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*Missouri State University*

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# EFFECTS OF SLEEP DEPRIVATION WITH 110-MINUTE REST PERIOD ON

# POSTURAL CONTROL IN YOUNG ADULTS

A Doctoral Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Doctor of Audiology

By

Whitney L. Hayden

May 2017

# EFFECTS OF SLEEP DEPRIVATION WITH 110-MINUTE REST PERIOD ON

# POSTURAL CONTROL IN YOUNG ADULTS

Communication Sciences and Disorders

Missouri State University, May 2017

Doctor of Audiology

Whitney L. Hayden

## ABSTRACT

Computerized Dynamic Posturography (CDP) is used by many different professionals as an objective tool to measure different aspects of postural control. For audiologists, CDP is used to assess the vestibular system and its interactions with the somatosensory and visual systems. There is evidence that postural control is negatively affected by sleep deprivation. To date, there is limited knowledge on whether a 110-minute rest period will improve or even restore postural control abilities back to baseline. The present study was designed to further study the effects of sleep deprivation on different aspects of postural control and to examine the effectiveness of a 110-minute rest period at restoring values to baseline. CDP was used to examine the following: sensory organization test (SOT), motor control test (MCT), and adaptation (ADT) at baseline, after 23-26 hours of sleep deprivation, and after a 110-minute rest period. Participants consisted of 19 young adults. Results indicated an increased composite MCT latency score following a rest period compared to baseline values. A decrease in ADT reaction time following a rest period was noted compared to baseline and sleep deprivation conditions. Future studies should make use of more sensitive equipment, utilize an EEG to ensure sleep and avoid testing during sleep inertia.

**KEY WORDS:** computerized dynamic posturography, sleep deprivation, 110-minute rest period, vestibular system, sleep inertia

This abstract is approved as to form and content

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Thomas C. Franklin, Ph.D.
Chairperson, Advisory Committee
Missouri State University

**EFFECTS OF SLEEP DEPRIVATION WITH 110-MINUTE REST PERIOD ON**

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May 2017

Approved:

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Thomas C. Franklin, Ph.D.

_____

Sarah R. Barber, Au.D.

_____

Susan Robinson, P.T., D.P.T.

_____

Julie Masterson, Ph.D.: Dean, Graduate College

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

**INTRODUCTION**

The demand of today's fast pace society routinely require workers in many

professions to perform at their best while being sleep deprived (Hsie et al., 2010).

According to the American Academy of Sleep Medicine, about one out of five adults do

not get enough sleep.  Everyone is at risk for sleep deprivation, but those at an increased

risk include shift workers, people who have a medical condition, and caregivers.  The

effects of sleep loss manifest in many different ways including altering ones mood,

decreasing different aspects of performance, and negatively impacting ones health.

When a person's performance on the job is compromised, as a result of sleep deprivation,

there is a decrease in concentration and an increase in distractibility, reaction time, poor

decision making, errors made, reckless behavior and forgetfulness (American Academy

of Sleep Medicine, 2008).

Even with all that is known on partial sleep deprivation and its effects on

cognitive performance, there is still not a clear answer on how the entire body responds to

24-hours of sleep deprivation (Zukerman, 2007).  Of particular interest to Audiologists, is

the effect of sleep deprivation on the vestibular system.  Interestingly, the effects of a rest

period following 24-hours of sleep deprivation on the vestibular system have yet to be

evaluated.  According to the National Sleep Foundation (2016), a nap can be defined in

three different ways: planned napping in preparation for lack of sleep, emergency

napping when your activity is interrupted by tiredness and a nap is need to off set

drowsiness, and habitual napping such as a child does at the same time every day.  There

are many benefits to taking a nap such as decreasing mistakes being made, increasing

alertness, and improved performance.  A study conducted by NASA on military pilots reporting sleepiness, found that a 40-minute nap improved performance by 34% and alertness by 100% (National Sleep Foundation, 2016).

Posturography has the ability to objectively measure and monitor the effects of sleep deprivation and fatigue on the body's vestibular system (Morad et al., 2007; Olchowik et al., 2015).  Maintaining postural control abilities requires integration of several different systems including the vestibular, proprioceptive, and visual systems.  If one of these systems is failing, a person will have a decreased ability to compensate and maintain their balance.

Several computer systems have been designed to measure postural control.  Most of these tests require the subject to stand on a moveable platform in a moveable surround.  A series of tests to evaluate each individual sensory system is administered.  This will give an idea as to which system is lacking and also provides a way to track progress during and after therapy.  The tests also objectively measure motor control abilities and the subject's ability to adapt to spontaneous movement.  Advantages of CDP include it being reproducible, quantifiable, non-invasive, and objective (Bougard et al., 2010; Morad et al., 2007).  For the purpose of this study, the focus of the literature review is on measuring the effects of sleep deprivation on a person's postural control.

# LITERATURE REVIEW

**Sleep**

Sleep can be defined as when the body is immobilized, is in a sleeping posture, and has a reduced sensory threshold, which in turn leads to an inability to communicate with the surroundings (Porkka-Hiskanen et al., 2013). Behavioral aspects of sleep consist of the person reclining, closing their eyes, and decreasing their movement (Markov, et al., 2006). Sleep is comprised of two phases: rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep. During REM, the eyes move rapidly and peripheral muscle tone decreases to the point that only muscles innervated by the cranial nerves and ones used for breathing are active. During NREM, there is a decrease in heart rate, blood pressure, breathing rate, and body temperature. NREM is further divided into three stages (N1, N2, and N3) that progressively increase in slow wave activity where most of the cortical neurons oscillate at a rate of less than 1 Hz during on and off periods (Porkka-Hiskanen et al., 2013). During "on" periods, neurons are depolarizing and firing action potentials. During "off" periods, neurons are in a state of hyperpolarization and not firing. The stages of sleep can be measured by brain electrical activity using electroencephalography (EEG) (Figure 1).

