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EFFECTS OF SLEEP DEPRIVATION ON POSTURAL CONTROL

Dissertação com vista à obtenção do grau de Mestre em Exercício e Saúde

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Resumo

O sono é um requisito biológico essencial para manter o organismo humano a regular o equilíbrio a nível fisiológico, físico, cognitivo, psicológico e emocional, de forma adequada e de acordo com as suas necessidades, permitindo restabelecer a sua funcionalidade para realizar as atividades diárias e garantir o seu bem-estar. Existe evidência de que a privação do sono tem um impacto negativo no desenvolvimento motor e na qualidade de vida. Uma das componentes que reflete o desempenho motor é o controlo postural. As situações de privação de sono aumentam consideravelmente as dificuldades na capacidade de estabilização do sistema neuromuscular e em adaptá-lo a constrangimentos do ambiente, tendendo a aumentar o risco de lesões e quedas. Desta forma, este estudo tem como objetivo investigar o efeito de 24 horas de privação do sono no controlo postural. Dezassete sujeitos saudáveis (idade 23.88±2.42 anos, altura 1.75±0.06 m, massa corporal 71.80±7.97 kg, índice de massa corporal 23.30±1.80 kg/m^2) visitaram o laboratório em duas ocasiões; pré e pós 24 horas de privação do sono. Nas duas sessões, os participantes realizaram a avaliação do controlo postural a partir da técnica de posturografia. O protocolo consistiu na estabilização da postura em pé e bipedal, durante dois minutos. A avaliação realizou-se duas vezes, sob duas condições: olhos abertos e olhos fechados. Foram analisados os parâmetros lineares que caracterizam o equilíbrio postural, a partir dos dados do centro de pressão. Foram também determinados parâmetros não lineares de variação da regularidade do controlo postural, através da métrica da entropia amostral, na direção ântero-posterior (SampEn AP) e médio-lateral (SampEn ML). Foram efetuados testes t para amostras emparelhadas e os testes de Wilcoxon para testar o efeito da privação do sono de todas as variáveis dependentes. Em quase todos os parâmetros lineares foi observado um aumento depois da privação de sono (com exceção da amplitude na direção ântero-posterior na condição de olhos abertos, que se manteve), enquanto a entropia amostral diminuiu. Os resultados indicam que a privação de 24 horas de sono afeta negativamente o controlo postural. Este estudo confirmou as observações de estudos anteriores a partir de variáveis lineares e ainda forneceu um novo contributo em relação aos efeitos da privação do sono na complexidade do controlo postural e do controlo motor. A medida reflete a adaptabilidade do controlo motor e atua como uma medida indireta da capacidade funcional do sistema neuromuscular humano. Um estado de 24 horas de privação de sono contribuiu para a redução das capacidades psicomotoras, cognitivas e a adaptabilidade aos constrangimentos, sugerindo-se que existe maior probabilidade em comprometer o sistema neuromuscular e, consequente, maior exposição para ocorrência de lesões e quedas.

Palavras-chave: Equilíbrio, Perda de Sono, Ritmo Circadiano, Controlo Motor, Posturografia, Centro de Pressão, Equilíbrio, Variabilidade Linear, Complexidade do Controlo Postural; Dinâmica Não-linear, Entropia, Estrutura Temporal, Cronótipo.

Abstract

Sleep is an essential biological requirement for the human organism to regulate its physiological, physical, cognitive, psychological and emotional resources, according to its necessities, allowing the functionality to carry out daily activities successfully. Evidence claims that sleep deprivation has a negative impact on physical performance, motor development and quality of life. One of the components that reflects motor performance is postural control. Sleep deprivation decreases considerably the capacity of stabilizing the neuromuscular system and adapting to environmental constraints, leading to a greater propensity to injuries and falls. This study aims to investigate the effects of a 24-hour sleep deprivation on postural control. Seventeen healthy participants (age 23.88±2.42 years, height 1.75±0.06 m, weight 71.80±7.97 kg, body mass index 23.30±1.80 kg/m^2) visited the laboratory on two occasions: pre and post 24 hours of sleep deprivation. In both sessions, participants performed the postural control assessment, using the posturography technique. The protocol consisted on stabilizing the body, standing on both legs over a platform, for two minutes, while remaining quiet. The evaluation was performed twice, under two conditions: with eyes opened, and with eyes closed. Linear parameters of the center of pressure data were analyzed. Non-linear parameters of variability in the regularity of postural control were also determined through the sample entropy metric. Paired samples t-tests or a Wilcoxon Signed-rank tests were performed to test the effect of sleep deprivation on all dependent variables. Nearly all linear parameters showed an increase after sleep deprivation (excluding range in the anterior-posterior direction in eyes opened condition, which was maintained), while sample entropy decreased. Our findings show that 24 hours of sleep deprivation negatively affects postural control. This study confirmed the observations of previous studies using linear variables and provided a new contribution regarding the effects of a 24-hour sleep deprivation on the complexity of postural control and motor performance. The measure of entropy reflects the adaptability of motor control and acts as an indirect index of the functional capacity of the human neuromuscular system. Accordingly, in a state of sleep deprivation, psychomotor, cognitive and adaptability capacities are reduced, suggesting that there is a greater probability of compromising the neuromuscular system and, consequently, a greater exposure to injuries and falls.

Keywords: Balance, Sleep Loss, Circadian Rhythm, Motor Control, Posturography, Center of Pressure, Linear Variability, Postural Sway, Postural Control Complexity, Non-Linear Dynamics, Entropy, Temporal Structure, Chronotype.

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List of Acronyms

AASM	American Academy of Sleep Medicine
AP	Anterior-posterior
BMI	Body mass index
CDCP	Center for Disease Control and Prevention
CNS	Central nervous system
CoM	Center of mass
CoP	Center of pressure
EO	Eyes opened
EC	Eyes closed
MEQ	Horne & Ostberg Morningness-Eveningness Questionnaire
ML	Medial-lateral
PNS	Peripheral nervous system
PSQI	Pittsburg Sleep Quality Index
PV	Perception of the vertical
RT	Reaction time
SampEn	Sample entropy
SD	Standard deviation
SDev	Standard deviation (postural control parameter)
SRS	Sleep Research Society
SVV	Subjective Visual Vertical Test

Units of Measure

m	Meter
mm	Millimeter
N	Newton
kg	Kilogram
kg/m^2	Kilogram per square meter
Hz	Hertz
min	Minute
sec	Second
^{o}	Degree

Chapter I - Introduction

1.1. Purpose and Scope of the Thesis

Sleep is a fundamental feature of life and essential for health and well-being, with significant impact on homeostasis, immunity system, physical development, psychological regulation, cognitive performance, motor control, mood and life quality (Chattu et al., 2018b; Grandner 2020; Watson, 2017; Watson et al., 2015b). Sleep is a homeostatically controlled behavioral state of reduced movement and sensory responsiveness that occur at habitual intervals throughout a 24 h period in humans (Fullagar et al., 2015). Along with being an integral part of recovery processes within the organism (i.e. nervous system, cardiac system, clearance of brain metabolites, appetite regulation) sleep is a good predictor of health and vitality. Evidence suggests that a well-balanced sleep routine, sleep duration and sleep quality are associated with improved performance in tasks that require cognitive and motor skills (Watson et al., 2015a).

The role of sleep is, nowadays, widely recognized as beneficial for human's health in industrialized countries. Throughout a 24-h time scale, a well-established sleep-wake cycle, following a circadian rhythm pattern, is a big contributing factor for general health and for the individual to respond to environmental constraints effectively during the day (Walker et al., 2020).

However, even if society regards sleep as an important factor, in the last decades, the amount of sleep deprivation cases have been growing substantially and the outcomes can be devastating. According to the literature, sleep deprivation leads to a disruption of the circadian rhythm of numerous systems (e.g. sleep-wake cycle, internal body temperature, hormone regulation) (Fullagar et al., 2015). A large number of studies indicate that a disruption of circadian regulation is associated with a wide variety of adverse health consequences, including increased risk for premature death, cancer, metabolic syndrome, cardiovascular dysfunction, immune dysregulation, reproductive problems and mood disorders. The ability to manage difficult emotions is compromised, therefore, the risks of anxiety and depression are much higher. (Gribble et al., 2007; Potter et al., 2016). Additionally, the learning capacities (e.g. attention and memory) are also affected and complex or prolonged tasks reduce substantially, producing cognitive deficits (Alhola & Polo-Kantola, 2007; Boonstra et al., 2007; Goel et al., 2009; Walker et al., 2020).

To investigate the effects of sleep loss in physiological, psychological and neurocognitive parameters, an extensive amount of evidence applies a certain period of sleep deprivation as an indicator. Although sleep is generally considered critical for motor performance, not all studies observe such results. Several studies demonstrate that sleep deprivation diminishes considerably motor control, but the results are not sufficiently consistent. Most of the evidence concludes that sleep deprivation affects negatively general neurocognitive and motor abilities, even for simple short-term tasks, as the reaction time (RT) is slower (Lisper, 1972). On the contrary, there is also evidence suggesting the significant effects of sleep deprivation only in more monotonous and prolonged tasks (Harrison & Horne, 2000). For instance, there is evidence showing the effects of sleep deprivation only on more complex and difficult tasks that require high-demanding executive control (Schlesinger et al., 1998). It is important to note that these controversial results may derive from the difference of the methodologies and procedures used: whether in sleep length, difficulty of the task, number or characteristics of the sample or other external and/or internal distinct components and materials used. In the study that contradicted others claiming that only the most difficult of the three RT tasks reduced significantly postural sway, the sample only contained five subjects.

The integration of mechanisms behind these conclusions are few, but strongly consistent among studies. It has been suggested that sleep deprivation induces the deactivation or less activation of areas of the brain related to neurocognitive abilities, such as attention, memory and problem-solving. Another reason is related to the disruption of the sleep-wake cycle. Circadian rhythm allows the nervous system of the human organism to anticipate the recurring environmental daily events through the coordination of different rhythms, whether metabolic, physiological or behavioral. Once there is a desynchronization of the signals the nervous system generates to the internal body cycle, cognitive and psychomotor performance are significantly diminished when occurring out of phase (Adan et al., 2012; Huang et al., 2011).

Postural control impacts motor performance demanding the individual to control the postural adjustments, ensuring that stability is maintained. Concerning the effects of sleep deprivation on motor control, the measure of postural control by the center of pressure (CoP) displacement provides an indirect output of the functional capacity of the neuromuscular system. The relevance of postural control assessment is essentially, but not exclusively, the detection of motor system impairments, which can posteriorly allow the prediction and prevention of risks of accidents, injuries and falls. In sleep deprivation situations, this analysis can be supportive for the intervention in such cases.

In order to determine eventual effects of a 24-h sleep deprivation on postural control, linear and non-linear parameters of CoP fluctuations will be determined. The nonlinear physiological parameter, referred to as entropy, is believed to reflect the ability of a given system to adapt to environmental challenges (Harbourne & Stergiou, 2009; Stergiou et al., 2006). This analysis will enable to detect new hidden characteristics of the time series and mechanisms related that the traditional linear measures methods are unable to detect. In the literature, various types of biological time series were already studied from a non-linear perspective, such as heart rate (Goldberger et al., 2002b), neural activity (Ivanov et al., 2009); gait (Delignières & Torre, 2009; Hausdorff, 2007; Hausdorff et al., 1996, 1997; Vaz et al., 2020a, 2020b) and balance (Cavanaugh, 2005a, 2005b; Delignières et al., 2011; Duarte & Sternad, 2008; Harbourne & Stergiou, 2003; Harbourne et al., 2009; Manor et al., 2010; Vaz et al., 2020c). This study will investigate the impacts of sleep deprivation and postural control from both linear and non-linear insights, and its potential to detect motor control variability.

1.2. Structure of the Thesis

This thesis covers as major topic the effects of sleep deprivation on postural control and motor system of human movement.

The first chapter of the thesis introduces the background information and the context within which this thesis was developed. In the second chapter, there is a presentation of the review of the literature. Several key topics are covered, the main ones being related to sleep deprivation, motor control and postural control. The third chapter introduces the purpose and goals of the study, along with the initial hypothesis expected. The fourth chapter details the methodological considerations and procedures used to collect the data, followed by the statistical analysis techniques applied to analyze the data. The fifth chapter presents the main results that were observed from the data. The sixth chapter provides the critical analysis and discussion of the main results that were observed, establishing a link between the observed results and the initial hypothesis. Additionally, limitations associated with the study are presented. The seventh chapter presents the main conclusions that can be drawn from this study. The eighth chapter presents several suggestions for future investigations. The ninth chapter includes the references that were cited throughout the study. The tenth and last chapter includes the appendixes referred throughout the thesis.

Chapter II - Literature Review

2.1. The Role of Sleep

Sleep is vital for health and well-being (Chattu et al., 2018b; Watson et al., 2015b) and a biological requirement for life (Grandner, 2020). Routinely sleeping seven to eight hours a night brings a multitude of health-ensuring benefits for the rest of the day. It not only contributes to restoring and growing tissues, but also maintains blood sugar levels and appetite and provides optimal conditions for protein synthesis, memory encoding and synaptic efficiency (Watson et al., 2015b). There is no organ functioning within the body, or process within the brain, that is not optimally enhanced by sleep (Walker, 2008; Walker et al., 2020). It is, therefore, essential for optimal performance, physiological processes, emotional regulation and quality of life (Knutson et al., 2017). Specifically, sleep plays a crucial role in homeostatic restoration, thermoregulation, tissue repair, immune control and memory processing (Walker, 2008). It also interferes with cognitive regulation and emotional state (Walker, 2009).

Sleep quality, alongside nutrition and exercise, is a pillar to a healthier life, both mentally and physically (Wickham et al., 2020). Good sleep quality is a well-recognized predictor of high mental and physical health, wellness and functionality (Buysse, 2014; Ohayon et al., 2017). The American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) support the general recommendation for obtaining 7 to 9 hours of sleep per night on a regular basis to promote optimal health among adults aged 18 to 60 years. These recommendations focus on the overall health and well-being and provide important basic information for improving sleep health (Watson et al., 2015b). Nevertheless, sleep quality is most frequently measured by the total sleep duration. Common assessed dimensions of sleep are, but not limited to, sleep continuity, sleep efficiency, sleep latency, sleep architecture, subjective feeling upon awakening and sleep schedule (Chaput et al., 2018; Krystal & Edinger, 2008; Ohayon et al., 2017; Watson et al., 2015b).

