Association Between Sleep Parameters and Postural Control: A Literature Review

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Background and Objective  
The purpose of the review was to explore the association between sleep parameters and postural control.

Methods  
The PubMed, Science Direct, and EBSCO were searched using the keywords ‘sleep’ including either sleep quality, sleep deprivation, poor sleep quality; and ‘postural control’ including either dynamic balance, static balance, postural balance, and balance control. Related studies published till December 2017 were selected.

Results  
Acute sleep deprivation resulted in an impairment in postural control. Chronic sleep deprivation and postural control were also found to be related in a similar way to that of total sleep deprivation, thus affecting postural control negatively. Time of day was found to influence the postural control such that the postural control was better in the morning than in the latter part of the day. A study of the impact of aging on the effects of sleep deprivation on postural control revealed that loss of sleep had a more disturbing effect on postural control in the older-adult group than in younger participants, thus indicating a high risk of fall among the elderly.

Conclusions  
Despite various limitations and methodological differences, this review has identified a negative influence on postural control due to impaired sleep in a wide range of populations, indicating the need for a more focused approach to sleep when assessing and measuring postural control.

Keywords  
Sleep; Sleep deprivation; Postural balance.

INTRODUCTION

Sleep is an important and complex physiological process [1]. National sleep foundation (2008) reports sleep as “food for the brain” [2]. Sleep is known to be a multidimensional concept [3] which is a “complex phenomenon that is difficult to define and measure objectively” [4]. According to the American Psychiatric Association (2000) [5], sleep quality is a “complex phenomenon involving many dimensions including perceived sleep quality, sleep response time, sleep duration, sleep efficiency, sleep disorders, sleep medication, and daytime dysfunction.” Castriotta and Lai [6] stated that the quality of sleep is determined by how the individual perceives his/her night-time habits such as the ability to sleep, the depth of sleep, and the ability to sleep without medical assistance. A reduction in the quality and/or duration of sleep brings about a plethora of physiological changes in the human body such as an increase in drowsiness, reduction in the ability to concentrate, etc. Reduced sleep leads to poor short-term memory and concentration, impaired self-control behavior, and ability to learn. Major health issues ranging from cardiovascular [7] to psychological [8] illnesses are associated with poor sleep quality. A decrease in sleep may ultimately lead to a reduction in overall lifespan [9] and many of these health-related problems may start as early as adolescence [10]. Numerous
factors can significantly lower the duration of sleep to less than suggested, thereby causing a variety of effects on muscular and neurological performance, cognition, and mood [11], yet, little attention has been paid to studying the effect of deprivation of sleep on these functions [12].

Postural control (PC) or balance is one of the major functions of the human body [13,14] and is one of the means of measuring the deficit of muscular and neurological performance. It is seen as a complex motor skill that checks the interaction of many sensorimotor processes [15] with two main functional objectives: postural equilibrium and postural orientation. The body’s posture and balance depend on the interaction of the central nervous system with proprioceptive, vestibular, and visual information [16-18]. This allows for the placement of different parts of the body about the other along with the position of the body in space which makes it possible to utilize the muscles sufficiently to maintain balance, which requires a high level of control, especially when one or the other sensory input is not effective [19]. Any pathology that affects the organs particularly involved in the maintenance of posture/balance affects the PC.

It has been shown that sleep deprivation leads to deficits in cognitive functions [20] which were specifically identified as disturbances in the circadian rhythms [21]; however, a knowledge gap still exists in understanding how sleep affects various important body functions, especially those related to neuronal and muscular systems which are measured particularly via balance [12]. With ongoing research, it has become clear that sleep disorders have some effect on balance and PC [22]. In addition, falls among vulnerable populations such as the elderly [23], as well as driving accident incidents are associated with various sleep disorders and consequent balance deterioration [24], but a deeper understanding of the concepts is needed.

The objectives of this review paper were: 1) To present a narrative review that investigates the relationship between sleep parameters and PC and 2) to cast light on the scope for further research in the future regarding balance and sleep.

METHODS

Identification of Relevant Literature

A literature search was done using PubMed, Science Direct, and EBSCO for related studies published till December 2017. The search words included: 1) Sleep (including either sleep quality, sleep deprivation, or poor sleep quality) and 2) PC (including either dynamic balance, static balance, postural balance, or balance control). The initial search of the literature resulted in 740 papers, out of which, 724 were excluded because they were either duplicate or did not satisfy the inclusion criteria. Fifteen articles were identified that met the inclusion criteria.