When a person is in a wake state, the waves of the EEG are low in amplitude and high in frequency. Waves during NREM sleep are high in amplitude and low in frequency, the opposite of REM sleep waves (Porkka-Hiskanen et al., 2013). When a person is in REM, the waveforms are similar to when in a wake state and the only way to distinguish between a wake state and REM sleep is to use electromyography
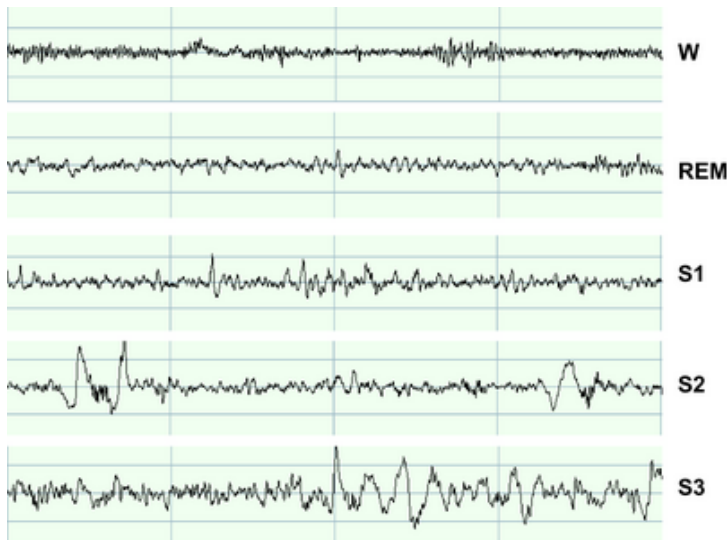
Figure 1. EEG stages of human sleep. Human EEG recording representing the different sleep stages: waking (W) and rapid eye movement (REM) sleep identified by low-amplitude, high-frequency waves, and non-rapid eye movement (NREM) stage 1 (S1) through 3 (S3) in the order of decreasing frequency and increasing amplitude of the waves (Porkka-Heiskanen et al., 2013).

to measure muscle tone and electro-oculography to measure the rapid eye movements known as saccades. The sleep cycle starts with NREM sleep, beginning in N1 and advancing to N3 where the brain waves become slower and more synchronous. N1 accounts for one to seven minutes of the total sleep time. During this phase the person can be woken easily and may not realize they have fallen asleep. N2 accounts for ten to twenty-five minutes of the total sleep time. During N2 the EEG recording shows sleep spindles and/or K complexes. The sleep spindles represent thalamic neurons that have become synchronized from gamma aminobutyrate (GABA)-ergic pacemakers; however, the exact origin of the K complex is unknown. During N2, the arousal threshold is increased and a greater stimulus is needed to wake a person in this state. N3 accounts for twenty to forty minutes of the total sleep time. It is characterized by delta waves seen on the EEG. During this stage the brain is even less responsive to external stimuli and it is

typically difficult to wake a person in this stage of sleep. After N3, REM sleep is started.

A person will cycle through NREM and REM cycles throughout the night, with the

length of the REM episode increasing as the number of cycles during the night increases.

The whole sleep cycle takes approximately 90-minutes (Markov et al., 2006).

There are several theories as to why a person needs sleep. Porkka-Hiskanen et al.

(2013) suggest the purpose of sleep can be broken up into three different areas including

energy metabolism, inflammation, and neural plasticity. During sleep, there is a

reduction in the use of ATP and glucose to save energy as well as restoration of glycogen

reserves. Glycogen is involved in synaptic activity and memory formation in addition to

serving as a source of energy storage (Obel et al., 2012). Interestingly, in a phenomenon

known as "local sleep," the neurons that were the most active during the day need the

most sleep to recover. Additionally, the human immune response follows the circadian

rhythm, thus a disruption in the circadian rhythm leads to an impairment of the immune

response. Certain inflammatory markers such as interleukin-1 beta (IL-1β) and tumor

necrosis factor alpha (TNF-α) promote NREM sleep independent of an immune system

challenge, while anti-inflammatory molecules actually inhibit sleep. During a wake state,

the brain utilizes neuronal plasticity for behavioral adaptation, learning, and memory

formation. When the brain enters a sleep state the memories created during the day are

processed and integrated with pre-existing memories (Porkka-Hiskanen et al., 2013).

For sleep to be beneficial, one must sleep a sufficient amount every day. The

hours of recommended sleep decrease with increasing age. According to the National

Sleep Foundation (2017), the recommended amount of sleep for adults, ages 26-64, is 7-9

hours.

**Sleep deprivation**

　　Sleep deprivation is among the most common causes for a person to seek medical attention and it is estimated 20% of adults suffer for sleep deprivation (Durmer, J. & Dinges, D., 2005; Porkka-Hiskanen et al., 2013).  Sleep studies have found sleep deprivation increases a person's tendency to sleep as well as reduce the time it takes to change from lighter stages of sleep to deeper stages.  Some of the effects of sleep deprivation on the brain metabolism and electrophysiology have been visualized by using functional magnetic resonance imaging (fMRI) and positron-emission tomography (PET).  PET studies have confirmed there is an overall decrease in glucose metabolism in the brain, as previously mentioned.  Specifically, there is a more isolated decrease in glucose metabolism in the prefrontal cortex, thalamus, and posterior parietal association cortices.  When a subject is impaired on a cognitive task, possibly due to sleep deprivation, there is even more of a decrease in the uptake of glucose in these areas (Durmer, J. and Dinges, D., 2005).

