mice did not display a dominant 24 h rhythm in wheel running. These results indicate that voluntary exercise can prevent weight gain induced by dLAN without rescuing circadian rhythm disruptions.

1. Introduction

Over the course of the 20th century body mass rapidly increased worldwide. By the year 2000 the number of adults with excess weight surpassed those who were underweight for the first time in human history. This excess adiposity is recognized as one of the world's leading health threats because obesity increases the risk of developing type II diabetes, cardiovascular disease, hypertension, and cancer [7]. The rapid growth in adiposity during the 20th century correlates with significant changes in human environment and lifestyle. In addition to changes in activity levels and dietary choices, a less appreciated environmental perturbation has been the shift in timing of daily activities. The invention of electrical lighting ~150 years ago has enabled humans to illuminate their homes, hospitals, factories, and night skies and engage in activities such as countercyclical shift work [23]. Widespread adoption of electric lights occurred well before an understanding of circadian biology, and without any consideration of the negative biological consequences that artificial light at night (LAN) may have on physiology and behavior.

Circadian regulation of energy homeostasis is organized by an endogenous biological clock located in the suprachiasmatic nuclei (SCN) of the hypothalamus. The circadian clock is entrained by light information that travels directly from light-sensitive ganglion cells in the retina to the SCN, thereby synchronizing individuals' physiology and behavior to the external day–night cycle [16,30]. Because light is the primary signal for the circadian clock, exposure to light at aberrant times can disrupt clock function [23].

Many studies suggest a direct link between the molecular circadian clock and metabolism [6]. Mice harboring a mutation in the core circadian gene *Clock* are susceptible to obesity and metabolic syndrome [33]. *Clock* mutants show dramatic changes in circadian rhythmicity, as well

* Corresponding author at: Department of Neuroscience, The Ohio State University Wexner Medical Center, 636 Biomedical Research Tower, 460 W. 12th Ave., Columbus, OH 43210, USA. Tel.: +1 614 688 4674; fax: +1 614 688 4733.
E-mail address: fonken.1@osu.edu (L.K. Fonken).
[1] Authors contributed equally to this work.

0031-9384/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.physbeh.2013.10.022

as altered timing of food intake and increased body mass. Serum leptin, glucose, cholesterol, and triglyceride levels are increased in *Clock* mutants compared to wild type (WT) mice. Mice with mutations in other clock related genes including *Bmal1*, *Per1*, *Per2*, *Vipr2*, and *Rev-erbα* display similar metabolic outcomes [3,8,10,19]. Even single tissue clock gene disruptions can result in metabolic disturbances [19,26]. Thus, it seems reasonable to propose that disrupted circadian clock function has the potential to derange normal metabolism.

Mice housed in dim LAN (dLAN) elevate body mass and reduce glucose tolerance independent of changes in total daily food intake or home cage locomotor activity (Fonken et al., 2010). dLAN mice increase the percentage of food consumed during the light phase as compared to mice housed in dark nights; restricting food intake to the dark phase ameliorates weight gain among dLAN mice (Fonken et al., 2010). Daytime food intake is associated with weight gain and metabolic disruption in mice in other contexts [1,5]. Furthermore, the relationship between the circadian clock and metabolism appears to be bidirectional as diet induced obesity can dampen circadian rhythms [18].

As mentioned, light is the dominant entraining factor for the circadian system; however, non-photic stimuli such as food intake and exercise can alter circadian rhythms [15,21]. Activity is both a behavioral output of the circadian system and an important feedback factor that can modulate rhythms [11,20,29]. In constant dark conditions, timed wheel access entrains circadian rhythms in mice [11]. Moreover, scheduled access to a running wheel can strengthen circadian rhythms in mice with disrupted clock function [28]. Even under a standard light–dark cycle, ad lib access to wheels can strengthen the power of circadian rhythms in wild type mice [31].

In addition to strengthening circadian rhythms, it is well established that exercise prevents weight gain [27]. Therefore, we hypothesized providing mice a running wheel for voluntary exercise would buffer against the effects of LAN on metabolism. Specifically, we hypothesized that mice exposed to LAN would increase body mass and alter feeding rhythms, indicating circadian system disruption. We predicted that providing mice running wheels would strengthen circadian entrainment preventing altered timing of food intake and LAN-induced weight gain.