Circadian rhythms are internal manifestations of the solar day that permit adaptations to predictable environmental temporal changes and affect the biological clocks within every region of the brain and every organ of the body (Walker et al., 2020). These clocks create a natural cycling rhythm that makes one feel tired or alert at regular times of night and day, respectively. The sleep-wake circadian rhythm activates brain and body mechanisms during daylight hours to keep humans awake, being removed during nighttime, and, consequently, forcing feelings of tiredness. For example, human's core body temperature rises starting at 12 pm (wake phase), reaching its peak in the late afternoon, and helps to be alert. Then, there is a temperature drop (sleep phase), peaking around two hours after sleep onset, exposing to sleepiness (Walker, 2018, p. 19). Other examples of circadian rhythms are heart rate, blood pressure, energy intake (Huang et al., 2011) and endocrine secretion, like melatonin, a hormone the brain produces in response to darkness (Cajochen et al., 2003). When there are disruptions in the light exposure throughout the day, cognitive, metabolic, cardiovascular, temperature and hormonal processes that influence mental and physical activities fluctuate (Adan, 2012; Gribble et al., 2007; Potter et al., 2016). As a result, internal and behavioural rhythms can become desynchronized, leading to negative consequences for health and lead to chronic diseases. Late sleep onset can cause an increase in homeostatic pressure and inflammatory biomarkers and affects core temperature, circulating levels of melatonin and emotional regulation (Fullagar et al., 2015).

Another factor that needs to be addressed is each individual's chronotype, which describes individual differences in sleep and wake timing in their circadian rhythms (Roenneberg et al., 2007). Some people notice their peak of their alertness during early times of day, being classified as "morning types". Others prefer to wake later in the day, having their peak of functional state around evening or nighttime, being known as *evening types* or, more commonly, night owls. The rest of the people are somewhere in-between, usually, but not necessarily, slightly leaning toward morningness or eveningness, being the "indifferent" type (Adan et al., 2012). Chronotype is strongly determined by biological markers, such as genetics, age and sex.

2.2. Sleep Quality, Sleep Restriction and Sleep Deprivation

Insufficient sleep is a global increasing problem that is becoming more prevalent in today's society. Despite the recommendations, the average number of hours of sleep per night for each individual has decreased over the past few decades (Chattu et al., 2018a). According to the Center for Disease Control and Prevention (CDCP), around 35,2% of American adults sleep less than 7 hours per day (Centers for Disease Control and Prevention, 2017, May 2). This sleep-loss epidemic is a common issue in most industrialized countries and has prejudicial consequences to public health (Walker, 2009). For instance, reduced sleep hours are associated with 5 of the 10 most common causes of death in the United States, including cardiovascular diseases, cancer, stroke, car accidents and diabetes mellitus (Ahmad et al., 2021).

The cause of insufficient or inadequate sleep quality is multifactorial. Sleep is influenced by psychological, behavioural, social, cultural and environmental factors (Chattu et al., 2018b; Grandner, 2020; Watson et al., 2015a). The most contributing factors are age, sex, occupation, marital status, socioeconomic status, ethnicity, psychological concerns, stress levels, exposure to tobacco, high levels of alcohol, overweight or obesity, diet, insufficient physical activity, poor mood, levels of anxiety and depression (Chattu et al., 2018b; Magee et al., 2009; Wang & Bíró, 2020). Additionally, electronic devices used until late hours, as well as excessive caffeine consumption, have a significant negative impact in adolescents and young adults' sleep patterns (Chattu et al., 2018b; Owens et al., 2014; Wang & Bíró, 2021). On another magnitude, some professions such as health care, security, transportation and military fields require working at night, which can compromise a whole night's sleep time, leading to an increased risk of chronic sleep deprivation (Alhola & Polo-Kantola, 2007).

The AASM and SRS noted the effects of insufficient sleep as pertaining to the following categories: general health, cardiovascular health, metabolic health, mental health, immunologic health, human performance, cancer, pain, and mortality (Watson et al., 2015b, 2015a). Moreover, another source behind the statistical numbers is associated with the circadian rhythm, which leads to a disrupted sleeping pattern. This is why jet-lag happens after arriving at a new time zone. There is a disturbance into the cycling behaviour throughout the twenty-four hour rhythm the human usually generates within his typical environment. People usually experience feelings of tiredness, drowsiness, poor mood and even anxiety throughout the next few days until they adjust into a new time zone. This situation is even more notorious in shift-workers as, unlike a sporadic jet-lag, forcefully it disrupts the normal sleep-wake cycle in a longer term, leading to chronic health problems and accidents. Shift workers display increased rates of cancer, incidence of cardiovascular and metabolic disorders. They are also more predisposed to psychiatric conditions and cognitive impairments (Chattu et al., 2018b; Potter et al., 2016; Walker et al., 2020; Watson et al., 2015a). Moreover, the rapid technology development nowadays induces cognitive and physiological arousals and it prolongs the exposure to light and electromagnetic transmissions, which make the initiation of sleep harder (Gradisar et al., 2013; Owens et al., 2014).

Not getting enough sleep, in a short period of time, leads to tiredness, raises anxiety levels and affects daily activities by decreasing coordination, judgement, cognition and decision-making, as well as an increase of RT (Thomas et al., 2000a). Several factors, such as work demands, can reduce the sleep duration below the recommended values eliciting a wide range of effects on mood, cognitive and motor functions (Goel et al., 2009). This can lead to catastrophic injuries and disabilities as a result of an increased number of accidents, including vehicle-accidents (Horne & Reyner, 1999; Gauchard et al., 2003) and falls (Gomez et al., 2008; Patel et al., 2008), especially among the elderly (Stelmach et al., 1990; Teasdale & Simoneau, 2001; Hill et al., 2007; Robillard, 2011a). Other populations that are more exposed to continuous wakefulness nights include the military, night shift-workers, long-distance drivers, aviators and health workers. In the long term, sleep deprivation is also linked with many chronic diseases and conditions, for instance, type 2 diabetes, heart disease, weight gain and obesity, depression and increased risk of death (Alvarez & Ayas, 2004; Chattu et al., 2018b; Walker, 2009, 2019; Watson et al., 2015a, 2015b).

2.3. Sleep Deprivation on Motor Control

Even though much was studied on the impacts of insufficient sleep on health, there is much less and more conflicting evidence among motor control. To our knowledge, studies that tried to assess the effects of sleep loss on human motor control are limited to attention and RT, balance/posture, and pacing strategies measurements. Despite that, scientific evidence appears sufficient to imply that insufficient sleep has a significant impact on motor control. Some indicators related to motor control performance have been reported to suffer decrements with insufficient or low quality sleep. Sleep loss can manifest as a result of total sleep deprivation, sleep restriction (also referred as partial sleep deprivation) or sleep disruption. Total sleep deprivation is the continuous wakefulness for a period of time (at least one night). Sleep restriction is a reduction in sleep time below an individual's usual baseline or the amount of sleep needed on a regular basis to maintain optimal performance. This is probably the most common form of sleep loss experienced in everyday life (Banks & Dinges, 2007). Sleep disruption occurs when there is an increase in awakenings and, typically, a reduction of deep sleep, which can contribute to daytime sleepiness (Stepanski, 2002).

It was observed that sleep deprivation leads to a slowing response and increased variability of movement performance, especially for simple measures of alertness, attention and vigilance (Alhola & Polo-Kantola, 2007; Arnal et al., 2015). Some of the cognitive functions particularly worsened by sleep loss include memory, psychomotor and cognitive speed, vigilant attention (Alhola & Polo-Kantola, 2007; Lim & Dinges, 2008; Arnal et al., 2015; Fullagar et al., 2015; Skurvydas et al., 2020), executive function, logical thinking and decision-making (Harrison & Horne, 2000; Fullagar et al., 2015; Skurvydas et al., 2020). Previous research suggests that its effects are even more notorious, the more attention the task demands (Teasdale & Simoneau, 2001). Other studies, however, observed that more monotonous attention requirements are more likely to induce accidents when sleep-deprived. For example, the monotonous characteristics in driving in highways tend to decrease attention substantially on sleep-deprived drivers, being more common to accidents than in urban areas, which have more variability in the environment (Larue et al., 2011). Goel et al. (2009) showed that once sleepiness is pushed beyond the approximate 16 hours, most individuals begin to show a substantial slowing RT, as well as a worsening performance accuracy on psychomotor vigilance tests (Goel et al., 2009). Opposingly, unlike other studies (Killgore, 2010; Santhi et al., 2007;), Skurvydas et al. (2020) showed that sleep deprivation did not change simple RT, precision of movement performance, speed, or intra-individual variability for simple and complex tasks (Skurvydas et al., 2020). But this could be due to the use of different tests and study designs, the variables considered or even the effect size used.

It was also demonstrated that sleep deprivation leads to a general slowing of response and movement variability, fundamentally for simple measures of alertness, attention and vigilance (Killgore, 2010). Although some of these relationships have been widely demonstrated, there is much less agreement about the effects of sleep deprivation on many higher-level cognitive capacities and executive functions (Killgore, 2010; Basner et al., 2015; Skurvydas et al., 2020). Much of the previous research reported that motor performance is negatively affected following sleep loss in simple cognitive tasks, whereas in more complex cognitive tasks, motor control remains disrupted (Lim & Dinges 2008; Skurvydas et al., 2020). Nevertheless, there is evidence suggesting the opposite effect on those higher-level cognitive capacities, which can lead to a decrement of attention and executive function, resulting in an increased number of errors on performance (Goel et al., 2009; Killgore, 2010). A reason behind these opposing ideas might be because interpreting measures of overall performance without consideration of the specific task requirements can lead to misleading conclusions (Jackson, 2013). Additionally, insufficient sleep induces more detrimental effects in longer and more monotonous tasks, compared to short duration tasks (Pilcher & Huffcutt, 1996). A previous meta-analysis suggests that effects of sleep deprivation on cognitive performance include a slowing on time response, reduced capacity to learn cognitive tasks, a decrement of performance requiring divergent thinking, as well as a worsened performance along the duration of the task, and an increase of errors during tasks. However, these results can be misleading as they do not have the intersubject and intrasubject variability in account (Durmer & Dinges, 2005). Interestingly, Riegler et al. (2021) compared the effects between sleep deprivation on injury-free athletes and post-concussion on sufficient sleep athletes, reporting both cause a worsening of attention and processing-speed, cognition, physical performance, well-being and mood. Overall, on a general perspective, insufficient sleep induces substantial deficits in various dimensions of neurobehavioral and cognitive performance (Durmer & Dinges, 2005).

The mechanisms by which sleep disruption reduces executive and cognitive functions are unknown, but likely involve functional impairment of the prefrontal cortex and/or its afferents which are particularly sensitive to sleep loss, firstly proposed by Horne (1993). The prefrontal cortex activity is linked to higher functions, such as language, executive functions, divergent thinking and creativity. This idea also assumes that the worsening of performance in simple, long monotonous tasks is essentially due to boredom (Harrison & Horne, 2000). Interestingly, after 16 hours of continuous wakefulness, the interindividual response to cognition measures worsens considerably, suggesting different vulnerability or compensatory responses from neurological systems involved in cognition (Goel et al., 2009), decreases that continue to worsen during wakefulness throughout the night into the early morning (Pilcher & Huffcutt, 1996). As in memory, sleep deprivation is likely to impair hippocampal function (Walker, 2008). These impairments on local brain activation produced by sleep loss may affect negatively the time of response, the process of acquisition of cognitive tasks and the performance in execution of motor tasks (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005; Harrison & Horne, 2000; Umemura et al., 2017). Interindividual differences should also be considered in effects of sleep deprivation, as sleep loss has more impact on some individuals than others (Van Dongen et al., 2005). On a global perspective, despite the study design, the length of sleep deprivation period used, and type of task assessed, available literature points to sleep deprivation attenuating ability to perform a variety of psychomotor tasks related to neuromuscular function.

There is some evidence indicating that sleep deprivation does not change motor characteristics for which performance does not require motor control precision; that is, gross motor performance, such as maximal voluntary contraction (Fullagar et al, 2015: Skurvydas et al., 2020). Motor control can mostly be maintained during 60 hours of sleep deprivation (Vaara et al., 2018), and maximal neuromuscular and aerobic performance are unaffected after one night of sleep restriction (Fullagar,et al. 2015; Skurvydas et al., 2020; Symons et al., 1988; Vaara et al., 2018), along with rate of force development (Skurvydas et al., 2020; Symons et al., 1988; Vaara et al., 2018), electromyographic recordings of the knee extensors (Vaara et al., 2018) and CMJ height (Skurvydas et al., 2020). Nevertheless, sleep deprivation can compromise submaximal cardiovascular performance in prolonged competitions in sports, such as ultramarathon races

(Symons et al., 1988; Vaara et al., 2018; Vernillo et al., 2016), intermittent-sprint performance and slower pacing strategies (Skein et al., 2011).

Maintaining a postural stability is an essential requirement for daily activities, from quiet standing and locomotion to other motor tasks (e.g. reaching, lifting) (Berrigan et al., 2006), as the human neuromuscular system has a need to adapt to perturbations. In fact, the upright stance actually requires two different actions: posture (maintaining alignment of the body segments with respect to each other and to external references; [gravitational vertical, visual vertical, or the support surface]), and balance, that is the ability to avoid falling in both static (e.g., quiet standing) and dynamic situations (e.g., walking, external perturbations). These two conditions are usually interdependent with each other, therefore, considered as a single process. Occurrence of changes in body alignment are usually in line with a need to find stability. However, the mechanisms by which the central nervous system (CNS) controls posture during standing may be different so it is unclear whether abnormal postural sway necessarily impairs control of balance (St George et al., 2018).

Postural control and associated variables are, therefore, an important measure of the severity and nature of postural instabilities (Benvenuti et al., 1999) and, more generally, of motor control, as they have recently been proposed as an indirect index of the functional capacity of the neuromuscular system (Munoz-Martel et al., 2019; Paillard & Noé, 2015). Posturography is a technique used to quantify the CNS adaptive processes (motor, sensory and central) involved in the control of postural function (Paillard & Noé, 2015).

Evidence considers that sleep deprivation also affects balance, by the increase of body movement variance, after 24 and 36 hours of sleep deprivation (Gomez et al., 2008). A reason behind this might be explained through reduced adaptation ability and lapses in attention. Moreover, dynamic balance control was much worse with external focus (i.e. focus on the surroundings) than with internal focus (i.e. focus on their feet) (Diekfuss et al., 2018). Also, self-selected walking pace decreased after 48h of sleep deprivation (Rodgers et al., 1995). These effects on postural stability deterioration, poor balance and walking can increase the risk of accidents, such as falls, which is rather common among the elderly, as postural control deteriorates with aging and can cause a great impact on quality of life (Laughton et al., 2003; Robillard, 2011a; Teasdale & Simoneau, 2001). The associations between sleep disturbances and risks of falling on older people are unequivocal. Possible causes for these consequences are linked with tiredness, poor judgement, slower nervous system responses, worsening of vigilance and difficult concentration, which can compromise cognitive function and movement control (Hill et al., 2007; Scott et al., 2006).

Sleep deprivation is associated with detrimental effects on human functioning, being undoubtedly associated with poorer mood states (Pilcher & Huffcutt, 1996), with increased feelings of fatigue, sleepiness, soreness, depression and confusion (Scott et al., 2006; Watson, 2017). In fact, meta-analysis suggests that the effects of sleep deprivation on feelings of fatigue and related mood states are greater than effects on cognitive performance or motor functions (Pilcher & Huffcutt, 1996). However, disturbances in mood regulation could reduce motor performance due to a reduced capacity to respond quickly, leading to a greater risk of accident (Scott et al., 2006). Nevertheless, some evidence observed a poor correlation between subjective sleepiness and motor performance, adding that possible reasons may be because the mere act of performing a test might momentarily enhance attention and motivation (Avni et al., 2006; Gomez et al., 2008; Patel et al., 2008). There was also a study by Karita et al. (2006) that did not see differences under the effect of sleep deprivation in mood between overtime and shorter time workers. The contradiction of the evidence's observation can be related by a variety of reasons, including the methodological procedures and materials used, the group of participants and its characteristics, or the variables observed and its effect size.