　　One of the most studied areas of cognition affected by sleep deprivation is working memory.  During working memory, information is temporarily stored and manipulated while utilizing the lateral prefrontal and parietal cortices.  It is believed that sleep deprivation impairs visual attention, thus decreasing ones working memory ability (Chee & Chuah, 2008).  In a study conducted by Chee and Chuah (2008), subjects were divided into two groups and were exposed to varied visual item load or visual short-term memory (VSTM) load following normal sleep and after sleep deprivation.  VSTM capacity was further decreased in the sleep-deprived subjects.  Further, state related activation decline was seen to occur in the parietal cortex before the memory capacity of

the subject was met. Interestingly, results from this study paralleled results from a similar study utilizing cognitive decline in aging populations as a variable. The effects of sleep deprivation have been found to impact decision making in such a way that is comparable to the decision making abilities of a person with an orbitofrontal lesion (Harrison,Y., Horne, JA., 2000; Killgore et al., 2006). An increase in risky decision making has been noted following a night of total sleep deprivation, in such a way that is seen in gambling related brain activation. In these situations the nucleus accumbens is activated when a reward is anticipated after the riskier of two choices is selected (Killgore, et al., 2006). Certain fMRI studies have also shown that there is an increase in thalamic activity after 24-hours of total sleep deprivation during attention demanding tasks. Thus suggesting that more energy is needed to carry out the task during stages of low arousal from lack of sleep. EEG studies conducted during sleep deprivation show a decrease in wave amplitude for spectral features associated with alertness during tasks associated with working memory and attention (Durmer, J. and Dinges, D., 2005).

**Napping**

Approximately 46% of people who responded to a study conducted by the National Sleep Foundation reported napping at least twice in the last month, with the nap lasting roughly one hour. Naps are taken for a variety of reasons including, after sleep loss, in preparation of sleep loss, or for the enjoyment of napping (Milner & Cote, 2009). In order for the body to recover from sleep deprivation, a recovery period proportional to the loss of sleep is necessary (Saper et al., 2005). Napping after sleep deprivation can improve vigilance, reaction time, attention, logical reasoning, and alertness (Milner &

Cote, 2009).  It is believed that naps taken between 3:00 to 5:00pm, when there is a

circadian decrease in alertness, are more beneficial than a nap taken between 7:00 to

9:00pm (Lavie & Weler, 1989).  Researchers are also trying to determine the shortest nap

duration that will achieve maximum benefits.  Brooks and Lack (2006) examined the

effectiveness of a 5, 10, 20, and 30-minute nap on improving alertness and performance

following restricted sleep.  Interestingly, the 5 and 30-minute naps showed no significant

improvement in subject alertness, whereas; the 10-minute nap indicated a significant

improvement in alertness.  Additionally, the improved alertness was maintained for the

next 2.5 hours. In regard to cognitive performance, the 20-minute nap indicated

significant improvement at 35 and 95 minutes post nap.  Tietzel and Lack (2002) used a

dose-response paradigm to compare 5, 10, 20, and 30-minute naps, as well as no nap to

examine the most effective nap duration.  The 10, 20, and 30-minute naps produced

improvements in cognition and alertness; with the 10-minute nap showing immediate

benefits.  There were no differences in the five conditions three hours post-nap.  Lumley

et al. (1986) found that a recovery nap of 15, 10, 60 and 120-minuntes, following a night

of sleep deprivation, led to an increase of alertness with increasing nap length.  Overall, a

healthy young adult should nap for approximately 10 to 20 minutes to see benefits

immediately after waking (Milner & Cote, 2009).


**Previously tested populations**

Excessive daytime sleepiness (EDS) affects 4 to 12% on the population (Souza et

al., 2005).  The effects of sleep deprivation cost an estimated \$43 to \$56 billion annually

(Durmer, J. and Dinges, D., 2005).  Numerous studies have been conducted on

individuals who work long shifts or overnight shifts and how the lack of sleep makes them a hazard on the job. Studies have been conducted to examine the effectiveness of counter measures to prevent the effects of sleepiness and increasing alertness during a night shift (Takeyama et al., 2004). These include exposure to light, sound, temperature, caffeine, pharmacological substances, and naps. Populations previously studied include, but are not limited to: motor vehicle drivers, medical residents, health care providers, police, and pilots.

The National Transportation and Safety Board (NTSB), in the United States, cites sleepiness while driving a motor vehicle is one of the most important contributing factors for road crashes (NTSB, 1999). It is estimated that approximately 10-20% of all crashes are possibly related to sleep or fatigue (Anund, et al., 2008). Not surprisingly, roughly 47% of long distance truck drivers in the United States have reported falling asleep at the wheel while driving (Souza, et al, 2005). A study conducted by Mitler et al, (1997) recorded the EEG of 20 professional U.S. truck drivers and found that 56% of the drivers demonstrated a minimum of 6 non-continuous minutes of EEG recorded sleep while driving. The National Transportation Safety Board reported in 1995, that if an accident occurred, the truck drivers reported an average of 6 hours of sleep in the 24-hour period prior to the accident. Being drowsy behind the wheel is not only dangerous, but it can also be considered breaking the law; in some cases, charges can be brought against the driver. In Arkansas, "fatigued driving" can be classified under negligent homicide, which is punishable by a class A misdemeanor, if the driver is involved in a fatal accident and has not slept in 24 hours (drowsy driving laws).

Gold (1992) reported only 6.3% of night nurses and no rotating nurses achieved what was referred to as "anchor sleep" regularly throughout the month at a Massachusetts hospital. Roughly 35% of the night shift nurses reported nodding off at least once a week. Sadly, rotating nurses were 3.9 times more likely and night shift workers were 3.6 times more likely to fall asleep while driving to or from work compared to nurses who worked day or evening shifts. This study came to the conclusion that the sleep deprivation experienced by the rotating and night shift nurses led to frequent lapses of attention and an increased reaction time. Thus, leading to increased error rates on performance tasks.

Police officers suffer from fatigue that negatively affects their performance, health, safety, relations with the public, and quality of their decision making abilities. Fatigue in police officers can be caused by shift rotations that don't allow for an adequate nights sleep, mandatory overtime, off-duty assignments, and double shifts to make up for personnel shortages. Police are commonly subjected to 17 to 19 hours of sustained wakefulness. One study found that 17 to 19 hours of sleep deprivation impaired the officer's performance as much as having a 0.05% blood alcohol content. Additionally, impairment of performance for officers who had sustained 24-hours of wakefulness was comparable to having a blood alcohol content of 0.10% (Vila, 2009).