Inclusion and Exclusion Criteria

Studies were included in the review if: 1) the association between sleep parameters and PC was reported; 2) the statistical methods were explained for assessment of the suitability of the analysis; 3) a quantitative clinical study that explained the outcome measures (subjective and/or objective) of sleep and balance and/or postural control and presented it numerically; and 4) the measures for sleep and PC were explained.

Review articles, conference papers, and unpublished dissertations were excluded. Studies were also excluded if they were not available in the English language and if no quantitative data were depicted.

RESULTS

The depiction of the “sleep” variable was evaluated in different views, for instance 1) sleep deprivation; 2) sleep quality; and 3) sleep duration. The methodological approach was common for all studies (i.e., the quantitative approach). Table 1 displays the authors, year of publication, type of sample, and age/status. Table 2 shows the main results of the studies conducted on sleep and balance/PC.

Overview of the Characteristics of the Studies

Publication year

A total of 15 studies met the inclusion criteria of the study. One article was published before the year 2000 [25], four in 2001–2004 [12,26-28], four in 2005–2010 [29-32]. Six articles were published in 2011–2016 [33-38].

Source of studies

Seven studies were conducted in the USA [25,27,28,34,35,37,38], out of which two studies [34,35] were conducted in North America and two in South America [37,38]. Three studies were conducted in Asia [12,26,32] including Japan [12,26] and China [32]. Three studies were conducted in Europe [29,31,33]. One study was conducted in the Middle East (Israel) [30]. One study was conducted in Australia [36].

Type of samples

Thirteen studies involved young adults [12,25–27,29,31-38] in which three studies specifically involved college and/or university student population [29,32,36], two included adults [26,28], two included adolescents [31,38]. Other included studies involved middle-aged adults and older adults [27,30,34].

Design of studies

All articles (n = 15) involved only clinical quantitative studies, such as the application of questionnaires and tools providing quantifiable results.
Various parameters of sleep were studied using different tools like subjective ratings of alertness, subjective assessment of sleepiness using the visual analogue scale method, electroencephalogram (EEG), Stanford Sleepiness Score, polysomnographic (PSG) adaptation and screening, Perceptual Psychomotor Vigilance Task, Actigraphy, Morningness-eveningness questionnaire (HO), Epworth Sleepiness Scale (ESS) and Pittsburgh Sleep Quality Index (PSQI). The assessment of PC and balance varied among the researchers. The majority of the studies used highly technical PC assessment equipment such as posture platform, force platform (AnimaG5500), AMTI Accu-Sway force plate, Stabilometric platform, FitScan Interactive Balance System, Forceplate (model NC-4060), EAB 100 balance examination system, Moving room paradigm and Biodex Balance System. Additionally, some clinical tests such as Star Excursion Balance Test (SEBT) and Romberg's index were also used.

Table 1. Articles included in the review and participants’ characterization (n = 15)

<table>
<thead>
<tr>
<th>Authors/year</th>
<th>Type of sample (age/status)</th>
<th>Total participants</th>
<th>M/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlesinger et al. [25] (1998)</td>
<td>Healthy young adults (mean age: 20 years)</td>
<td>5</td>
<td>2/3</td>
</tr>
<tr>
<td>Nakano et al. [12] (2001)</td>
<td>Healthy male young adults (21–27 years)</td>
<td>10</td>
<td>10/0</td>
</tr>
<tr>
<td>Liu et al. [26] (2001)</td>
<td>Healthy male young adults (mean age: 23.5 ± 0.8 years)</td>
<td>7</td>
<td>7/0</td>
</tr>
<tr>
<td>Caldwell et al. [27] (2003)</td>
<td>Healthy young adults and middle-aged adults (26–44 years)</td>
<td>16</td>
<td>15/1</td>
</tr>
<tr>
<td>Gribble and Hertel [28] (2004)</td>
<td>Healthy adults (mean age: 20.0 ± 2.1 years)</td>
<td>24</td>
<td>13/11</td>
</tr>
<tr>
<td>Fabbri et al. [29] (2006)</td>
<td>Healthy students (mean age: 23.45 ± 3.29)</td>
<td>55</td>
<td>16/39</td>
</tr>
<tr>
<td>Morad et al. [30] (2007)</td>
<td>Healthy young, middle-aged, and older adults (20–60 years)</td>
<td>12</td>
<td>6/6</td>
</tr>
<tr>
<td>Patel et al. [31] (2008)</td>
<td>Healthy adolescents and young adults (16–38 years)</td>
<td>18</td>
<td>10/8</td>
</tr>
<tr>
<td>Ma et al. [32] (2009)</td>
<td>Healthy male senior college students (mean age: 20.75 ± 1.18 years)</td>
<td>16</td>
<td>16/0</td>
</tr>
<tr>
<td>Bougard et al. [33] (2011)</td>
<td>Young adult males (mean age: 24.6 ± 4.6 years)</td>
<td>20</td>
<td>20/0</td>
</tr>
<tr>
<td>Robillard et al. [34] (2011)</td>
<td>Healthy young adults (20–28 years) and older adults (60–70 years)</td>
<td>30</td>
<td>16/14</td>
</tr>
<tr>
<td>Robillard et al. [35] (2011)</td>
<td>Healthy young adults (mean age: 25.0 ± 2.7 years)</td>
<td>13</td>
<td>7/6</td>
</tr>
<tr>
<td>Smith et al. [36] (2012)</td>
<td>Young adult university students (18–25 years)</td>
<td>9</td>
<td>3/6</td>
</tr>
<tr>
<td>Aguiar and Barela [37] (2014)</td>
<td>Healthy young adults (Sleep Deprived group, mean age: 24.93 ± 5.60 years; control group, mean age: 27.16 ± 5.70 years)</td>
<td>60</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>Furtado et al. [38] (2016)</td>
<td>Healthy adolescents and young adults (18–29 years)</td>
<td>30</td>
<td>6/24</td>
</tr>
</tbody>
</table>