2.4. Sleep Deprivation on Postural Control

Motor coordination processes require the integration of information from visual, vestibular and somatosensory receptors (Batuk et al., 2020; Fabbri et al., 2006; Furtado et al., 2016; Liu et al., 2001; Schlesinger et al., 1998; Teasdale & Simoneau, 2001). Postural control is a motor skill that demands the interpretation of information from the somatosensory, visual and vestibular systems to determine body alignment, motion and relative stability (Batuk et al., 2020; Fabbri et al., 2006; Furtado et al., 2016; Horak & Kuo, 2000; Liu et al., 2001; Schlesinger et al., 1998). A stable balance is crucial to functional independence and plays an important role in the daily routine. Postural stability is usually measured by the CoP. CoP is the central application point of the ground reaction force. It constantly moves around the center of mass to maintain balance, so its dynamic parameters, such as range, velocity and variability displacements, are commonly used to characterize postural control. Different values of these parameters affect different postural states. The increase of range, velocity, and variability of CoP displacement characterizes a more unstable state and a higher risk of falls and accidents. On the other hand, CoP displacement that has low range, speed and variability indicate an overly rigid or stiff postural stability, with reduced sensory input and less ability to adapt to external perturbations. Some studies show that sleep deprivation increases the range, variability and velocity of CoP during upright stance. As a result, balance capacity deteriorates (Avni et al., 2006; Fabbri et al., 2006; Gribble & Hertel, 2004; Liu et al., 2001; Robillard, 2011a). The increase of postural sway prior to sleep deprivation is observed by higher values of parameters, including CoP, variability or surface area (Fabbri et al., 2006; Forsman et al., 2007; Robillard, 2011a), CoP velocity (Fabbri et al., 2006; Gribble et al., 2007; Robillard, 2011a), accuracy of balance or length in function of surface (LFS) (Fabbri et al., 2006), and CoP range, whether the direction of movement is anterior-posterior (AP) or medial-lateral (ML) (Fabbri et al., 2006; Ma et al., 2009; Patel et al., 2008; Robillard, 2011a; Smith et al., 2012).

Considerable evidence ought to understand the effects of sleep deprivation on variables related to postural control, manipulating different systems (vision, proprioception, and vestibular inputs), using different study designs and procedures. Many include tests of dynamic versus static conditions, or tasks requiring less or more attention demands, or eyes opened (EO) versus closed conditions (EC). Most literature indicate a detrimental effect of sleep deprivation on postural control, observing higher values of postural sway (Aguiar & Barela, 2014; Avni et al., 2006; Batuk et al., 2020; Bougard et al., 2011; Fabbri et al., 2006; Haeggstrom et al., 2006; Gomez et al., 2008; Gribble & Hertel, 2004; Gribble et al., 2007; Liu et al., 2001; Morad et al., 2007; Nakano et al., 2001; Patel et al., 2008; Robillard, 2011a; Umemura et al., 2018). However, not all literature establishes a relationship between sleep deprivation and postural control in isolation. Several studies reported that sleep deprivation induced significant increases in postural sway, but only when the participants were tested with the EC condition (Furtado et al., 2016; Liu et al., 2001; Ma et al., 2009; Martin et al., 2017; Nakano et al., 2001; Robillard, 2011a; Smith et al., 2012).

Liu et al. (2001) noticed that continuous sleep deprivation during 27h increased parameters of CoP area, CoP AP direction and frequency in both AP and ML directions, especially during the night after the night of sleep deprivation, reaching its peak at 4:00 am, noting it might have been due to feelings of sleepiness. The increases of CoP area and AP frequency of postural sway were larger with EC than with EO, because of the compensatory effects of visual input. Moreover, there was a strong correlation between objective measures in the EC condition with subjective feelings of sleepiness, leading the authors to conclude that the sensitivity to increased sleepiness depends on postural sway parameters. Generally, sleep deprivation seems to affect balance negatively in people with lower sleep quality, in a similar way as those that spent one night without sleep (Furtado et al., 2016).

However, not all studies reported these changes. Vaara et al. (2018) observed a deterioration of postural control values (expressed as a change in postural sway distance in the AP and ML directions, which corresponds to the distance of the CoP from the center of gravity over the respective axes), with EO after 48h of sleep deprivation (PRE: 97 ± 26 mm ML at 36h vs. POST: 100 ± 25 mm ML at 48h sleep deprivation) (PRE: 212 ± 71 mm AP at 36h vs. POST: 237 ± 82 mm AP at 48h sleep deprivation). Nevertheless, these changes were not observed for the EO condition (Vaara et al., 2018). Moreover, Patel et al. (2008) reported that postural control decreased after 24 h of sleep deprivation, yet, the decrement did not continue after 36h and was even partly recovered in some cases. Besides, the subjective feeling of sleepiness was poorly associated with motor performance in both studies. The authors assumed that the decrease of postural stability until the 24 h of sleep deprivation was a result of the regions within the brain that regulate attention, alertness and cognitive abilities suffered an activity deactivation. As the continued wakefulness continues, the plateau (or even improvement in some participants) noticed in motor control performance and in RT occurred due to a learning effect. Another possible explanation might be because postural control is affected by a circadian rhythm. Patel et al. (2008) also assumed that the balance decrement is more pronounced in long and monotonous tasks rather than in shorter tasks (Pilcher & Huffcuff, 1996). On the other hand, Gomez et al. (2008) observed a similar pattern, but the decrease in performance stopped at 24 h instead. Indeed, the authors observed some improvement in postural control between the 24 h and 36 h of sleep deprivation, suggesting that postural performance might be affected by circadian rhythm effects and not only by the length of sleep deprivation (Avni et al., 2006; Gribble & Hertel, 2004; Nakano et al., 2001). In another study by Vaara et al. (2018), postural control also reduced slightly during the first 24 h of sleep deprivation, but mostly maintained until the 60h of sleep deprivation. This led to assume that the length of sleep deprivation may not affect decrement of motor performance in a linear manner, following Gomez et al. (2008) and Patel et al. (2008), due to the learning effect of repeated trials. However, the study did not mention the circadian rhythm effect as a contributing factor, explaining it could be because the participants were military officers used to spending nights of sleep deprivation. Partly, the controversial findings may relate to differences in methodological issues and study designs, such as the length of sleep deprivation period and the type of test procedure used.

A study by Aguiar & Barela (2014), instead of a posturographic force plate, utilized a room with the ability to move to assess the effects of sleep deprivation on the relationship between visual information, altered by the manipulated moving room, and body sway. The results showed larger and faster body sway in sleep deprived individuals, whether with EO or EC. Authors proposed that these results indicate that sleep deprivation status induces less stability and accurate visual information to motor control. This effect is suggested to occur due to decrements of cognitive function, suggesting that not only attentional difficulties but also to processes that do not involve conscious awareness.

The physiological mechanisms behind the effects of sleep deprivation on postural control are still unclear. General evidence suggests sleep deprivation affects regions of the brain involved in posture stability, such as thalamus, pre-frontal cortex and cerebellum, resulting in a worsening of postural control (Thomas et al., 2000; Umemura et al., 2018, 2019). According to the evidence, there are few hypotheses on how sleep deprivation reduces motor response and, therefore, results in an affected motor response, less able to produce and maintain postural stability (Umemura et al., 2017).

Attention plays an essential role in processing sensory information to maintain postural stability (Fabbri et al., 2006; Schlesinger et al., 1998; Woollacott & Shumway-Cook, 2002). Several studies have reported reductions of performance in tests for vigilance, attention and RT following complete sleep loss (Fullagar et al., 2015). Curiously, the reduced levels of alertness induced by sleep deprivation peak when the body temperature reaches its minimum (Nakano, 2001). It is possible that the sleep deprivation and consequent decrease of attention and alertness lead to slower or less accurate sensory integration, resulting in an imbalanced system to maintain postural control (Fabbri et al., 2006; Gomez et al., 2008; Liu et al., 2001; Nakano et al., 2001; Robillard, 2011a). Few authors have proposed that the motor deficits are caused by alterations in the attentional state of the brain (Fabbri et al., 2006; Nakano, 2001; Schlesinger et al., 1998). Schlesinger and associates (Schlesinger et al., 1998) reported that under the conditions of low postural control demand, such as standing on a fixed platform or in a simple reaction task, postural sway did not increase after 24 h of sleep deprivation. But during a task requiring the intermittent inhibition of attention (IRT) postural sway increased. A possible explanation for this is the inhibition of motor inputs involved in complex tasks, which require integration of information processing, opposed to simple tasks. Some literature show an increase of simple RT, defined as the minimal time necessary to respond to a stimulus (Woods et al., 2015), after sleep deprivation (Batuk et al., 2020), while others show no changes (Vaara et al., 2018), with different levels of requirements to maintain postural control.

Visual inputs are also affected by sleep deprivation (Liu et al., 2001; Gomez et al., 2008; Patel et al., 2008). Sleep deprivation had less effect on postural stability with EO than with EC. One study suggested that sleep deprivation affects postural control even in unchallenged sensory and cognitive functioning conditions (Robillard, 2011b), though there is also evidence contradicting this (Nakano, 2001; Schlesinger, 1998). According to literature (Avni et al., 2006), the vestibular system is the most vulnerable to the impact of fatigue, compared to visual and somatosensory systems (Avni et al., 2006). However, a recent study evaluated postural balance on vestibular and visual parameters together in sleep-deprived conditions, suggested that the decrease of postural control after sleep deprivation was more influenced by changes in the visual system rather than on the vestibular (Batuk et al., 2020), because differences were obtained between minimum and maximum visual perception time comparing a regular day (22,25±4,97 s; 20.00-40.00 s) and a day with sleep deprivation (42,58±36,87 s; 20.00-170.00 s) (p = 0.001). If so, a longer visual perception time induces a slower RT, which can increase the risk of errors and accidents, as well as negatively affect physical performance. These conflicting observations might be due to different study designs used by authors.

While there is conclusive evidence on the effects of daily variation and circadian rhythms on physical performance (Symons et al., 1988), the reports on postural control performance were not as consistent. The majority of studies stated that, after a normal day of sleep, there is no effect of time of day on postural control, as CoP sway remains steady, but increases throughout a day of sleep deprivation (Avni et al., 2006; Morad et al., 2007; Nakano, 2001), in parallel with subjective scores of sleepiness (Liu et al., 2001; Martin et al., 2018; Zouabi et al., 2016). On the contrary, other studies (Bougard et al., 2011; Forsman et al., 2007; Gribble et al., 2007; Smith et al., 2012) observed a time-of-day variation in balance skills on a regular sleep day, with better performances in the morning, followed by a gradual decline mid-morning and reaching the worst performances at the beginning of the afternoon. The studies then shared the same observations of a decrement of postural control during times of day after a night of sleep deprivation, along with other studies (Avni et al., 2006; Gribble et al., 2007; Martin et al., 2018; Nakano et al., 2001; Patel et al., 2008; Robillard, 2011a; Smith et al., 2012; Zouabi et al., 2016). Whether is past 19h of sleep deprivation (Nakano et al., 2001), throughout 24 h of sleep deprivation (Bougard et al., 2011), and past 36h of sleep deprivation (Forsman et al., 2007; Haeggstrom et al., 2006), the highest values of CoP area were registered in the middle of the day (Bougard et al., 2011), although two denied the diurnal variation effect (Martin et al., 2018; Zouabi et al., 2016). Regardless, the lack of consensus regarding the existence of a circadian rhythm of postural control during a regular sleep day between studies may be linked to methodological limitations, as study designs vary depending on the authors.

One of the reasons behind the capacity to maintain upright standing is related with the impaired ability to adapt to sensorimotor coupling while controlling posture when a reduction of the visual input occurs, which, in this case, is triggered by sleep deprivation (Martin et al., 2018). To modify the discrepancy of insights related to the effects of sleep deprivation and time of day on postural control, two studies introduce the term *perception of the vertical* (PV), a subjective indicative measure of upright orientation of the body in relation to gravity (Martin et al., 2018; Zouabi et al., 2016). The proper balance adjustments of the standing body are regulated by the integration of the sensorial (visual, somatosensory and vestibular) information in the CNS to build an internal representation of the vertical direction, providing the orientation needed (Laughton et al., 2003). In other words, the brain receives the information of the unstable body to recognize objects vertically aligned, mostly with the visual input, which is crucial for postural control. Then, the CNS uses the information to activate the antigravitational muscles needed for the control of body stability. It is widely known that visual input causes changes to postural control after a night of sleep deprivation, but the same is not investigated for the PV.

The two studies ought to assess the effects of time of day (Martin et al., 2018; Zouabi et al., 2016) and sleep deprivation (Martin et al., 2018) on postural control and PV, as well as investigate if changes of the PV after sleep deprivation could play a significant role on the capacity to maintain postural stability.

The research of Zouabi et al. (2016) applied a discontinued procedure, in order to avoid learning and fatigue effects. The protocol was composed of six test sessions executed throughout the day (2 am, 6 am, 10 am, 2 pm, 6 pm, 10 pm), once per week, lasting for six weeks. Parameters representing postural control (CoP total length, CoP area, CoP velocity and CoP average position) and PV (absolute average error) were evaluated, using posturography and the Subjective Visual Vertical Test (SVV), respectively. The SVV evaluates the ability of a person to estimate verticality. Participants were asked to adjust a projected light stick with a remote control, against a wall at a 3 m distance from them, inside a completely dark room. Participants performed eight trials in a specific order of degree, from 10 to 40º. The defining variable is the absolute average error (difference between the real length and the measured length) count of the eight measurements. Martin et al. (2018) used a rather similar protocol and procedures, but instead of a discontinued protocol, used a continuous protocol, with successive test sessions, including results during a normal night of sleep and a night of sleep deprivation.

These two studies reported that, after a normal night of sleep, contrary to postural control, PV presents a diurnal rhythm, with better estimations during morning, peaking around 10 am, and worse estimations in the evening, with the lowest values at approximately 10 pm. Nevertheless, PV does not seem to affect postural control parameters, suggesting that postural control has its own function of compensatory mechanisms that take place during the time of day in order to avoid any risk of imbalances (Zouabi et al., 2016; Martin et al., 2018), opposing to the findings observed in other previous experiments (Avni et al., 2006; Forsman et al., 2007; Gibble et al., 2007; Haeggstrom et al., 2006; Morad, 2007; Nakano, 2001). This disparity of observations between studies might be due to the differences of protocols. After a night of sleep deprivation, the estimations on the diurnal fluctuations of PV worsened significantly, as a consequence of the loss of the circadian rhythm. However, as well as a night of sleep condition, no daily fluctuations were observed in postural stability throughout the day. On the contrary, such parameters remained stable after sleep deprivation. In addition, postural control decreased at any time of day, in agreement with past studies (Aguiar & Barela, 2014; Avni et al., 2006; Bougard et al. 2011; Furtado et al., 2016; Gomez et al., 2008; Nakano et al., 2001; Patel et al., 2008).