A study conducted by Shearer and colleagues (2001), tracked blood plasma levels of certain cytokines and receptors following partial sleep deprivation over a 44-hour period with two 2-hour naps/day or 4 days of total sleep deprivation in astronauts. It was found that there was an increase in TNF-α receptor 1 and IL-6 plasma levels in astronauts, suggesting that these markers are sensitive to sleep homeostasis. Increases in

plasma levels of TNF-α receptor 1 and IL-6, as well as other cytokines, are known to affect the target cell surface expression of viral receptors. Examples of this up regulation are seen in the blood plasma levels of patients with acquired immunodeficiency syndrome (AIDS) and patients who have a reactivation of a virus. However, the increase in inflammatory cytokine markers was reduced with regularly spaced naps (Shearer et al., 2001).

In addition to sleep deprivation negatively affecting job performance of individuals involved in aviation, there are also impairments to their vestibular system and its ability to function. These impairments become evident through decreased postural control (Liu et al., 2001; Morad et al. 2007; Schlensinger et al. 1998).


**The balance system**

Balance is controlled by three sensory systems including the vestibular, somatosensory, and visual system. These sensory systems, in addition to the motor output of the muscles and the eyes, must all work together to maintain balance. If one of these systems is compromised, it will alter the ability to maintain an up-right posture (Morad, et al., 2007; Watson & Black, 2016). Sensory input from the visual, proprioceptive, and vestibular systems is sent to the brainstem, where it is sorted out and sent on to the cerebellum and the cerebral cortex.

**Sensory input.** The vestibular system is responsible for sensing the head's position in space in order to maintain postural control and to stabilize images on the fovea of the retina during movements of the head. The vestibular system is housed within the vestibular labyrinth. The vestibular labyrinth and the cochlear labyrinth are

11

both found within the inner ear.  The vestibular system is made up of five neural

structures including three semicircular canals (SCCs) and two otolith organs, the urtricle

and saccule (Figure 2).  The SCCs are filled with endolymph and respond to angular

acceleration.  Angular acceleration is detected by displacement of a gelatinous structure

known as the cupula is located in a dilated portion of the SCC known as the ampula.  The

cupula is situated on top of the crista, which contains sensory cells and vestibular

afferents.  The utricle and saccule contain hair cells that project into a gelatinous material

that has otoconia embedded in it.  The otoconia, made of calcium carbonate, increase the

specific gravity of the endolymph and make the otolith organs responsive to linear

acceleration.  Specifically, the utricle responds to horizontal linear acceleration and the

saccule responds to vertical linear acceleration (Jacobson & Shepard, 2014).  When both

vestibular organs are working properly, the brain is receiving symmetrical impulses from
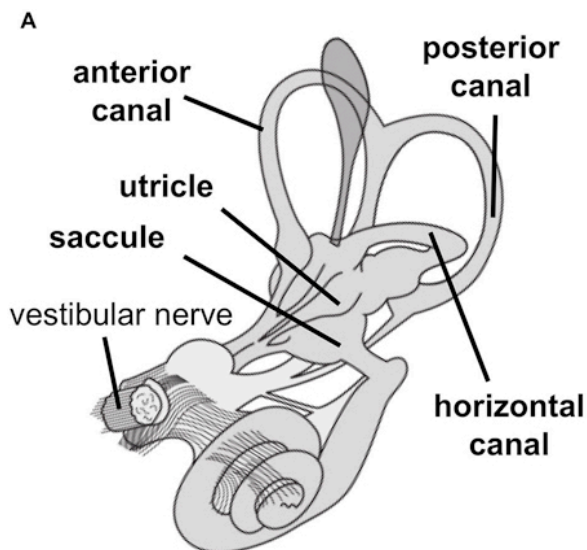
both sides (Watson & Black, 2016).

Figure 2. Peripheral vestibular organ. The inner ear consists of the otolith organs (utricle
and saccule) and the semicircular canals (anterior, posterior, and horizontal.)  The
vestibular nerve receives signals from the otolith organs and the semicircular canals
Adapted from Pfeiffer et al., 2014.

Proprioception is what gives one the sensation of where their body is located relative to the space it is in. Proprioception is controlled by the somatosensory system, which receives its information from muscles, joints, and the skin. Signals are sent to the brain when the sensory receptors detect touch, pressure, pain, vibration, and temperature. Feed-back from the sensory cells can come from places such as the neck, back, and ankles (Watson & Black, 2016).

Sensory cells, known as rods and cones, in the retina send impulses to the brain when light is detected. This allows a person to know their orientation relative to other objects in their visual field (Watson & Black, 2016).

**Motor output.** Once the sensory information has been obtained and sent to the brainstem, impulses are transmitted to muscles throughout the body that control the head, neck, trunk, legs, and eyes. The body utilizes reflexes as a safety measure to keep the body in an upright position. Since these reflexes are vestibular driven, they function at a much shorter latency than could happen if the information had to travel all the way to the cortex to be processed first (Jacobson & Shepard, 2014). There are three vestibular reflexes that can be observed: the Vestibulo-Ocluar Reflex (VOR), the Vestibulospinal Reflex (VSR), and the Vestibulocolic Reflex (VCR) (Jacobson and Shepard, 2014). The purpose of the VOR is to maintain an image on the fovea of the retina during head motion. This reflex works in conjunction with the six extraocular muscles of the eye (Figure 3).
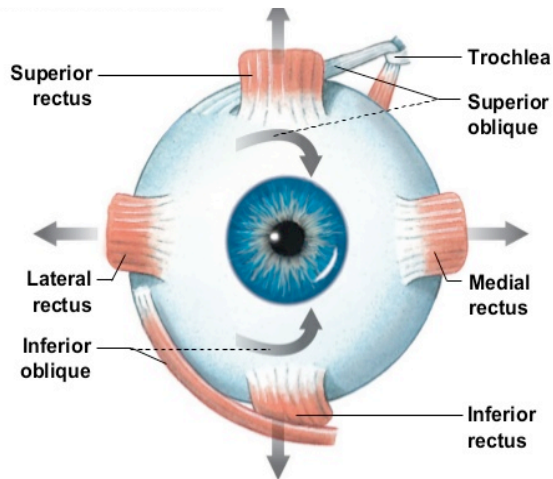
Figure 3. Extraocular muscles. Six extraocular muscles of right eye: superior rectus, superior oblique, inferior rectus, inferior oblique, medial recuts, and lateral rectus. Adapted from Pearson Education Inc. 2012.