2. Materials and methods

2.1. Animals

Forty male Swiss-Webster mice (~8 weeks of age) were obtained from Charles River Laboratories. The mice were individually housed in propylene cages (dimensions: 33 × 19 × 14 cm) at an ambient temperature of 22 ± 2°C and provided with Harlan Teklad 8640 food (Madison, WI) and filtered tap water ad libitum. Upon arrival, mice were maintained in a standard 14:10 light (150 lx)/dark (0 lx) cycle (LD; lights on at 2:00 EST) for 1 week in order to habituate to local lighting conditions and recover from the effects of shipping. After this period mice were randomly assigned a group, weighed, and transferred to either a cabinet with LD or dim light at night [dLAN; 14:10 light (150 lx)/dim (5 lx) light cycle]. Within each lighting condition mice received either a locked wheel or a low-profile running wheel (running surface of 15.5 cm diameter) for voluntary exercise (Med Associates, St. Albans, VT). Wheel running was constantly monitored using a wireless interface hub system which transmitted the data to a computer. Locked wheels were provided to control for the presence of a novel object in the cage. Mice were weighed every week at Zeitgeber Time (ZT) 7.

After 3 weeks in experimental conditions, food was weighed twice daily, immediately before the onset of the dark phase (ZT 12) and immediately after the onset of the light phase (ZT 22). Average food intake for the light and dark phases over three days was used to quantify percentage of daytime food intake. At the conclusion of the study mice were individually brought into a procedure room, anesthetized with isoflurane vapors, and rapidly decapitated between ZT 7 and 9; a blood sample was then collected and epididymal fat pads were removed and weighed.

2.2. Statistical analyses

One dLAN mouse with a running wheel was removed from statistical comparisons because it did not use the wheel and one mouse was removed from the locked wheel LD group for demonstrating sickness behaviors. Effects of lighting condition and wheel access on body mass gain,

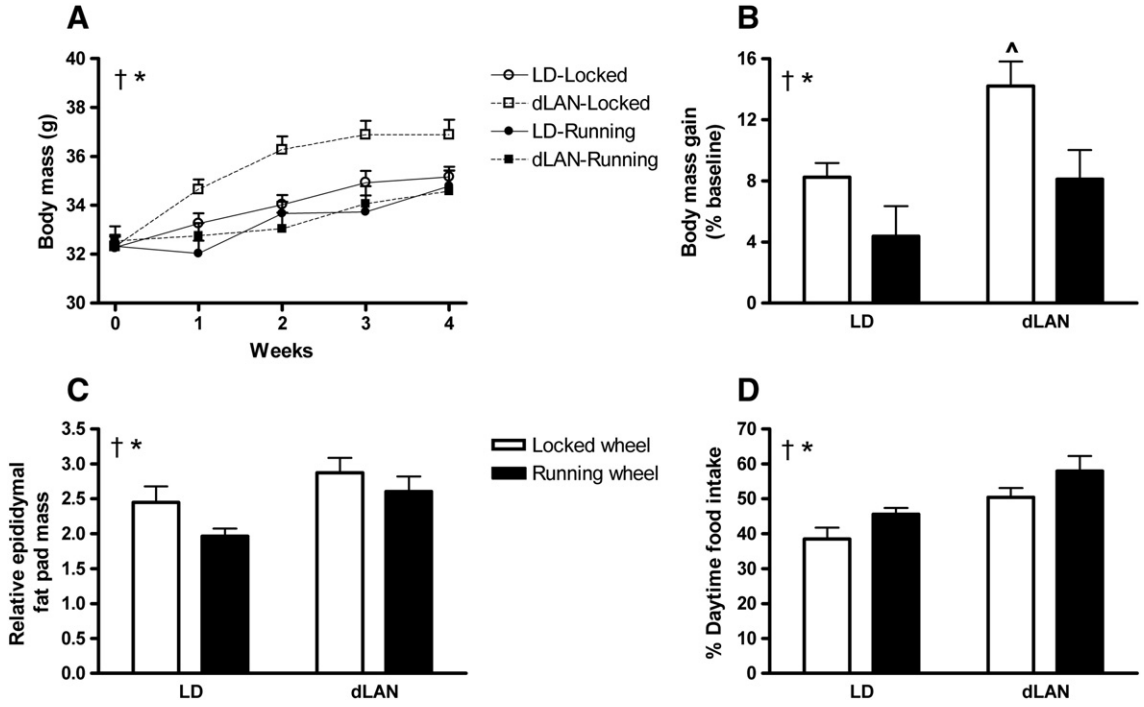

Fig. 1. Voluntary exercise prevents weight gain induced by exposure to dLAN. (A) Body mass over the course of the study. (B) Body mass gain expressed relative to baseline body mass. (C) Epididymal fat pad mass expressed relative to final body mass. (D) Percentage of food consumed during the light phase. All data are presented as mean ± SEM. *indicates main effect of lighting condition, †indicates main effect of wheel, ^differs from all other groups.