Three of the most important features of balance ability (vestibular function, attentional resources and muscular strength) are influenced by circadian rhythms and present a daily variation (Gribble et al., 2007). The vestibular system and the sustained attention are known to decrease throughout the day (Wright et al., 2002), and the muscular strength that peaks in the afternoon (Gauthier et al., 2001). The decrease of the function of the two features, vestibular input and attentional resources, would be compensated by activation in neuromuscular capacity and arousal to maintain constant postural performance throughout the day. Sleep deprivation effects would diminish these three preventive mechanisms, leading to more propensity to postural imbalances, accidents, injuries and falls. For instance, the possible explanations behind the flattening of PV with time and a decrement of postural control system are related to a reach of a functional limit of compensation mechanisms; incapacity to increase muscular activation and attentional demanding (Zouabi et al., 2016; Martin et al., 2018).

Evidence has reported that short and intensive exercise performance that can result into an appreciable lactate accumulation threshold induces muscle fatigue and the reduction of effectiveness of sensory inputs that can contribute to an increase of postural sway (Paillard, 2012).

The assessment of postural sway through a postural sway test can also be an indicator of mental fatigue (Ma, 2009). It is well known that a state of sleepiness affects performance negatively, with a predisposition to errors and accidents (Lal, 2001). Mental fatigue is a result of a gradual cumulative process associated with a decline to exert any effort, reduced efficiency and alertness and impaired mental performance (Grandjean, 1979). It can also be linked with increased feelings of tiredness and an impairment of cognitive abilities (Boksem & Tops, 2008), submaximal intensity performance (Pageaux & Lepers, 2018) and motor control (Jacquet et al., 2020). The negative impact of mental fatigue on physical performance is possibly attributed to a higher perception of effort, a perception thought to be involved in the engagement and the regulation of physical behavior (Pageaux & Lepers, 2018). Mental fatigue affected by sleep deprivation can be subjectively measured, although evidence has shown that these evaluations do not reflect accurately the objective physiological status of a tired individual, mainly because subjective reports are influenced by motivation, personal factors, experience and training (Ma et al., 2009; Morad et al., 2007), so it is recommended to also evaluate mental fatigue according to objective parameters. There is a wide evidence about the effects of sleepiness and mental fatigue, aroused by sleep deprivation, on specific objective parameters of postural control, derived from posturography (Avni et al., 2006; Bougard et al., 2011; Fabbri et al. 2006; Forsman et al., 2007; Gribble & Hertel, 2004; Gomez et al., 2008; Haeggstrom et al., 2006; Liu et al., 2001 ; Martin et al., 2018; Ma et al., 2009; Morad et al., 2007; Nakano et al. 2001; Patel et al., 2008; Schlesinger et al. 1998; Zouabi et al., 2016). The computerized force plates enable to relate CoP oscillations with neuropsychological processes affected by fatigue, leading to believe that mental fatigue can be considered a possible cause for the effects of sleep deprivation on balance (Ma, 2009). So, measuring postural performance permits a better characterization of the state of mental fatigue.

Subjective effects of sleepiness appear to follow a circadian rhythm pattern over a daily time with regular sleep, being higher in the middle of the night (maximum at 6:00 am) and lower during morning (minimum at 10:00 pm). Even if postural control parameters are not affected by daily time with sleep, the continuous wakefulness during a night dysfunctions the effects of the circadian rhythm of balance and logically accentuates the subjective feelings of sleepiness (Liu, 2001; Zouabi et al., 2016; Martin et al., 2017). Considering that the ability to sustain postural sway is important for daily life activities and can be considered a key component of motor control, it is important to integrate mental fatigue and subjective feelings of sleepiness while investigating its impact on postural control.

Extensive evidence suggest that sleep deprivation negatively affects postural control. However, investigations on interaction of the mechanisms behind this effect remain with gaps in need to be addressed. One of the processes responsible for the regulation of postural control is the vision input. Some authors advocate that the effect of sleep deprivation on postural control is shown in both EO and EC conditions, whereas others consider the effect of sleep deprivation solely on the EC condition. Such results raise questions on whether the simple and common measures of CoP displacements are sufficiently consistent to assess motor performance while sleep deprived. According to past research, the analysis of non-linear approaches enable richer characteristics of the time series that linear measures are unable to detect (Cavanaugh, 2005a; Cavanaugh et al., 2006; Harbourne & Stergiou, 2003; Stergiou & Decker, 2011). Furthermore, although past studies explored the complexity of standing postural sway, no evidence exists addressing the effects of sleep deprivation on temporal organization of CoP (i.e. regularity) and the new information it can provide, which reflects a non-linear analysis of postural stability. Since postural control is regarded as an indirect approach of the functional capacity of neuromuscular system and motor performance, its insight is a potential alternate method of a robust measure for injury risks in rehabilitation and aging, as well as errors and accidents related to night shift work and jet-lag effects. Attending the conflicting findings exposed from the traditional CoP oscillations, a different approach adding the potential utility of entropy measures to explore the temporal structure of CoP oscillations should be addressed, in order to obtain a more complete disclosure about a system's state and behaviour i.e. whether is more rigid or more random). Hence, this study sought to investigate the impacts of sleep deprivation and postural control from both linear and non-linear insights, and its potential to detect motor control variability through the analysis of CoP measures associated with postural stability.

Chapter III – Aim and Hypothesis

The aim of this study is to investigate the effects of 24 hours of sleep deprivation on postural control related measures (Sway, Range, Standard Deviation [SDev - magnitude of variability] and regularity [structure of variability]). We, therefore, tested postural control before and after 24 hours of sleep deprivation in EO and EC conditions. Considering the previous findings on the effect of sleep deprivation on postural control, we hypothesized that Sway, Range in both anterior-posterior and medial-lateral directions, and Standard Deviation in both anterior-posterior and medial-lateral directions would increase during both conditions; while regularity, assessed through Sample Entropy, would decrease after 24 hours of sleep deprivation.

Chapter IV - Methodology

4.1. Sample size

An *a priori* power analysis showed that fifteen participants would provide 95% power to detect an effect size of 1.190 at a significance level of 0.01. This calculation was based on the results found by Furtado et al. (2016). In total, the number of participants included in this study was seventeen, to avoid eventual dropouts. Participants were recruited from local communities via word-of-mouth.

4.2. Participants

For the purposes of this study, the sample was based on seventeen young participants (age 23.88±2.42 years, height 1.75±0.06 m, body mass 71.80±7.97 kg, BMI 23.30±1.80 kg/m^2) which fulfilled the following requirements: healthy and active male adults aged 18 to 30 years with no neurologic and/or musculoskeletal limitations, lower limb disabilities or disease. Additional exclusion criteria included being a smoker or having stopped smoking in less than 6 months, having a known metabolic, cardiovascular or pulmonary disease and other orthopedic issues that could limit exercise, and having a Pittsburg Sleep Quality Index – Portuguese version (PSQI-PT) (João et al., 2017) (Appendix 1 – Pittsburgh Sleep Quality Index – Portuguese version [PSQI-PT]) score equal or higher than 5 (0-21 scale).

Alongside the informed consent, participants were required to complete a health screening PARQ+ questionnaire, the PSQI-PT, to evaluate sleep quality, and the Horne & Ostberg Morningness-Eveningness Questionnaire – Portuguese Version (MEQ-PT) (Silva et al., 2002) (Appendix 2 – Horne & Ostberg Morningness-Eveningness Questionnaire – Portuguese Version [MEQ-PT]), to evaluate their chronotype.

The PSQI-PT is a self-rated questionnaire which assesses sleep quality, sleeping patterns and disturbances over the last month. The test includes a scoring key to calculate the subject's seven components about sleep: subjective sleep quality; sleep latency; sleep duration; usual sleep efficiency; sleep disturbances; use of sleeping medication and day-time dysfunction, each of which can range from 0 to 3. The sum of the component's sub scores incorporates a global score that can range from 0 to 21. Participants with PSQI score higher than 5 (0-21 scale) were classified as having poor sleep quality, being excluded from the study (Beaudreau et al., 2012; João et al., 2017).

Chronotype profile was assessed by fulfilling the MEQ-PT. The questionnaire has 5 factors: wake-sleep habits, activation, independence from homeostasis, performance and diurnal-time awareness. These five factors generate, in total, 16 items that identify the morningness-eveningness chronotype for each participant with the range of score from 16 to 86. Higher values of the questionnaire indicate stronger morningness profiles, while low values are related to stronger eveningness profiles. For this study, the following cut-offs to classify each chronotype were used: 16 to 31 score for *definitely evening type*; 31 to 41 for *moderately evening type*; 42 to 58 for *indifferent*; 59 to 69 for *moderately morning type* and 70 to 86 as *definitely morning type* (Silva et al., 2002). The morningness-type individuals tend to prefer going to bed early (around 22 or 23h) and get up early (around 6h) without any difficulty, demonstrating good physical and mental performances during these time periods. On the contrary, eveningness-type individuals go to bed at late hours (around 1h) and wake up late (around 10h), presenting better performance during the afternoon and in the beginning of the evening. The indifferent chronotypes are more flexible and choose intermediary times according to their routine needs.

The mean sleep quality assessed through the PSQI-PT was 3.53±0.85. Both mean and mode chronotype classification assessed through the MEQ-PT questionnaire were *indifferent*.

4.3. Informed Consent

Participants were provided with verbal information about the requirements and demands of the study, followed by a written consent document including the experimental procedures to sign, which were approved by the local Ethics Committee of the Faculty of Human Kinetics, University of Lisbon (CEFMH nº 2/2020) (Appendix 3 – Ethical Approval) and conducted according to the principles expressed in the Declaration of Helsinki. Additional supplementary explanations were provided to questions asked by the participants. All the subjects gave their written consent.

The risk of health complications during the course of this study was minimal. The participants were overseen by a researcher, who briefed them on the procedures, with the option to pause or withdraw from the experiment at any point in case of self-perceived fatigue or any other complication, with no prejudice to themselves. Participants were strongly advised not to drive on the day after the continuous wakefulness and to be accompanied home to make sure they got back safely.

4.4. Experimental Design

This study followed a one-group pretest-posttest pre-experimental design and was part of a project in which several variables were monitored. In the present study (a subpart of the major project), participants were asked to visit the laboratory in three different days. During their participation, the participants were instructed to maintain their normal sleep pattern.

Participants were instructed to abstain from alcohol, energy drinks, caffeine, cacao, tea and other stimulant substances 8 to 12h before the day. Furthermore, the participants were also instructed to avoid moderate to vigorous physical activity and resistance training, as well as taking naps after POS during the course of the study.

During their first visit, a baseline session (PRE7), participants were familiarized with all the testing equipment and procedures. The second visit (PRE) to the laboratory occurred approximately seven days after the baseline session, and the last session (POS) occurred 24 h after the PRE session. Thus, the 24-h of sleep deprivation protocol lasted between the PRE and POS sessions, and the sleep deprivation took place in the night from PRE to POS sessions.

At the night of sleep deprivation, participants were asked to be in the laboratory approximately at 10 pm. They could engage in activities with low physical stress like reading, playing cards or video games, using electronic devices, standing up and walking (Arnal et al., 2016; Martin et al., 2018). All the activities were supervised by a researcher, who was present in the laboratory to monitor and support the participants during the night of sleep deprivation, until the POS session was completed.

The three sessions were always conducted at the same time of the day (7 am – 9 am), to avoid daily variations of postural control related to human circadian rhythms (Bougard et al., 2011; Forsman et al., 2007; Furtado et al., 2016; Gribble et al., 2007; Martin et al., 2018; Zouabi et al., 2016). In each session, the participants were asked to perform a posturography test, as described in *Data Collection and Materials* in detail.

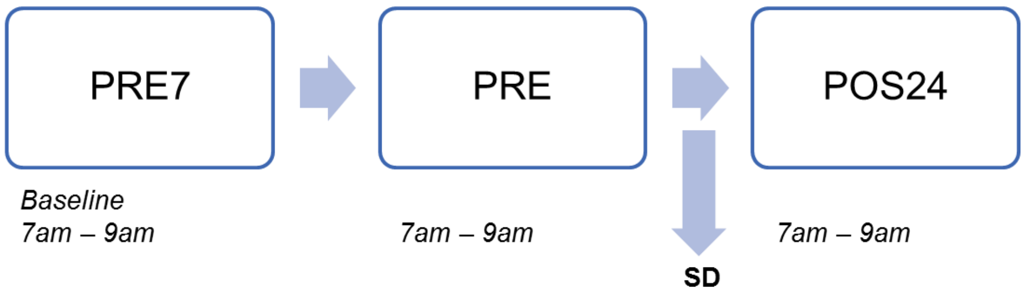

Figure 1. Diagram of the study design.

4.5. Data Collection and Materials

The participants were asked to stand double-leg stance over a force platform (*Plux Wireless Biosignals S.A.*, *Lisbon*, Portugal), to be assessed through a technique called posturography. Posturography is a commonly used method of quantifying the balance in the upright stance in both static or dynamic conditions, and it has been previously shown to be a reliable indicator for detecting postural control and balance impairments related to oscillations of CoP (Schwesig et al., 2014; Janusz et al., 2016), and for all populations, including in children (Gabriel & Mu, 2002) and elderly (Benvenuti et al., 1999).

The *Plux* portable wireless forced platform is a multipurpose device that can measure postural control. The assessment is done by four sensors that capture the displacement of the CoP of the individual, at a sampling rate of 1000 Hz.

During the protocol, the participants were instructed to remain in the standing position, double-leg stance and barefoot, placing both feet aligned with pelvis, the arms placed alongside the body and knees slightly flexed, with a comfortable posture, firstly with EO, then with EC. The trial for each condition lasted for 2 minutes. Throughout this test, the CoP deviation values were permanently displayed on a computer screen, through the *Bioplux* device. As mentioned earlier, tests were performed during different conditions: during baseline status or PRE7, after a night of normal sleep or PRE and after a night of sleep-deprived or POS. Data was collected through the *Biosignals* software.

4.6. Data Analysis

All data was analyzed using code written in Matlab® R2018a (The MathWorks, Natick, MA, USA). First, the CoP was determined. All signals were then downsampled to 50 Hz, determined after visually inspecting the signals' spectrograms and finding 50 Hz as the appropriate sampling frequency to contain all the relevant information. Then, the signals were cropped to remove the initial 5 sec during which the participants kept adjusting their feet. Then, several parameters of interest were calculated from the 2-minute long time series. First, SampEn (Richman & Moorman, 2000) was used to determine the temporal structure of the postural control output. SampEn determines the probability that short sequences of data points are repeated throughout a temporal sequence of points. A time series with similar distances between data points would result in a lower SampEn value, while large differences would result in higher SampEn values. A perfectly repeatable time series thus has a SampEn value equal to zero and a perfectly random time series has a SampEn value converging towards infinity (Richman & Moorman, 2000). In this study, a pattern length (m) of 2, error tolerance (r) of 0.2 and data length (N) of 6000 data points (i.e., 50 Hz x 120 sec) were selected and used in the determination of SampEn values (Yentes et al., 2013). The reliability of entropy measures was shown to be optimal when these input values are identical for all trials and participants (Cavanaugh et al., 2005a). Other than SampEn, we have also calculated common linear measures of balance: Range, Sway Path, and SDev. Range, SDev and SampEn were independently calculated for both CoP directions, SampEn AP and SampEn ML. For statistical purposes, the average of the two trials was used.