For example, during horizontal head movement to the right; the nerve pathway for VOR starts by a SCC being activated by the turning motion which causes the cupula to deflect towards the utricle, then sending impulses to the vestibular nerve (part of cranial nerve VIII) (Wright & Schwade, 2000). This disturbance in equilibrium causes an increase in neural discharge from the right ear and a decrease in neural discharge from the left ear. The decrease in neural discharge in the left ear is from the cupula being defected away from the utricle. From the vestibular nerve, the impulse travels along to the vestibular nuclei located in the brainstem. There, the signal synapses with the contralateral abducens nerve (cranial nerve VII), which innervates the lateral rectus muscle of the left eye. At the same time an impulse is also sent back to the ipsilateral oculomotor nucleus via the medial longitudinal fasciculus. From the occulomotor nucleus, the impulse is sent to the right medial rectus via the occulomotor nerve (Table 1) (Jacobson & Shepard, 2014). The VSR is responsible for maintaining the body's posture and center of mass over a person's base of support (Jacobson & Schepard, 2014). When the body becomes off balance and the head is tilted to one side, the canals and otolith organs on that side are

activated.  Similar to the VOR, the vestibular nerve and nucleus become activated and send signals to the lateral and medial vestibulospinal tracts.  These tracts project to the spinal cord causing extensor muscles on the side of the head tilt and flexor muscles on the opposite side to be activated (Hain, 2014).  The VCR is a righting reflex and works to maintain the head in the horizontal plane relative to gravity and is independent of trunk movement.  The exact neural tracts activated in this reflex are not known at this time; however, studies suggest it is mediated through the otolith organs and the medial vestibulospinal tract (Jacobson & Shepard, 2014)

**Cortical processing.** Several studies have identified direct connections of the vestibular nuclei to the reticular formation, thalamus, and the cerebellum (Brodal & Brodal, 1985; Buttner & Henn, 1976; Troiani et al., 1976) (Figure 4).  Human studies, utilizing fMRI, suggest the parietal and insular regions of the cortex are responsible for processing vestibular information (Brandt et al., 2002; Jacobson & Shepard, 2014).  Additionally, several areas of the cortex have been found to integrate vestibular, visual, and somatosensory information (Fasold et al., 2002).  They found that the temporoparietal junction (TPJ), a portion of the occipital lobe, central regions, and cingulate gyrus were all activated in subjects who had undergone caloric stimulation (a way to activate the peripheral vestibular system) using cold nitrogen (Figure 4).
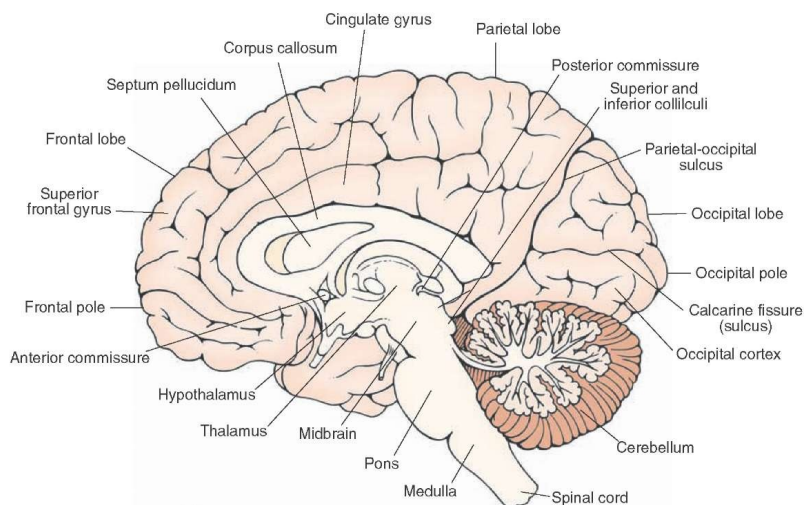
Figure 4. Midsaggital view of the human brain: right hemisphere and brainstem. Notice the Reticular Formation is not labeled, but is located in the region between the Pons and the Medulla. Image from google images (http://what-when-how.com/neuroscience/overview-of-the-central-nervous-system-gross-anatomy-of-the-brain-part-1/)

All subjects in this study showed activation of the TPJ and in some subjects, activation extended into the anterior and posterior insular cortex. Lesions to the TPJ region cause a misperception of verticality and asymmetrical disturbances of the VOR. The homologous brain region of the lateral occipital gyrus in monkeys has been found to be responsible for visual motion detection, encoding optic flow and receiving information from the semicircular canals. Central sulcus activation indicates a possible close link between the vestibular system and the somatosensory system. Anterior and posterior portions of the cingulate gyrus, which monitors head and body movement in space, were activated in subjects. Interestingly, there is right hemispheric dominance when the vestibular cortical network is activated.

**Computerized dynamic posturography**

Posturography refers to interpreting posture as a static relative position of different body parts with respect to each other. Assessing posture and balance is used

16

clinically to help with a differential diagnosis and early detection for people at risk of falling and for developing treatment for specific needs.  It is also a way to document the progress of therapy and to better understand the pathophysiology behind posture and balance disorders (Visser et al., 2008).  The study of posture can be further divided into static (subject is unmoving, with no external forces acting upon them) and dynamic (subject is moving as a result of externally induced balance disturbances) posturography. Computerized dynamic posturography (CDP) allows for more precise quantification and increased objectivity.  Additionally, CDP examines the components of balance; vestibular, somatosensory, and visual, both separately and combined.  CDP allows for the clinician to separate the sensory and motor contributions of balance by being able to position the center of gravity (COG) relative to the base of support and not have it accurately sensed and by utilizing automatic movements, which are not timely or effectively coordinated, that require the patient to bring the COG to a balanced position (Jacobson & Shepard, 2014).  Conflicting sensory input that happens in every day life is simulated in CDP.  For example, when one is sitting in a parked car and the car next to them starts to back out of a parking space, the brain has to quickly decide if the visual information being received indicates a forward movement of the person or a backward movement of the other car.  During CDP, somatosensory information is gained by having contact with a fixed support (or platform) and can be disrupted by irregular movement of the support.  When the support surface is variable, vision plays a significant role in maintaining balance.  If the surround becomes dark (eyes closed) or variable, for example as it does when watching waves in the ocean while standing on the shore, the use of the visual system for maintaining balance becomes compromised (Jacobson & Shepard,