M, male; F, female.

**Acute Sleep Deprivation and Postural Control**

Majority of the studies included in this paper (n = 14) [12,25-37] analysed the effects on PC because of ‘acute’ sleep deprivation. The studies involved sustained wakefulness of 24 h [25,31,32], 18 h [12], 6h [26,33], 28 h [27], 48 h [28], 12 h [29,37], 26 h [30,34,35], 36 h [31], and 14 h [36]. The results of all these studies indicated an impairment in the PC due to impaired sleep.

**Chronic Sleep Deprivation and Postural Control**

Out of all the studies in this paper, only one study [38] assessed the effects of ‘chronic’ sleep deprivation on the body’s PC system.

**Time of Day and Postural Control**

One study [33] examined the effect of the time of the day or any diurnal variations and indicated that there exists an influence of time of day over the PC such that the PC is better in the morning than in the latter part of the day.

**Impact of Aging on the Effects of Sleep Deprivation on Postural Control**

One of the included studies [34] examined the effect of aging on the interactions between PC and sleep. The study involved the comparison between two groups (one group included young adults and the other group included older adults) based on outcomes involving postural and auditory tasks after total sleep deprivation and after a night of sleep.

A thorough review of the results of all the included studies indicated the existence of a unidirectional relationship between the sleep and body’s PC, i.e., any deterioration in the sleep parameters would have a negative impact on the PC. No study was found to be having an alternate result, thus, all the results pointed in the same direction.

**DISCUSSION**

The present study reviewed the papers that evaluated the association between various sleep parameters and PC and indicated that impairment in sleep has a negative impact on the body’s PC. This review shows that individuals who experience poor sleep, have a greater risk of developing alterations in the PC than those having an adequate amount of sleep. All the in-
Table 2. Main results of the studies conducted on sleep and PC (n = 15)