4.7. Statistical Analysis

Statistical tests and analyses were conducted with the IBM SPSS software, Version 27.0. (Armonk, NY: IBM Corp), for Windows. Standard descriptive statistics (mean and standard deviation - SD) were used to summarize the data. All the five variables were tested for normality, through the Shapiro-Wilk test. Paired samples t-tests were performed to determine and compare the effects pre to post-24 h of sleep deprivation on postural control (range AP). The Cohen's *d* was calculated as measure of effect size, as $d = t / \sqrt{N}$. The *t* stands for the statistical value and *N* for number of observations. When normality in the distribution of data was not observed, the non-parametric one-sample Wilcoxon signed rank test was used (Sway, Range ML, SDev AP, SDev ML, SampEn AP and SampEn ML). In this case, effect sizes were calculated through the equation $r = Z / \sqrt{N}$. The Z stands for the statistical value and N for number of observations. Statistical significance was accepted considering the p-value < 0.05, for all the statistical tests performed.

Chapter V - Results

5.1. Sample Characteristics

The variables associated with the characteristics of the sample (n=17) are displayed in table 1.

Table 1. Individual characteristics of the sample.

Age (years)	23.88 ± 2.42
Height (m)	1.75 ± 0.06
Body Mass (kg)	71.80 ± 7.97
Body Mass Index (kg/m^2)	23.30 ± 1.80

The mean sleep quality, as assessed through PSQI-PT, was 3.53±0.85. Regarding the participants' chronotype assessed through the MEQ-PT questionnaire, 3 participants were classified as *moderately-morning* types, 9 were classified as *indifferent* and 5 as *moderately-evening* types.

The variables associated with the postural control measurement are displayed in Table 2.

Table 2. Center of pressure parameters for each group and landing direction.

	EO				EC			
	PRE	**POS**	***p***	**Effect Size**	**PRE**	**POS**	***p***	**Effect Size**
Sway Path (mm)								
	396.33 ± 114.66	567.46 ± 245.62	0.006*	0.672	486.21 ± 139.04	669.71 ± 275.02	0.013*	0.603
Range (mm)								
AP	26.20 ± 27.71	28.35 ± 19.33	0.309	0.247	18.78 ± 8.86	29.20 ± 15.90	0.0003*	0.867
ML	32.71 ± 10.18	45.94 ± 26.41	0.015*	0.591	42.52 ± 12.61	62.81 ± 39.73	0.009*	0.637
Standard Deviation								
AP	3.06 ± 1.53	4.35 ± 2.37	0.017*	0.580	3.01 ± 1.36	4.63 ± 3.37	0.011*	0.614
ML	4.96 ± 1.24	7.17 ± 3.02	0.005*	0.683	6.48 ± 2.01	8.67 ± 2.96	0.028*	0.534
Sample Entropy								
AP	0.96 ± 0.35	0.73 ± 0.34	0.019*	0.631	0.96 ± 0.32	0.71 ± 0.33	0.003*	0.840
ML	0.58 ± 0.22	0.40 ± 0.14	0.007*	0.649	0.48 ± 0.25	0.33 ± 0.10	0.022*	0.557

5.2. Linear Measures

Sway Path

A significantly higher Sway Path was observed during EO condition following 24 h of sleep deprivation (p = 0.006, $Z_{(17)}$ = -2.769, r = 0.672, PRE = 396.66±114.66, POS = 567.46±245.62) (Figure 2).

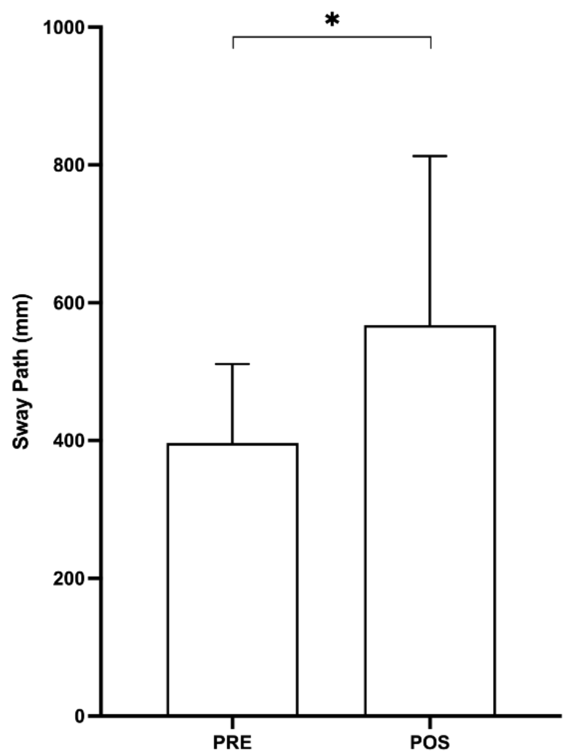

Figure 2. Sway path (mm) mean values for the eyes opened condition, in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

A significantly higher Sway Path was observed during EC condition, having increased from PRE to POS (p = 0.013, $Z_{(17)}$ = -2.485, r = 0.603, PRE = 486.21±139.04, POS = 669.71±275.02) (Figure 3).

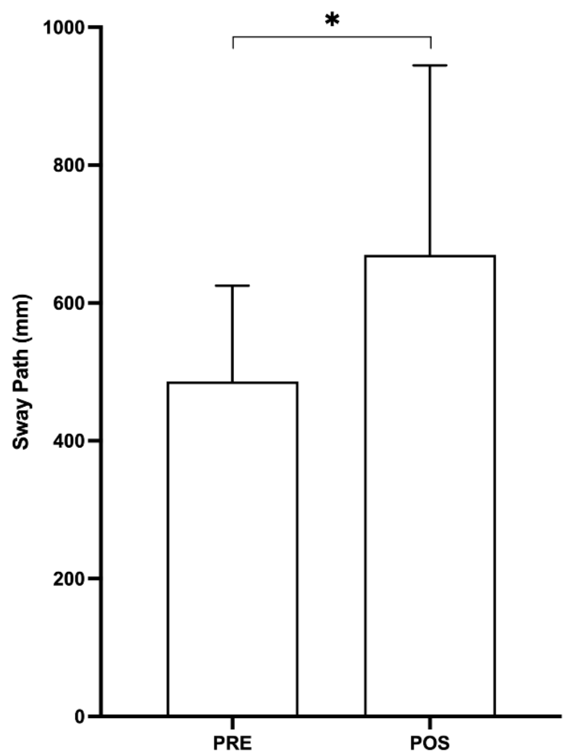

Figure 3. Sway path (mm) mean values for the eyes closed condition, in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

Range

For the Range, during the EO condition, no statistical differences were found in the Range AP after the 24 h of sleep deprivation ($p = 0.309$, $t_{(17)} = -1.018$, $d = 0.247$, PRE = 26.20±27.71, POS = 28.35±19.33). However, an effect of the Range ML component was found, having increased values between PRE and POS ($p = 0.015$, $Z_{(17)} = -2.438$, $r = 0.591$, PRE = 32.71±10.18, POS = 45.94±26.41) (Figure 4).

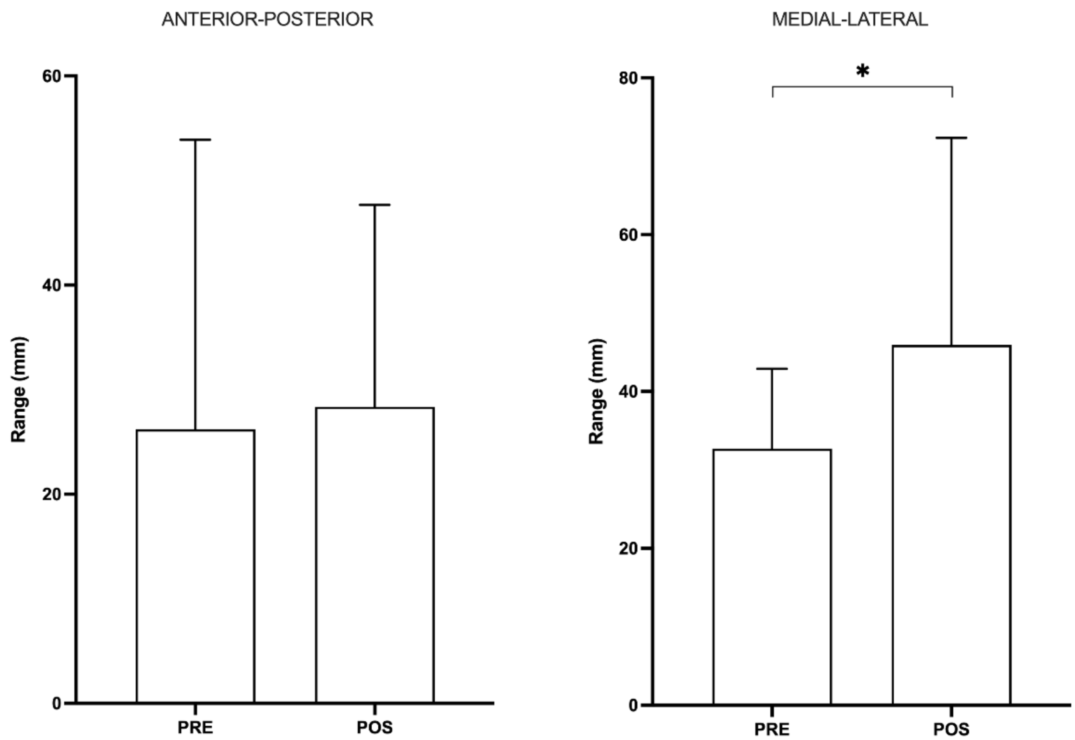

Figure 4. Range mean values (mm) for the eyes opened condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

During the EC condition, a significant higher value of Range AP was observed, having increased between the PRE and the POS ($p = 0.0003$, $Z_{(17)} = -3.576$, $r = 0.867$, PRE = 18.78±8.86, POS = 29.20±15.90). Also, there were significant differences for the Range ML, having increased after 24 hours of interrupted sleep ($p = 0.009$, $Z_{(17)} = -2.627$, $r = 0.637$, PRE = 42.52±12.61, POS = 62.81±39.73) (Figure 5).

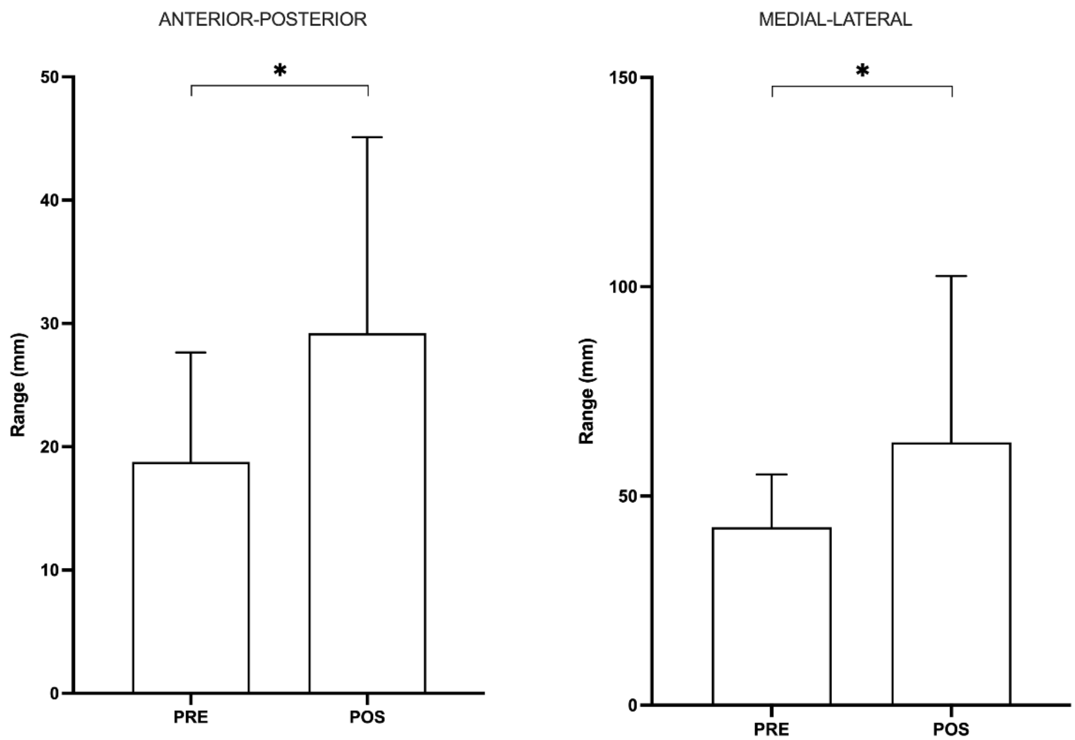

Figure 5. Range mean values (mm) for the eyes closed condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

Standard Deviation

For the Standard Deviation, during the EO condition, significant differences were found in both SDev AP ($p = 0.017$, $Z_{(17)} = -2.391$, $r = 0.580$, PRE = 3.06±1.53, POS = 4.35±2.37) and SDev ML ($p = 0.005$, $Z_{(17)} = -2.817$, $r = 0.683$, PRE = 4.96±1.24, POS = 7.17±3.02) directions, having increased between PRE and POS (Figure 6).