2014).  As a result of the somatosensory and visual systems being more sensitive to sway than the vestibular system, when the other systems are intact, the vestibular input only has a minor role in maintaining COG (Bles et al., 1984; Nashner et al., 1982; Shupert et al., 1988).  Due to the vestibular system rarely providing misleading input, its input is critical when the brain is trying to interpret misleading somatosensory or visual input (Black & Nashner, 1984)(Black & Nashner, 1985).

The protocols and data analysis used in CDP are based on a model of human posture that has been derived form experimental research on normal and abnormal human balance and movement control (Jacobson and Shepard, 2014).  Commonly used tests during CDP include the Sensory Organization Test (SOT), the Motor Control Test (MCT), and the Adaptation Test (ADT) (Olchowick et al., 2015).

The SOT is used to examine the body's ability to balance under incoming, conflicting sensory signals.  Conflicting sensory signals are achieved by systematically eliminating the patient's visual and/or support surface information, thus isolating vestibular balance control (Figure 5).  The conflicting sensory signals also induce an adaptive response from the central nervous system. A patient may either demonstrate an inability to effectively utilize individual sensory systems or have an inappropriate adaptive response (Natus Balance & Mobility, 2017).  There are three main advantages of the SOT.  Performance is continuously measured so it correlates more closely with the patient's functional abilities and status.  If the task condition leading to poor performance is known, the cause of instability can be isolated to further help improve the balance and the individual balance component can be examined to document the patients strategy for utilizing it under different task conditions.
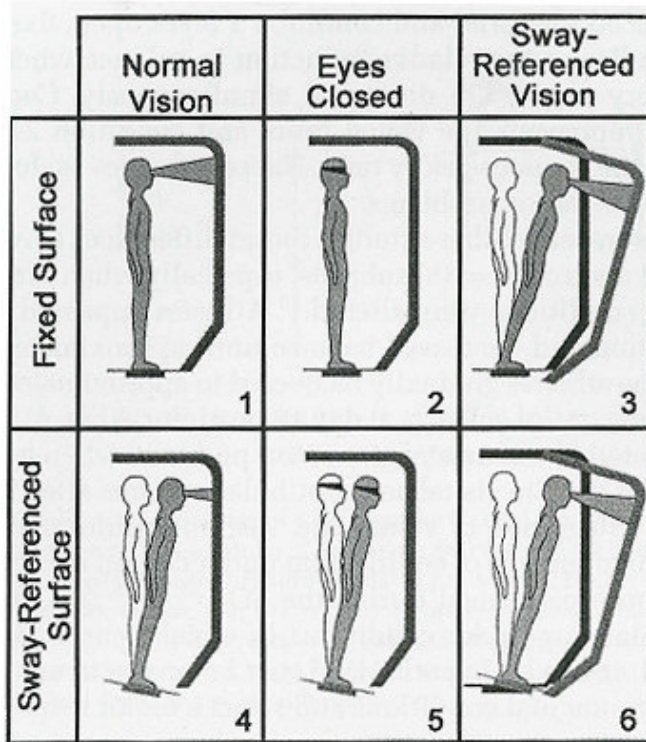
Figure 5.  Sensory Organization Test (SOT). Six conditions of the SOT.  Image adapted from NeuroCom International, Inc.

Last, this test can also track balance improvements with repeated practice, thus helping identify those patients that would benefit form therapy.  During the SOT, the subject's ability to maintain balance, while receiving false somatosensory and/or visual information, is tested using six conditions that increase in difficulty.  The method of providing false somatosensory and/or visual information, known as "sway referencing", tilts the support surface and/or the visual surround.  A healthy subject's brain will ignore the sway reference sensory input and utilize other sensory input to maintain balance (Jacobson & Shepard, 2014).

The MCT assesses the postural reaction to unexpected platform movements (Figure 6).
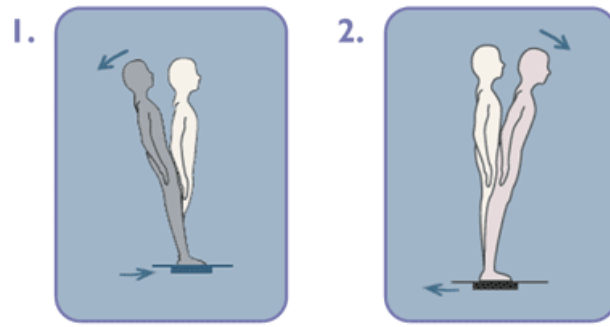
Forward/Backward Translations

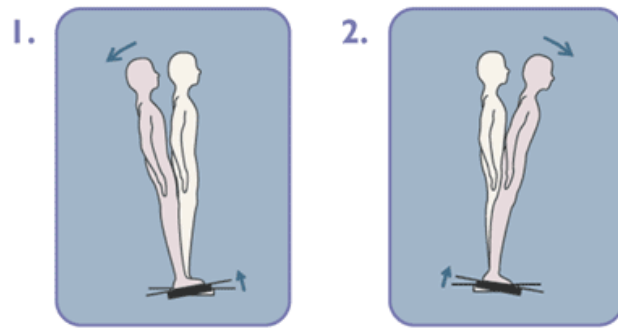Figure 6. Motor Control Test (MCT). The support surface is translated forward or backward while the position of the upper body initially remains stationary. Image adapted from NeuroCom International, Inc.