<table>
<thead>
<tr>
<th>Authors/year</th>
<th>Instruments used</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlesinger et al.</td>
<td>Posture platform (Equitest, Neurocom, Inc.)</td>
<td>The ability to maintain a postural balance while standing was affected by a combination of cognitive demands and sleep deprivation.</td>
</tr>
<tr>
<td>(1998)</td>
<td></td>
<td>Sleepiness that was intolerable due to sleep deprivation led to a significant deterioration in PC, especially during the time of the lowest temperature of the rectum.</td>
</tr>
<tr>
<td>Nakano et al.</td>
<td>EEG and Subjective ratings of alertness  Rectal temperatures  Performance tests  Alpha Attenuation Test  Postural balance tests</td>
<td>Changes in postural sway at night were affected by an increase in sleepiness.</td>
</tr>
<tr>
<td>(2001)</td>
<td></td>
<td>The upright position led to increased EEG excitement and constant attention.</td>
</tr>
<tr>
<td>Liu et al.</td>
<td>Force platform (AnimaG5500; Anima, Tokyo, Japan)  Subjective assessment of sleepiness using the visual analogue scale method  Electrocardiogram  Subjective ratings of alertness  Rectal temperatures  Performance tests  Alpha Attenuation Test  Postural balance tests</td>
<td>The ability to maintain the posture in the bipedal position during the sleep deprivation period was influenced by the time of day. Notable changes in center of pressure velocity occurred with the lowest values occurring at midnight.</td>
</tr>
<tr>
<td>(2001)</td>
<td></td>
<td>The efficiency of the postural system was influenced by two main factors: a night of forced awakening and the visual state of recording. The accuracy of the PC was reduced after a night without sleep.</td>
</tr>
<tr>
<td>Caldwell et al.</td>
<td>PVT (Ambulatory Monitoring, Inc., Ardsley, NY, USA) test  Electrocardiogram  Subjective ratings of alertness  Rectal temperatures  Performance tests  Alpha Attenuation Test  Postural balance tests</td>
<td>PC was significantly affected after 24 hours of sleep, but less after 36 hours. VAS scores showed little correlation with performance control indicators.</td>
</tr>
<tr>
<td>(2003)</td>
<td></td>
<td>Stability and sway intensity during closed eyes showed a significant circadian pattern with a peak during early hours in the morning along with a recovery at 10:00 the following day.</td>
</tr>
<tr>
<td>Fabbri et al.</td>
<td>Stabilometric platform, using normalized balance platform system  Global Vigor and Affect scale  Digital thermometer  Electrocardiogram  Subjective ratings of alertness  Rectal temperatures  Performance tests  Alpha Attenuation Test  Postural balance tests</td>
<td>Sleep deprivation may cause fatigue and may affect PC as well.</td>
</tr>
<tr>
<td>(2006)</td>
<td></td>
<td>Improvement in PC occurred after a normal night’s sleep according to the time of day. Sleep deprivation led to poor PC, specifically at mid-day (10:00 AM and 2:00 PM).</td>
</tr>
<tr>
<td>Gribble and Hertel</td>
<td>AMTI AccuSway force plate (AMTI, Inc., Watertown, MA, USA)</td>
<td>Sleep loss had a more disruptive effect on PC in older participants and therefore might lead to a greater risk of falls in the elderly.</td>
</tr>
<tr>
<td>(2004)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
cluded papers pointed in the direction of a positive association between sleep and PC, i.e., any disturbance in sleep would result in deterioration of PC.

The majority of the studies focused on finding the effects of ‘acute’ sleep deprivation (ranging from 6 to 36 hours) on PC, concluding that acute sleep deprivation influences the PC negatively. Interestingly, one of the studies showed the relationship between acute sleep deprivation and PC differently, incorporating the effect of ‘positioning’ [27]. Caldwell et al. [27] examined the effects of posture on brain activity using EEG and Psychomotor Vigilance Task (PVT) performance in individuals having sleep deprivation. They concluded that the upright position increased EEG stimulation and attention, suggesting that postural manipulations could be useful in addressing the ill effects of sleep deprivation.

Out of all the papers, only one study [38] focused on the impact of ‘chronic’ sleep deprivation on PC. The study involved the use of actigraphy and three questionnaires (HO, ESS, and PSQI) for the assessment of various sleep parameters. The posture was assessed using the Biodex Balance System (BBS, Biodex Medical Systems Inc., Shirley, NY, USA) with the postural tests being divided into dynamic and static. The study concluded that impairment in the PC due to chronic poor sleep quality occurred in a way similar to that of total sleep deprivation. Also, during the testing with closed eyes, the group having worse sleep quality exhibited poor PC performance, thus indicating that lack of vision impaired PC to a greater extent in participants with chronic sleep inefficiency. However, more studies are required to study the changes in the PC as a result of chronic impairment of sleep as changes in sleep over a longer period may represent a better exposure measure.

The effect of poor sleep in relation to the time of day was also studied and it was concluded that it influenced the body’s PC [33]. According to Bougard et al. [33], PC was particularly affected at mid-day (10:00 AM and 2:00 PM) along with improved PC after a normal night of sleep. One of the studies explored the impact of aging and concluded that loss of sleep had a more disturbing effect on PC in the older-adult group than in younger participants [34]. This also indicated a high risk of falling among the elderly.

Table 2. Main results of the studies conducted on sleep and PC (n = 15) (continued)