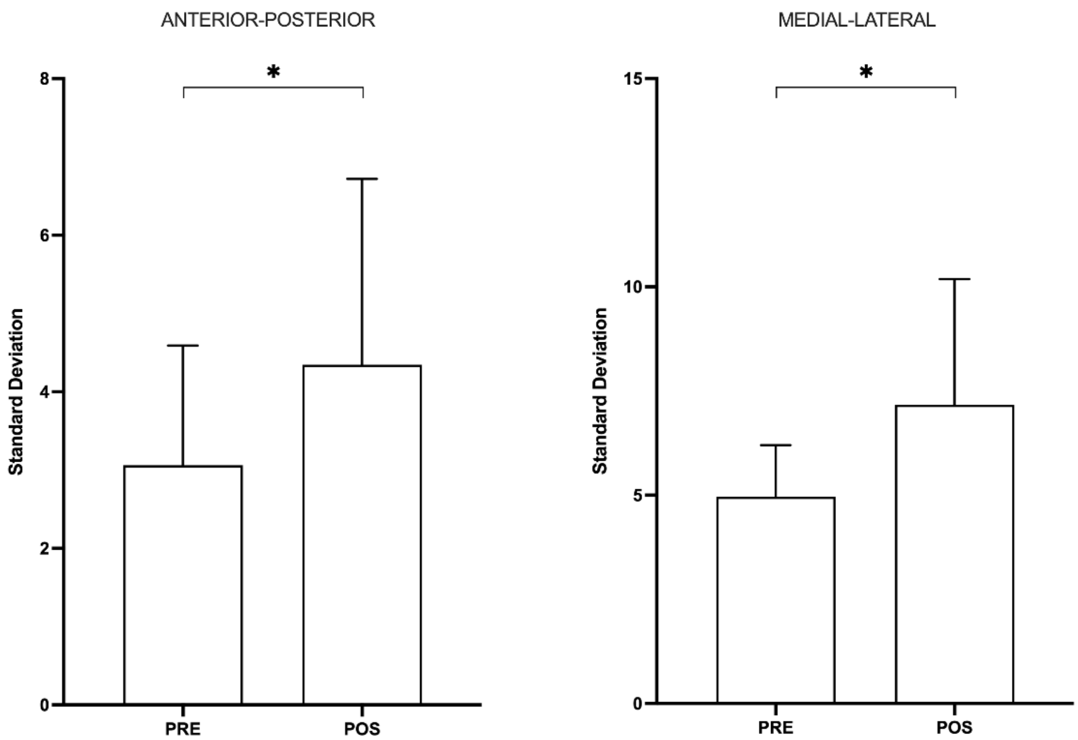

Figure 6. Standard deviation mean values for the eyes opened condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

During the EC condition, significant differences were found in the SDev AP ($p = 0.011$, $Z_{(17)} = -2.533$, $r = 0.614$, PRE = 3.01±1.36, POS = 4.63±3.37), as well as for the SDev ML ($p = 0.028$, $Z_{(17)} = -2.201$, $r = 0.534$, PRE = 6.48 ± 2.01, POS = 8.67±2.95), having increased values between the PRE and POS (Figure 7).

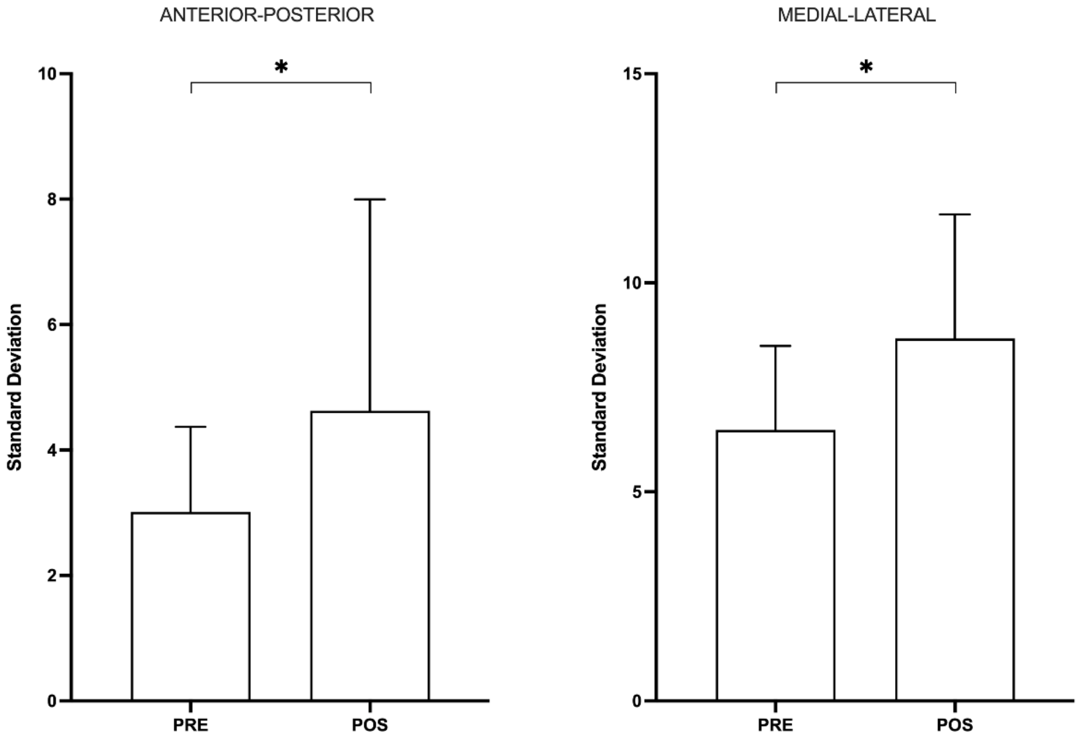

Figure 7. Standard deviation mean values for the eyes closed condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups ($p < 0.05$).

5.3. Nonlinear Measures

Sample Entropy

For the SampEn, during the EO condition, significant differences were found in the SampEn AP (p = 0,019, $Z_{(17)}$ = 2.60, r = 0.631, PRE = 0.96±0.35, POS = 0.73±0.34) and the SampEn ML directions (p = 0.007, $Z_{(17)}$ = -2.676, r = 0.649, PRE = 0.58±0.22, POS = 0.40±0.14), having decreased in both components 24 h after sleep deprivation (Figure 8).

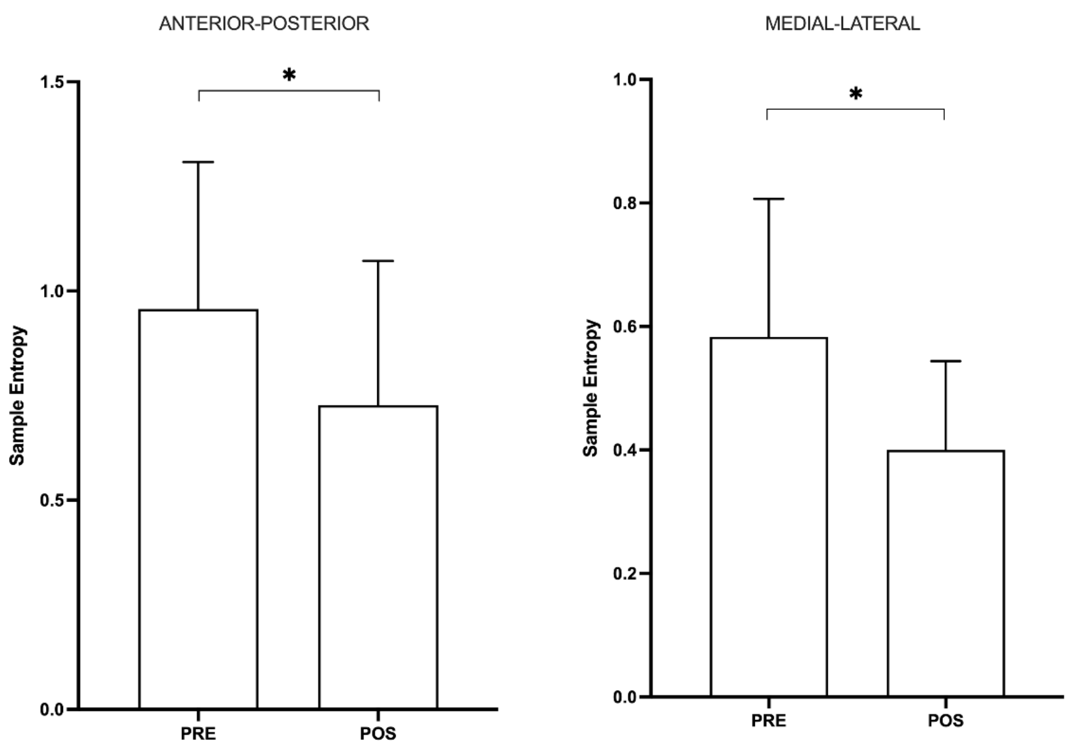

Figure 8. Sample entropy mean values for the eyes opened condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups (p < 0.05).

During the EC condition, significant differences were also found in the SampEn AP (p = 0.003, $Z_{(17)}$ = 3.463, r = 0.840, PRE = 0.96±0.32, POS = 0.70±0.33), SampEn ML (p = 0.022, $Z_{(17)}$ = -2.296, r = 0.557, PRE = 0.48±0.25, POS = 0.33±0.10), having decreased between the PRE and POS test (Figure 9).

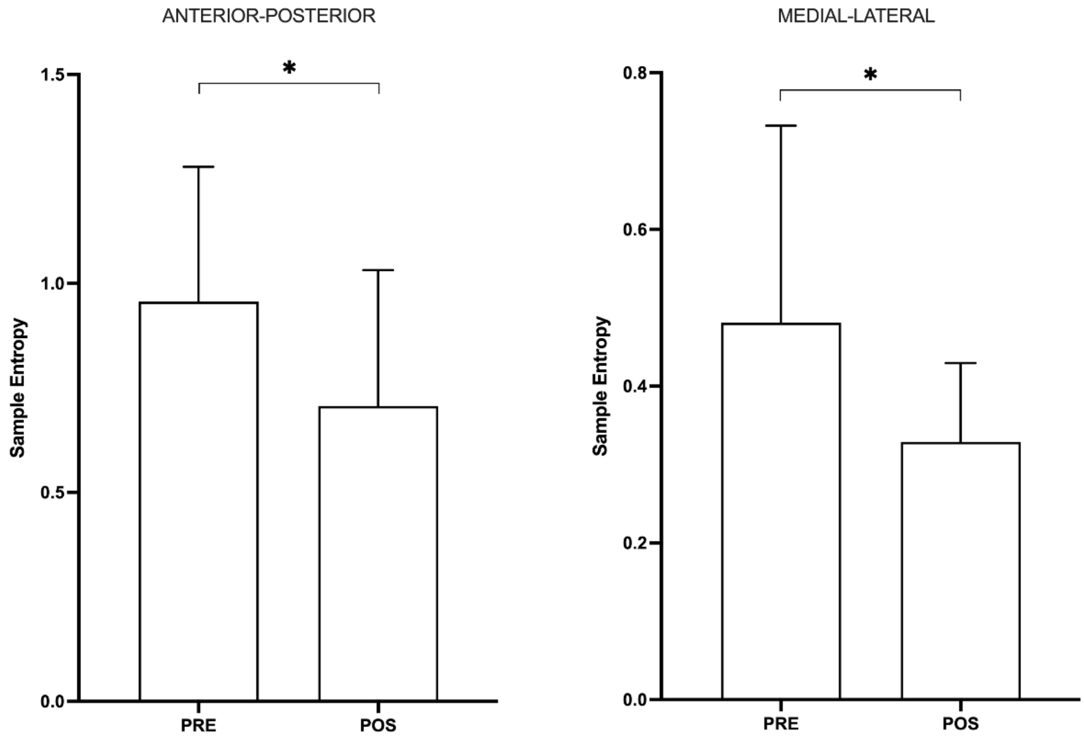

Figure 9. Sample entropy mean values for the eyes closed condition, for the anterior-posterior (left panel) and medial-lateral (right panel) center of pressure components in both time points: PRE (before) and POS (after 24 h of sleep deprivation). Data is presented as mean and SD. * indicate differences between groups (p < 0.05).

Chapter VI - Discussion

The aim of this study was to investigate the effects of a 24 h sleep deprivation on parameters associated with postural control, in a mixed, healthy and active young-adult population. To the best of our knowledge, this was the first study to date which sought to address the effects of sleep deprivation on non-linear measures of postural control such as signal's regularity (i.e., sample entropy). We hypothesized that 24 h of sleep deprivation would lead to an increase of linear parameters of postural control (sway path, range AP and range ML, standard deviation AP and ML) during both EO and EC conditions, as observed in past scientific evidence (Aguiar & Barela, 2014; Furtado et al., 2016; Liu et al., 2001; Ma et al., 2009; Martin et al., 2018; Nakano et al., 2001; Nielson et al., 2010; Robbillard, 2011a; Smith et al., 2012; Umemura et al., 2019). Conversely, regularity, addressed through entropy values, would decrease, as observed in recent scientific literature that have studied other conditioning factors of regularity, for example, on the effect of healthy ageing (Lipsitz & Goldberger, 1992; Lipsitz, 2004), disease (Goldberger et al., 2002a; Hausdorff et al., 1997), injury (Vaz et al. 2020c) and in motor performance (Morrison, 2012).

In accordance with our hypothesis, after 24 h of sleep deprivation, we observed that most of the linear parameters increased in both conditions, excluding only the AP component of range during EO condition, which did not suffer significant differences. Additionally, our hypothesis of the non-linear parameters related to regularity decreased was also verified. We observed reduced values of entropy on both conditions, which represent increased regularity of the temporal structure of CoP oscillations after 24 h of sleep deprivation. This means that the effect of continuous wakefulness inflicts more CoP oscillations on postural control, indicating a more rigid body structure, with less ability to adapt to internal changes and external surroundings, and more prone to conditions related to illness. These results are in line with most of the literature. Some evidence supports the decline of postural stability in most linear parameters being associated with aging process (Hill et al., 2007; Kurz et al., 2013; Laughton et al., 2003; Richer et al., 2019; Robillard, 2011b; Teasdale & Simoneau, 2001), disease (Wikstrom et al., 2010), neuromuscular fatigue (Paillard, 2012) and sleepiness (Fabbri et al., 2006; Furtado et al., 2016; Gomez et al., 2008; Liu et al., 2001; Ma et al., 2009; Nakano et al., 2001; Patel et al., 2008; Schlesinger et al.,1998).

The choice of parameters that allow the analysis of CoP is essential to determine if there is an impact of sleep deprivation on balance and motor control. Nevertheless, there is no consensus concerning the most sensitive criteria to study the behaviour of postural control using force platforms (Forsman et al., 2007; Liu et al., 2001; Umemura et al., 2019; Zouabi et al., 2016). In agreement with previous literature, this study observed an increase of Sway Path (Furtado et al., 2016; Liu et al., 2001; Ma et al., 2009; Martin et al., 2018; Nakano et al., 2001; Robillard, 2011a; Umemura et al., 2019; Zouabi et al., 2016), CoP range in both AP and ML directions (Aguiar & Barela, 2014; Nielson et al., 2010; Robillard, 2011a) and standard deviation (Umemura et al., 2019). Additionally, significant changes of these variables were observed in both conditions, EO and EC, as observed in other study (Aguiar & Barela, 2014; Avni et al., 2006; Batuk et al., 2020; Bougard et al., 2011; Fabbri et al., 2006; Haeggstrom, 2006; Gomez et al., 2008; Gribble et al., 2007; Gribble & Hertel, 2004; Liu et al., 2001; Morad et al., 2007; Nakano et al., 2001; Patel et al., 2008; Robillard, 2011a; Smith et al., 2012; Umemura et al., 2018).