If all systems are working properly, the patient should quickly and automatically recover from the unexpected platform movements (Natus Balance & Mobility, 2017). An advantage of the MCT is results of the test are little affected by patient motivation and effort, due to the response not being under conscious control (Jacobson & Shepard, 2014). During the MCT, the automatic postural responses are analyzed over a range of velocities (threshold, intermediate, and saturating) and timing. The responses to the forward translations are analyzed separately from the backward translations due to the difference in the flexor and extensor pathways that automatically work to maintain balance. Additionally, the right and left legs are analyzed separately due them being affected differently by certain pathologies (Jacobson & Shepard, 2014). If all systems are working properly, the patient should be able to distribute their weight evenly and have onset latencies that are comparable to normative data.

The ADT assesses the central nervous systems ability to modify motor reactions and minimize sway when there is unexpected platform movement (Figure 7).

Toes Up and Toes Down Rotations

Figure 7. Adaptation Test (ADT). The support surface is tilted up from the front of the platform or the back of the platform while the position of the upper body initially remains stationary.  Image adapted from Neurocom International, Inc.

The ADT is particularly useful due to its ability to demonstrate how a patient will react in real life conditions such as when walking on uneven terrain (Natus Balance & Mobility, 2017).  During this test the platform will rotate the patients toes up and toes down for five trials.  It is expected that the patient will be able to start to predict the rotations of the platform, thus decreasing their reaction time to the movement and their overall COG sway (Jacobson & Shepard, 2014).  If a person performs poorly on this test, it is expected that they will have difficulty on irregular surfaces.

There are minimum requirements that need to be met before CDP can be conducted (Jacobson & Shepard, 2014).  The patient must be able to stand up, unassisted with their eyes open for a multiple periods of a minimum of one minute. It should be noted, prior to testing, if patients have arthritic or orthopedic conditions affecting the ankles, knees, hips, or back.  Numerous studies have demonstrated that increasing age does negatively impact postural control abilities. Typically, older adults are defined by the age group of 60-75 years of age (Hageman et al., 1995; Stelmach, et al., 1989).

21

Interestingly, gender does not appear to affect the balance system and SOT, MCT, or

ADT (Hageman et al., 1995; Olchowik et al., 2015).

In summary, computerized posturography is a way to objectively analyze and

quantify sensory and motor components of the vestibular system and the adaptation

mechanisms that occur in the central nervous system (Olchowik et al., 2015).

Researchers utilize this objective measurement to examine the effects of sleep

deprivation on ones postural control.


**Implications of sleep deprivation and postural control**

Sleep deprivation has been shown to decrease ones postural control abilities.

Postural sway parameters have been shown to have a positive correlation with

subjectively rated sleepiness and to have a negative correlation with EEG alpha

amplitude, which supports that the increase is sway is due to sleepiness (Liu et al., 2001).

Schlesinger et al. (1998) investigated the effects of 24-hour sleep deprivation, in five

healthy subjects, on postural sway (when the center of gravity changes on a movable

platform) under three conditions: during a simple reaction time task, during a task

requiring intermittent inhibition of reaction time, and in the absence of a concurrent

information processing task.  It was found that postural sway was increased significantly

in during the task requiring intermittent inhibition of reaction time.  Morad et al. (2007)

examined the effectiveness of posturography as an indicator of fatigue due to 26-hours of

sleep deprivation.  In this study, the parameters of posturography examined were the

stability index, weight distribution, synchronizations (assess the quality and efficiency of

coordination movements), and the intensity of sway.  Parameters were assessed 10 times

for each patient.  Results indicated that stability and sway were significantly affected. Thus suggesting, that posturography can objectively assess fatigue caused by sleep deprivation.  A common theme across the reviewed studies is that postural sway is further increased in conditions when the subject's eyes are closed (Liu et al., 2001; Morad, 2007).

**Purpose**

The present study will attempt to provide additional insight on the known negative effects of sleep deprivation on a persons postural control abilities.  This study is adding the variable of a rest period post sleep deprivation.  The aim of this study is to determine if a 110-minute rest period will help improve postural control abilities towards their line values.

**METHODS**

**Participants**

Nineteen male (6) and female (13) adult volunteers between the ages of 18-30 years, served as the participants. Each participant was screened to confirm there were no pre-existing postural control issues. If postural control issues were found, the participant was excluded from the study. Additional exclusion criteria included, minor orthopedic abnormalities, sleep disorders, injury to the lower extremity in the previous 12 months, head injury in the previous 6 months, and confirmed vestibular disorders. Participants were asked to answer questions about their subjective level of athleticism, their chronotype, and their height. Interpretation of results for the MCT section of the study is dependent on the participant's height. Participants who gave answers at the extreme ends of the spectrum were excluded from the study.

Prior approval for this project was obtained from the Missouri State University Institutional Review Board (IRB-FY2016-142, approved March, 12, 2016). Prior to testing, informed consent was obtained from each participant. By signing the consent form, participants agreed to uphold all of the requirements of the study, including refraining from alcohol, tobacco, and caffeine consumption and napping while during the sleep deprivation portion of the study.

**Instrumentation**

The NeuroCom Balance Master System by Natus was used for this study. This study utilized the following protocols: Sensory Organization Test (SOT) with six subtests

for SOT: 1) participants eyes open with stable platform and visual surround 2) participants eyes are closed with the stable platform 3) participants eyes open with a fixed platform and visual surround is sway referenced 4) participants eyes open, platform is sway referenced and the visual surround is fixed 5) participants eyes are closed with the platform sway referenced and eyes closed 6) participants eyes are open with both the platform and visual surround sway referenced.  The SOT protocol consists of eighteen 20-second trials, three consecutive trials for each of the six sensory conditions.  During each trial, the participant is instructed to ignore any surface or visual surround motion and to remain upright and as steady as possible.  Scores for SOT are based on the assumption that a normal person can sway anterior to posterior over an approximate total range of 12.5 degrees without falling.  Scores range from 0 to 100, with a score of 0 indicating the participant fell on the trial and 100 indicating the participant was perfectly stable.  To be considered normal, the participant must score above the 95th percentile for their age matched peers.