<table>
<thead>
<tr>
<th>Authors/year</th>
<th>Instruments used</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robillard et al. [35] (2011)</td>
<td>PSG, AMTI force platforms (Advance Mechanical Technology Inc.), PVT test</td>
<td>Sleep deprivation weakened PC when the attention and sensory resources were not challenged. In the case of high cognitive load conditions, loss of sleep resulted in a general freezing effect that appeared to be adjusted to the degree of degeneration in psychomotor speed.</td>
</tr>
<tr>
<td>Smith et al. [36] (2012)</td>
<td>Force plate parameters of mediolateral and anterior-posterior sway, COP trace length, area, and velocity, Computer-based Perceptual Psychomotor Vigilance Task, Actigraphy</td>
<td>A significant effect of the long-term wake on psychomotor vigilance and anterior-posterior sway was found. Prolonged waking might increase the risk of falls or other outcomes related to poor PC.</td>
</tr>
<tr>
<td>Aguiar and Barela [37] (2014)</td>
<td>Moving room paradigm</td>
<td>After sleep deprivation, adults became less stable and precise in associating visual signals with motion. Sensorimotor coupling impairments were perceived after sleep deprivation.</td>
</tr>
<tr>
<td>Furtado et al. [38] (2016)</td>
<td>Biodex Balance System, Postural tests: dynamic using platform tilt; static using clinical test of sensory integration, International Physical Activity Questionnaire, Metabolic Equivalent of Task, Actigraphy, Morningness-eveningness questionnaire, Epworth Sleepiness Scale, Pittsburgh Sleep Quality Index</td>
<td>PC was impaired due to chronic poor quality of sleep in a similar way to total sleep deprivation. Lack of vision-impaired PC to a greater extent in participants with chronic sleep inefficiency.</td>
</tr>
</tbody>
</table>

PC, postural control; EEG, electroencephalogram; PVT, Psychomotor Vigilance Task; SSS, Stanford Sleepiness Score; VAS, Visual Analogue Scale; COP, centre of pressure; PSG, polysomnographic.
The exact mechanisms that underlie this relationship between sleep and PC have not been fully understood. According to this review, factors associated with deteriorated PC due to impaired sleep included increased postural sway [12,25,26,29,37], difficulty in maintaining upright posture [27,28], reduction of adaptation [31], feeling of fatigue [32], diurnal fluctuations of the centre of pressure (COP) surface area [33], and alteration in COP range and speed [34-36]. It was noticed that the effect of fatigue on postural performance due to sleep deprivation enhanced following the occlusion of vision [30]. An increase in the risk of falls due to extended periods of wakefulness was also observed [31,36]. The role of visual information was also studied indicating that visual cues play a key role in maintaining balance after a period of sleep deprivation [12,26,30-32,34,35,37].

There were a few limitations to the studies. The sleep assessments performed were either subjective or quantitative, depending on the tools used. The studies involved the assessment of various parameters of sleep using different tools ranging from questionnaires to instrument-based assessments. This discrepancy in the method of evaluating the different sleep parameters and cross-study outcomes could not limit variability due to differences in methods. However, as sleep is a multidimensional measure, it is difficult to limit it to only one type of assessment method. The majority of the included studies used subjective sleep assessment which enabled to provide an individual's perception of sleep along with the evaluation of psychological disorders, thereby proving to be more useful in clinical settings [39] which is somewhat difficult with the objective assessment of sleep [40]. However, actigraphy, sleep diaries, and PSG from small-scale investigations and some large populations showed a high correlation between subjective estimates of sleep with more direct evaluations [41,42].

Since the majority of the included studies had young adults as the study participants, a good amount of heterogeneity was not present to verify the different aspects of sleep and PC in diverse populations. This heterogeneity is important as the quality of sleep and PC are capable of affecting the health of different types of populations. The associations are therefore needed to be studied in a variety of populations. It has been seen that older individuals have slower reaction time as compared to young individuals in the PVT performance irrespective of sleep deprivation, however, in the case of sleep deprivation, the older individuals show a greater decline in the reaction time till 16 hours of sleep deprivation following which, both the young and older individuals show a similar decrement in the PVT performance. This indicates that age also plays a major role in determining the level of performance in sleep-deprived individuals [43]. Only one study [34] focused on the effect of age on the changes observed in PC due to sleep deprivation indicating that sleep has a negative influence on PC.

Investigations in the majority of the included papers were done in terms of sleep deprivation. No study measured the effect of ‘excessive quantity of sleep’ on the balance system. An excessive amount of sleep is found to be prevalent throughout the population and is similar to a wide range of sleep-related, neurological and mental disorders, and its effects are therefore needed to be carefully studied [44].

The results of this study can only be representative of studies that have been included and are unable to provide representative inference for all published studies, but not included. Although there was no bias in the selection process, some studies could have been missed out from the analysis. To the best of our knowledge, no review has been performed to provide an exhaustive summary of current literature related to the relationship between sleep and PC. Further research in this area should be encouraged, including individuals having chronic sleep deprivation, considering various other factors such as their age, gender, BMI, etc.

Availability of Data and Material

Data sharing not applicable to this article as no datasets were generated or analyzed during the study.

Author Contributions


Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Funding Statement

None

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