Although the traditional linear approaches are the standard used measures, they can limit the perception of a system when it comes to search how it adjusts to the external and internal conditions in order to maintain postural stability. The biomechanical and linear approach to measure postural control include the lack of external perturbations interfering with the system, only internal perturbations (e. g. neuromuscular ability, cognitive activity), being somewhat restricted. Another issue of this approach is that linear statistics (e. g. mean and SD) ignore the temporal “hidden” structure of variability, by assuming that errors related to CoP are random and independent. In addition, as mentioned before, the linear perspective is missing a gold standard criteria when it comes to evaluate specific parameters (Cavanaugh, 2005a). An alternative measurement approach that can give additional information in this regard is based on a nonlinear dynamics framework of motor control. Interestingly, there is much less evidence about non-linear parameters of complexity of the temporal structure of CoP oscillations. The main problem about the exclusive use of linear measures is that they only measure the amount of variability and postural sway, not the nature of the variability in the system (stability of the system itself), which is described by the complexity of postural control (Cavanaugh, 2005a; Harbourne & Stergiou, 2003). The complexity represents the adaptability of a certain system to the surrounding context (Stergiou & Decker, 2011). Here, we measure regularity through a SampEn algorithm, which is one measure of complexity. These fluctuations of the temporal structure provide information about the state of a system (Pethick et al., 2021; Vaillancourt & Newell, 2003). In other words, healthy physiological systems have an ideal level of regularity; not too regular but also not too random, otherwise the system becomes less adaptable to changes in environment or perturbations (Stergiou et al., 2006).

The loss of the right amount of physiological complexity is associated with unhealthy systems tending for disease states, such as aging, disease (Goldberger et al. 2002a; Lipsitz & Goldberger 1992; Lipsitz, 2004), neuromuscular fatigue (Pethick et al., 2021) and loss of motor control (Newell, 2006; Vaillancourt & Newell, 2003). By analyzing the postural control complexity, we can predict the adaptability of motor control, as they are linked by similar physiological phenomena. The postural control system is nonlinear, because the regulation of the standing postural sway requires the integration of numerous sensory inputs from the autonomous nervous system, a set of cognitive functions and the peripheral neuromuscular system, all operating over different time scales (Zhou et al., 2017). These nonlinear dynamics confer the postural control system the capacity to adapt to an unpredictable environment. Hence, the use of nonlinear measures along the linear measures to describe the CoP variability is crucial, as they may be useful in identifying instability that is not apparent only with linear variables.

According to literature, the CoP variability during quiet standing, regardless of appearing irregular and erratic, is not the result of a random error, but rather have deterministic properties. Since the CoP variability holds a "hidden" structure of orderliness that emerges through time, possibly as a result of interactions among the postural control system properties, it is an indicator of postural control system performance (Cavanaugh, 2005b). Hence, the nonlinear analysis of postural control complexity is revealed by the structure of the CoP time series. The increase of CoP variability is related to the increase of entropy and consequent instability of the motor control system, given the less number of motor solutions to deal with the environment's constraints. Thus, the decreased entropy represents increased regularity, and the system becomes more rigid. The entropy parameter is used to measure CoP time series in standing. Evidence has observed that, as a posture becomes more developed and adaptive, entropy decreases over time, while linear measures are unchanged (Harbourne & Stergiou, 2003; Newell, 1998). Newell (1998) also found differences in entropy between the CoP time series of young and old standing adults, and interpreted this decrease as a loss of complexity over aging process, which are in line with what other authors observed (Lipsitz & Goldberger, 1992; Goldberger et al. 2002a; Lipsitz, 2004). A single study contradicts the idea of a reduced postural complexity in older people (Duarte & Sternad, 2008). The authors suggested that this result was due the consequence of adaptability processes and to a short period of time, where it does not play a noticeable effect that could be seen in longer time scales. Besides, conflicting findings can be attributed to differences in methodology and in research designs. Considering this information and the negative impact of the sleep deprivation on neurocognitive and motor function, we aimed to study whether the 24-h sleep deprivation would lead to a detriment of postural control parameters of CoP indirectly associated with motor performance under two perspectives: from a linear (represented by linear parameters) and from a non-linear analysis (represented by sample entropy). Having found the increment of postural sway linear parameters and a decrease of sample entropy after 24-h of sleep deprivation, we can assume that sleep deprivation negatively affects motor performance and its complexity. In other words, it affects the adaptability of the postural control system to adapt to possible perturbations. To investigate the effects of sleep deprivation on postural control in a non-linear framework, this study analyzed the SampEn of the CoP, in both EO and EC conditions, which decreased significantly after 24 h of sleep deprivation. We observed greater regularity (i.e., lower SampEn) on the temporal structure of the CoP oscillation, in both ML and AP components, for sleep-deprived individuals. This implies that, with the decrease of postural stability after sleep deprivation, the postural system state becomes less healthy, therefore, with more propensity to suffer from injuries, accidents or falls.

The human postural control system is highly complex and integrates various mechanisms that prevent the human body to lose stability or fall. Postural control reflects the capacity to activate the neuromuscular system in response to a perturbation, and is determined by a continuous interplay of visual, proprioceptive and vestibular sensory inputs (Teasdale & Simoneau, 2001). When vision and proprioception display no sufficient information, the vestibular system plays a central role in maintaining postural control.

Humans use both central and peripheral systems to regulate postural stability (Gribble & Hertel, 2004; Horak, 2006; Ivanenko & Gurfinkel, 2018; Munoz-Martel et al., 2019). The CNS regulates sensory information from these inputs to produce adequate motor output, controlled by the peripheral nervous system (PNS). The mechanisms behind the link between the CNS and the PNS are responsible for the control of the upright standing, by being able to compensate for internal or external perturbations (Horak, 2006; Ivanenko & Gurfinkel, 2018). Once the nervous system detects a disturbance of balance, it releases impulses from sensory receptors to activate reflex contractions in the musculature involved in the preservation of equilibrium during postural control. These reflex contractions of the group muscles cause continuous oscillations to contradict the imbalance and maintain the dynamic equilibrium of upright stance. The neuromuscular response to loss of postural control of the center of mass (CoM) generates the CoP when the individual stands on top of the force platform (Ma et al., 2009). This method allows the assessment of the individual's balance by measuring the displacement of the CoP, in relation to the CoM movements and the muscles contraction to maintain postural control. A healthy individual shows lower CoP oscillations, contrary to an individual with altered sensory system integration, who presents higher values of CoP oscillations.

As observed in our study, SampleEn measures were significantly reduced after 24 h of sleep deprivation, leading to assume that lack of sleep negatively affects the capacity to respond to perturbations. Postural control complexity indicates low adaptability to motor control. Our results suggest that SampEn is a particularly sensitive measure to identify individuals at risk of accidents or injuries while sleep deprived. Thus, entropy measures of postural control seem to reflect the functionality of the CNS. In a sleep deprivation state, the lack of control of the CoP indicates a too regular system, possibly suggesting reduced proprioception within the system and hence, greater likelihood to injury.

One night of sleep deprivation diminishes neural activity especially in certain regions of the brain. Areas of the cerebral cortex, regions of the prefrontal cortex and thalamus, are responsible for regulation of attention, alertness and neurocognitive ability (Thomas et al., 2000). These areas are prone to suffer deactivation following 24 h of sleep deprivation (Thomas et al., 2000), and decrease activity as the sleep deprivation period continues (Thomas et al., 2003), which cause drops alertness resources and supervising function (Thomas et al., 2000; Fabbri et al., 2006; Ma et al., 2009). The resulting decrease of attentional resources induces slow or inappropriate responses from the sensory integration. Neuronal network loses the capacity to respond normally when the brain is presented by non-challenging or short-term tasks, and these effects are even worse in more complex tasks, reducing performance or increasing its response even more. As a result, the ability to control motor activity and maintain the postural stability is compromised (Furtado et al., 2016; Liu et al., 2001; Nakano et al., 2001; Patel et al., 2008; Ma et al., 2009).

A recent study by Qiao (2021) observed a reduced postural complexity (CoP entropy) after a concussion. Brain regions such as cerebellum, basal ganglia, thalamus, and prefrontal cortex have been identified as regions of interest in concussion mechanism studies and are known to contribute for postural stability, although the connection between standing posture deficits and concussions is still unknown. We know that these regions of the brain also influence the effects on sleep deprivation. This leads to presume that the effects of concussions are similar to effects on sleepiness when it comes to physiological complexity, although the magnitude of the effects may vary considerably. This leads to some speculation that a night of sleep deprivation compromises the human nervous system and its postural complexity from another perspective (besides the linear measures). The control of movement performance decreases towards a more unstable state, by exposing to a less capacity to create motor answers in order to deal with constraints created by environmental factors, therefore, potentially increases the risk of injury.

Additionally, we assume that vision input, a great contributing factor to regulate postural control, is decreased with sleep deprivation, which supports the findings of Gomez et al. (2008). Vision input provides information to assist postural control. Nevertheless, the diminished or lack of vision may compromise more visual information which gives more responses to adapt orientation and compensate for imbalances. Hence, the additional vision information seemed not to be sufficient to completely negate the deterioration of postural control caused by extended wakefulness, even if the parameters presented even more significant values related to EO condition. Because there are also effects of sleep deprivation on postural control during EO condition, it is not an isolated cause.

The closed eyes condition allows us to assess the standing balance system through the vestibular and proprioceptive inputs. The lack of visual information affects the vestibule-labyrinth system, where a visual system is needed. Thus, measurements of postural control with EC can be valuable information when examining the relationship between sleep deprivation and the postural control system. A considerable number of evidence demonstrated the effects of sleep deprivation on postural control only in eyes-closed situation (Furtado et al., 2016; Liu et al., 2001; Nakano et al., 2001; Ma et al., 2009; Robillard, 2011a; Schlesinger et al., 1998), contrary to this study. According to these findings, evidence suggests that the lack of vision impairment on postural stability is more accentuated due to disturbances in the function of sensorial areas of the brain that regulate alertness and cognitive ability especially in chronic low sleep quality situations (Furtado et al., 2016).

Additionally, reduced postural stability after sleep deprivation is affected by psychological factors such as increased subjective sleepiness and tiredness, deterioration in mood and decreased alertness. These psychological factors can have a detrimental effect on levels of motivation and RT (Fabbri et al., 2006; Fullagar et al., 2015; Goel et al., 2009; Ma et al., 2009; Schlesinger, 1998). Thus, we can speculate that the individuals' psychological profile seems to be determinant on how sleep deprivation affects the postural control and, therefore, the capacity of the neuromuscular system to adapt to changes in environment (Harbourne & Stergiou, 2003; Newell, 1998).

It is known that sleep deprivation affects the individuals' circadian rhythms (Goel et al., 2013). About the possible existence of a circadian rhythm linked with postural control, this study showed more CoP variations in the morning after sleep deprivation compared to the morning of the day before. These results are in line with most of the literature indicating that sleep deprivation can interrupt postural control's circadian rhythms, as there is a disruption of the circadian rhythm after the night of sleep deprivation (Liu et al., 2001; Gribble & Hertel, 2004; Nakano et al., 2001). To avoid the effects of circadian rhythm in this study, the evaluations were performed at the same time, either in PRE and POS (7 – 9 am). However, there were only two moments of evaluation in this study, and this assumption can be ambiguous.

Another leading factor that could alter the decrease of postural control after sleep deprivation was the time length. Several studies observed standing posture performance during different time periods: 14 h (Smith et al., 2012), 19 h (Nakano et al. 2001), 24 h (Aguiar & Barela, 2014; Bougard et al., 2011; Furtado et al., 2016; Ma et al., 2009; Martin et al., 2018; Schlesinger et al., 1998; Zouabi et al., 2016), 26 h (Robillard, 2011a) 27 h (Liu et al., 2001); 36 h (Haeggstrom et al., 2006), 48 h (Gribble & Hertel, 2004) and 60 h (Vaara et al., 2018) of continuous wakefulness.

Decreases in standing posture were observed after 24 to 36h (Bougard et al., 2011; Furtado et al., 2016; Haeggstrom et al., 2006; Liu et al., 2001) and after 36h of continuous wakefulness, with levels starting to stabilize around the 36-h mark (Gomez et al., 2008; Gribble & Hertel, 2004; Patel et al., 2008; Vaara et al., 2018), possibly due to a disruption of circadian rhythm effects that decrease through time, starting approximately 36 h after sleep deprivation. In this study, sleep deprivation occurred during 24 h and a decrease of balance parameters was observed. These results are in line with observations made by a majority of studies (Aguiar & Barela, 2014; Bougard et al., 2011; Furtado et al., 2016; Gomez et al., 2008; Gribble & Hertel, 2004; Haeggstrom, 2006; Liu et al., 2001; Ma et al., 2009; Martin et al., 2018; Patel et al., 2008; Schlesinger et al., 1998; Vaara et al., 2018; Zouabi et al., 2016).

Most of the evidence that studied the effects of sleep deprivation on postural stability used in their protocols of 30 sec time mark to observe CoP oscillations (Liu et al., 2001, Furtado et al., 2016; Gomez et al., 2008; Haeggstrom et al., 2006; Martin, 2018; Patel et al., 2008). Gribble and Hertel (2004) evaluated for three 15 sec trials, only with EO. A single study observed the CoP oscillations for 40 sec (Nielson et al., 2010), 51.2 sec (Bougard et al., 2011; Zouabi et al., 2016) and another study for 1 min (Aguiar & Barela, 2014; Karita et al., 2006). Another study utilized a 3 min time length to measure variables related to CoP fluctuation (sway, CoP range, CoP area and CoP velocity) (Smith et al., 2012). This study, along with Robillard (2011a) are the only ones using the 2 min evaluation in the protocol. Although in Robillard's study, participants performed the test 2 h after the habitual wake time, besides, participants were all tested at the same time interval (7 – 9 am). Independently of the measurement time (between 3 sec and 3 min), the results showed a decrease of sleep deprivation in the majority of the studies.

Following the assessment of the more traditional linear properties that characterize postural control, the calculation of SampEn values in CoP time series for the motor performance while in a sleep deprived state appears to have a great potential as a robust measure of injury, accident and fall risk. The use of a force plate in motor performance researching laboratories and clinical settings is common, easy to acquire and accessible to use. As a measure, it can also provide important clinical information, for example, to make decisions regarding practical implications in shift work and occupations that require continuous wakefulness, the diagnosis and intervention of an individual with frail motor control or even the return to practice after rehabilitation process or injury risk screening.

Chapter VII - Conclusions

The results of this study revealed that 24 hours of sleep deprivation compromises postural control. It was demonstrated that sleep deprivation diminishes the majority of postural control linear parameters (Sway, Range ML, SDev AP, SDev ML) in both EO and EC. The only exception that did not suffer significant changes was Range AP under EO condition. In summary, the sensory system seems to be compromised, including or not the visual input.

Furthermore, to the best of our knowledge, this was the first study to investigate the effect of 24 hours of sleep deprivation on postural control complexity. It was demonstrated that the postural control complexity tends to decrease with sleep deprivation. The sample entropy values reveal an increase of the regularity CoP oscillations, indicating a possible loss of adaptability of the system to adapt to external constraints. Considering that postural control complexity reflects the adaptability of motor control and indirectly expresses functional capacity of the sensorial system, these results suggest that sleep deprivation may play an important role in a deletion of motor control.

With these robust results, it seems plausible to admit that sleep deprivation can compromise the ability to maintain a standing posture. The response to select the appropriate stability pattern on individuals seems to be slower. Therefore, the risk of having accidents increases considerably, contributing to falls and injuries, and are more prone to demonstrate poorer cognitive performance. A good quality sleep time should be more seriously taken into account to ensure safety, including in work environments. The groups at higher risk include night-shift workers, medical professionals and frail populations, such as the elderly, but athletes can also see their motor performance decreased.

This study had contributed with a new insight of the effect of sleep deprivation in motor control in general, and in postural control in particular. The analysis of CoP adjustments through sample entropy in sleep-deprived individuals might be an effective predictor of health and occurrence of injuries or falls, adding richer information to clinical diagnosis.

Chapter VIII – Limitations and Future Directions

8.1. Limitations

The study presents several limitations, which may limit the degree in which we can generalize the outcomes from the observations reported.

In terms of sleep quality, the measures used were not entirely objective. To assess the participant's sleep quality, the use of information from reports can be easily biased. The measures from sleep questionnaires lack reliability, as they are subjective and can be influenced by a variety of factors (e. g. mood, fatigue, stress, unreliability, difficulty to self-perceive, limited response, possibility of manipulating entries, etc.). Reliable and valid devices, such as actigraphy, could be used to provide new and objective information regarding the usual sleep quality and quantity, sleep-wake cycle, sedentary behaviour and chronotype, as they represent major contributing factors for postural sway variations on sleep-deprived. Despite this, actigraphy has its downsides related to lack of distinction between low activity in the dark and sleep.

There could have been more evaluation tests throughout a certain time period (e.g.: 4 to 4 hours per session) in order to assess how changes in the eventual impairment of circadian rhythm after a night of sleep deprivation affect postural sway. Our study only included three experimental morning sessions: during a week of normal sleep, the day before sleep deprivation and the day after sleep deprivation. With the inclusion of more evaluation moments, a more accurate pattern of circadian rhythm changes could be observed, allowing more detailed new information to be analyzed and a better understanding on its involvement on postural stability throughout a time scale during the day, until the 24-h mark.

Adding oral temperature and/or melatonin secretion measures to the methodology could also be helpful to investigate circadian phases more rigorously by major factors after the night of sleep deprivation. These parameters directly influence the circadian rhythm and the consequent tendency to sleep.

Another limitation of this study is the fact that we did not evaluate whether sleep deprivation induced central and/or peripheral fatigue. However, considering scientific literature, sleep deprivation does not include central fatigue (Arnal et al., 2016) and the disturbance of circadian rhythm caused by sleep deprivation can affect the individual's predisposition to activate the neuromuscular system in order to compensate CoP oscillations due to external and internal perturbations.

More research work is also needed to explore how reliable Sample Entropy is, as well as its changes through rehabilitation programs. Besides the quiet stance, the understanding of how the control of movement, such as gait, is altered in injury and/or fall risk situations.

8.2. Future Directions

In addition to the conclusions, the topic could be investigated further in order to get a better perception.

In further studies, it should be investigated if one night of sleep following the night of sleep deprivation is enough for the body to return to baseline parameters of postural control, or to determine the magnitude and duration of recovery after a certain interval period of sleep. Tools such as actigraphy could be used to provide new and relevant information regarding sleep quality and quantity, and their influence on motor control improvement. More specifically, it might provide the needed information to understand the neurophysiological mechanisms that explain the recovery and adaptability of the system in the following days.

As an extension to this study, it would be relevant to understand the effects of partial sleep loss on postural control, since sleep restriction is much more common nowadays. Furthermore, it would be interesting to compare the effects of sleep restriction versus sleep deprivation on postural control parameters.

Future research should seek to elucidate in future studies the proprioceptive and vestibular perturbations, besides the lack of vision, to study the effects of sleep deprivation on postural control, with more depth on a non-linear perspective, focusing on how the areas of the brain function and motor control are affected after one night of sleep deprivation and these perturbations.

It is of high importance to determine how brain functioning is altered after one night of sleep deprivation. Tools such as electroencephalography or brain functional near-infrared spectroscopy, may provide new and relevant information regarding timing and spatial changes in brain functioning. In particular, it might provide the needed information to understand the neurophysiological mechanisms that explain the existence of an impairment of motor performance.

Moreover, evidence could include: the interference of cognitive tasks (including dual tasks), or control tasks; and the execution of dual-task activities or dynamic tests requiring the different sensory information. Different factors related to postural control should be manipulated.

Adding and exploring nonlinear insights on systems' behaviour could also be considered in further investigation. Future research should further explore the potential of measures of temporal structure and their meaning, focusing its effects on postural control. This could also include the existence of a correlation between the temporal organization of postural control and the risk of injuries and falls.

Additionally, it would also be interesting to study the effects of sleep deprivation on body movement and gait regularity, not only in quiet stance. Sleep-deprived individuals are usually night-shift workers (e.g. military, security officers, health professionals, activity sectors related to driving and airlines) required to walk and stand upright during prolonged nocturnal hours. There is a combination of spontaneous dynamic balance and stability during movement that could be explored on how it is affected by sleep deprivation and/or sleep restriction.

Finally, since sleep deprivation and sleep restriction are more frequent amongst the elderly and this population is more prone to falls, it would be interesting to extend the demographics of this study to include older individuals.

Chapter IX - List of References

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Chapter X - Appendices

10.1. Appendix I – Pittsburgh Sleep Quality Index – Portuguese Version (PSQI-PT)

Índice de qualidade do sono de Pittsburgh – versão portuguesa (PSQI-PT)

Nome:____ Idade:______

Data:____/____/____

*As questões a seguir são referentes à sua qualidade de sono apenas durante o **mês passado**. As suas respostas devem indicar o mais correctamente possível o que aconteceu na **maioria** dos dias e noites do último mês. Por favor responda a todas as questões.*

1) Durante o mês passado, a que horas se deitou à noite na maioria das vezes?

Horário de deitar:______h______min

2) Durante o mês passado, quanto tempo (em minutos) demorou para adormecer na maioria das vezes?

Minutos demorou a adormecer: ________min

3) Durante o mês passado, a que horas acordou (levantou) de manhã na maioria das vezes?

Horário de acordar: _____h______min

4) **Durante o mês passado, quantas horas de sono por noite dormiu?** (pode ser diferente do número de horas que ficou na cama).

Horas de noite de sono: _____h______min

Para cada uma das questões seguintes, escolha uma única resposta, a que lhe pareça mais correta. Por favor, responda a todas as questões.

5) Durante o mês passado, quantas vezes teve problemas para dormir por causa de:

a) Demorar mais de 30 minutos para adormecer:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

b) Acordar ao meio da noite ou de manhã muito cedo:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

c) Levantar-se para ir à casa de banho:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

d) Ter dificuldade para respirar:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

e) Tossir ou ressonar alto:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

f) Sentir muito frio:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

g) Sentir muito calor:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

h) Ter sonhos maus ou pesadelos:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

i)Sentir dores:

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

j) Outra razão, por favor, descreva: ____

____

Quantas vezes teve problemas para dormir por esta razão, durante o mês passado?

( ) Nunca ( ) Menos de 1x/semana ( ) 1 ou 2x/semana ( ) 3x/semana ou mais

e) Outros sintomas na cama enquanto dorme, por favor, descreva:

____
____
____
____
____

10.2. Appendix II - Horne & Ostberg Morningness-Eveningness Questionnaire – Portuguese Version

Questionário de Horne e Oestberg

(Adaptado por Silvério, Silva e Macedo, 1998)

Data: ___/___/____

Nome: ____ Idade: ________

Sexo: Masculino (   )   Feminino (   )

Estado civil: _______________________

Residência: ____

Cód. Postal: ___________________________ Tel.: ______ - ______________

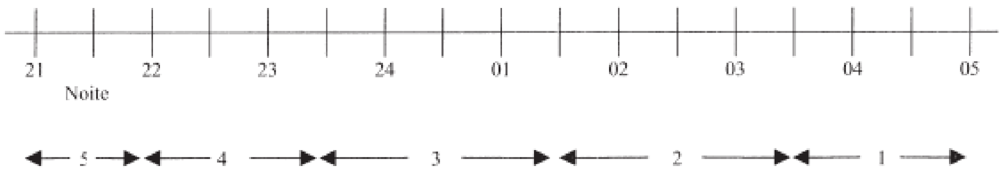
Profissão: ____

Horário habitual de trabalho: ____

Instruções:

1. Leia atentamente cada questão antes de responder.
2. Responda a **todas** as questões.
3. Responda às questões respeitando a sua ordem numérica.
4. Cada questão deve ser respondida independentemente das outras; não volte atrás nem altere as respostas anteriores.
5. Para cada questão coloque apenas uma resposta (uma cruz no local corresponden-te); algumas questões têm escalas, neste caso, coloque a cruz no ponto apropriado da escala.
6. Responda a cada questão com toda a honestidade possível. As suas respostas e os resultados são **confidenciais**.
7. **Não se esqueça** de preencher os seus dados pessoais.

1. Considerando apenas o seu bem estar pessoal e tendo liberdade total para planear a sua noite, a que horas se deitaria?



2. Até que ponto precisa do despertador para acordar a uma determinada hora de manhã?

Não preciso --------------------- ( )

Preciso poucas vezes --------- ( )
Preciso muitas vezes --------- ( )
Preciso sempre ---------------- ( )

3. Quando está em boas condições mentais, físicas e ambientais (ex.: temperatura do quarto agradável) com que facilidade acha que se levanta de manhã?

Nada fácil ------------------ ( )
Pouco fácil ----------------- ( )
Fácil ----------------------- ( )
Muito fácil ----------------- ( )

4. Na primeira meia hora depois de ter acordado de manhã, em que medida se sente desperto?

Nada desperto ------------------ ( )
Pouco desperto------------------ ( )
Desperto------------------------ ( )
Muito desperto ----------------- ( )

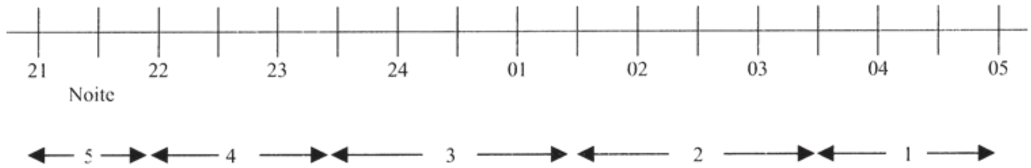
5. Depois de acordar, como é o seu apetite durante a primeira meia hora?

Muito mau apetite--------- ( )
Mau apetite----------------- ( )
Bom apetite---------------- ( )
Muito bom apetite--------- ( )

6. Depois de ter acordado de manhã, em que medida se sente cansado na primeira meia hora?

Muito cansado ----------------- ( )
Cansado ------------------------ ( )
Fresco -------------------------- ( )
Muito fresco ------------------- ( )

7. Habitualmente, a que horas da noite se sente cansado e com vontade de dormir?



8. Quer estar **no máximo da sua forma** para fazer um teste que dura duas horas e sabe que é mentalmente cansativo. Considerando o seu bem estar pessoal e com liberdade total para planear o seu dia, qual destes horários escolheria para fazer esse teste?

Das 08:00 às 12:00 horas ------------- ( )
Das 12:00 às 16:00 horas ------------- ( )
Das 16:00 às 20:00 horas ------------- ( )
Das 20:00 às 24:00 horas ------------- ( )

9. Depois de um dia normal, qual seria o seu nível de cansaço se tivesse que se deitar às 23:00 horas?

Nada cansado --------------------- ( )
Cansado --------------------------- ( )
Muito cansado -------------------- ( )
Extremamente cansado ----------- ( )

10. Por alguma razão, foi dormir várias horas mais tarde do que é habitual. Se no dia seguinte não tiver hora certa para acordar, o que acontece?

Acordo à hora habitual, sem sono --------------------- ( )
Acordo à hora habitual, com sono --------------------- ( )
Acordo à hora habitual, mas adormeço novamente -- ( )
Acordo mais tarde do que é habitual ------------------ ( )

11. Se tiver de ficar acordado das 04:00 às 06:00 horas da manhã para realizar uma tarefa e não tiver nenhum compromisso no dia seguinte, o que faz?

Durmo só depois de realizar a tarefa --------------------------------------- ( )
Tiro uma soneca antes da tarefa e durmo depois ------------------------- ( )
Durmo bastante, antes de realizar a tarefa, e tiro uma soneca depois -- ( )
Só durmo antes de realizar a tarefa -- -( )

12. Imagine que tem duas horas de exercício físico pesado para realizar. Considerando apenas o seu bem estar pessoal e tendo total liberdade para planear o seu dia, qual destes horários escolheria?

Das 07:00 às 11:00 horas ------------- ( )
Das 11:00 às 15:00 horas ------------- ( )
Das 15:00 às 19:00 horas ------------- ( )
Das 19:00 às 23:00 horas ------------- ( )

13. Decidiu fazer exercício físico "duro". Um amigo sugeriu o horário das 22:00 às 23:00, duas vezes por semana. Considerando apenas o seu bem estar pessoal, como acha que seria o **seu desempenho** se fizesse exercício entre as 22:00 e as 23:00?

Seria excelente ------------ ( )
Seria bom ------------------ ( )
Seria mau ------------------ ( )
Seria muito mau ---------- ( )

14. Suponha que poderia escolher o seu próprio horário de trabalho e que deveria trabalhar **cinco horas** seguidas por dia, sendo possível efectuar pequenos intervalos nesse período. Imagine que seja um serviço interessante e que você ganharia pelos resultados da produção. A que horas começaria a trabalhar? [Assinale, colocando uma cruz (x) no quadrado por cima da respectiva hora]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

← 1 →← 5 →← 4 →← 3 →← 2 →← 1 →

15. Em termos de bem-estar geral a que hora do dia se sente no seu melhor?

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

← 1 →← 5 →← 4 →← 3 →← 2 →← 1 →

16. Ouve-se dizer que há pessoas que funcionam melhor de manhã (tipo matutino) e pessoas que funcionam melhor à tarde/noite (tipo vespertino). Qual destes tipos acha que é?

Sem dúvida do tipo matutino ----------------------- ( )
Mais matutino que vespertino ---------------------- ( )
Mais vespertino que matutino ---------------------- ( )
Sem dúvida do tipo vespertino --------------------- ( )

10.3. Appendix III – Ethical Approval

fMH FACULDADE DE MOTRICIDADE HUMANA

Conselho de Ética
para a Investigação

Para:

Dr. João Oliveira
Faculdade de Motricidade Humana

Data: 28 de Janeiro de 2020

Projeto: "The Effects of Sleep Deprivation on the Complexity of Motor Control"

Estado CEIFMH: Positivo, com Recomendações (em anexo)
Parecer CEIFMH N.º: 2/2020

Este Conselho analisou o projeto em epígrafe. Confirma-se que o mesmo está em conformidade com as diretrizes nacionais e internacionais para a investigação científica que envolve seres humanos, incluindo a Declaração de Helsínquia sobre os Princípios Éticos para a Investigação Médica em Seres Humanos (2013) e a Convenção sobre os Direitos do Homem e a Biomedicina ("Convenção de Oviedo", 1997). As recomendações não envolvem alto risco e são deixadas ao critério do investigador.

A Vice-Presidente do Conselho de Ética para a Investigação da FMH

Paula Marta Pereira Bruno

Paula Marta Pereira Bruno

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