Motor control test (MCT) consisting of height scaled balance disturbances: small (1.25cm in 250ms), medium (3.15cm in 300ms), and large (5.7cm in 400ms) in the forward and backward directions.  Each of these disturbances are repeated three times. To be considered normal, the composite latency must be within the 95th percentile for age matched peers. Latency, weight symmetry, and amplitude scaling are measured.  This study examined latency measures only and utilized the composite score of the right and left leg for forward and backward translation in the statistical analysis.

Adaptation test (ADT) consists of surface disturbances of 20 degrees/second with five toes up and five toes down, repeated five times.  The sway energy is measured and

quantified as the force produced against the platform to recover from the surface disturbance. Sway energy should decrease from trial 1 to trial 5. To be considered normal, the participant needs to progressively expend less effort to return to center and be within the normal limits of age matched controls.

**Rest Period**

Participants were told to rest for a total of 110-minutes (enough time for the participant to undergo a full cycle of sleep) directly after the sleep deprived testing. No devices were used to verify if the participant did fall asleep and undergo a full cycle of sleep; therefore, this was called the rest period.

**Procedures**

Each participant was tested during three separate conditions: base line, sleep deprived for 23-hours minimum, and after a 110-minute recovery. The base line testing was conducted in the morning between 7:00 am and 11:00 am over a three-week period. Sleep deprived testing was conducted between 7:00 am and 11:00 am during a 24-hour period for 5 weeks. Participants were asked to wake up at their normal time the day of testing and to report to the designated meeting area at 10:00 pm where they were monitored to ensure complete sleep deprivation. Once in the designated meeting area, participants were free to do what they wanted, but had to refrain from consuming caffeine, alcohol, and tobacco. Food and non-caffeinated beverages were provided throughout the evening. Following sleep deprivation testing, participants were allowed to rest for 110-minutes. After the rest period, participants were tested again. After the

participants completed all of the testing, the examiner arranged for transportation home. The examiner also checked in with each of the participants following the evening of sleep deprivation.

**Statistical Analysis**

A One-Way Analysis Of Variance (ANOVA) for repeated measures was used to evaluate the condition effects (baseline, sleep deprivation, rest period) on the three protocols for posturography (SOT, MCT, and ADT). Statistical significance was set at $p<0.05$. If statistical significance was determined following ANOVA, a Bonferroni correction was used *post-hoc* to evaluate between condition differences.

# RESULTS

Young adults who met certain qualification criteria were tested under three conditions utilizing posturography: baseline, sleep deprived, and after at 110-minue rest period. Data were collected over approximately a 24-hour period.

## Sensory Organization Test

An ANOVA with pairwise comparisons of test of within subject effects indicated there was not a statistically significant difference in SOT composite scores when comparing the main effects of the three test conditions (df= 1.980; F= 2.775; p= 0.076) (Figure 8).
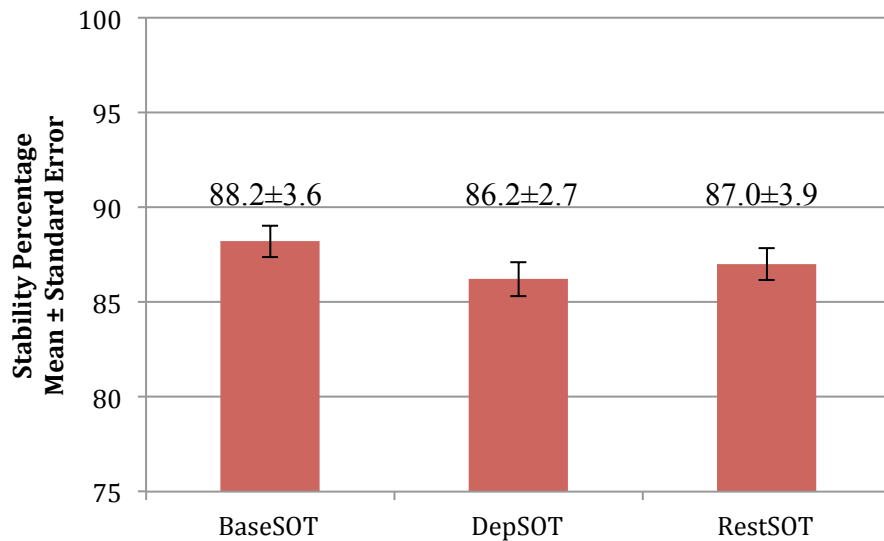


Figure 8. SOT composite stability percentage score (n=19). There was no statistically significant difference in SOT composite scores when comparing the three test conditions of base line (BaseSOT), sleep deprivation (DepSOT), and rest period (RestSOT) (p>0.05).

**Motor Control Test**

One-way ANOVA with pair wise comparisons indicated a statistically significant difference in MCT composite latency scores when comparing the main effects of the three test conditions (df= 1.996; F= 4.861; p= 0.014). *Post hoc* analysis using Bonferroni correction method indicated a significant difference between the baseline vs. rest period conditions, with p= 0.034. There was not a statistically significant difference between the sleep deprivation vs. rest period conditions, with p=1.000. Differences in MCT scores comparing baseline vs. sleep deprivation conditions approached statistical significance, with p= 0.052 (Table 1) (Figure 9).

| (I) factor1 | (J) factor1 | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -5.263 | 2.007 | .052 | -10.560 | .034 |
| | 3 | -5.737[*] | 2.083 | .039 | -11.234 | -.240 |
| 2 | 1 | 5.263 | 2.007 | .052 | -.034 | 10.560 |
| | 3 | -.474 | 2.037 | 1.000 | -5.849 | 4.902 |
| 3 | 1 | 5.737[*] | 2.083 | .039 | .240 | 11.234 |
| | 2 | .474 | 2.037 | 1.000 | -4.902 | 5.849 |

Table 1. Post hoc analysis for tests of within-subjects effects (n=19). Pairwise comparisons for BaseMCT (factor 1), DepMCT (factor 2), and RestMCT (factor 3).
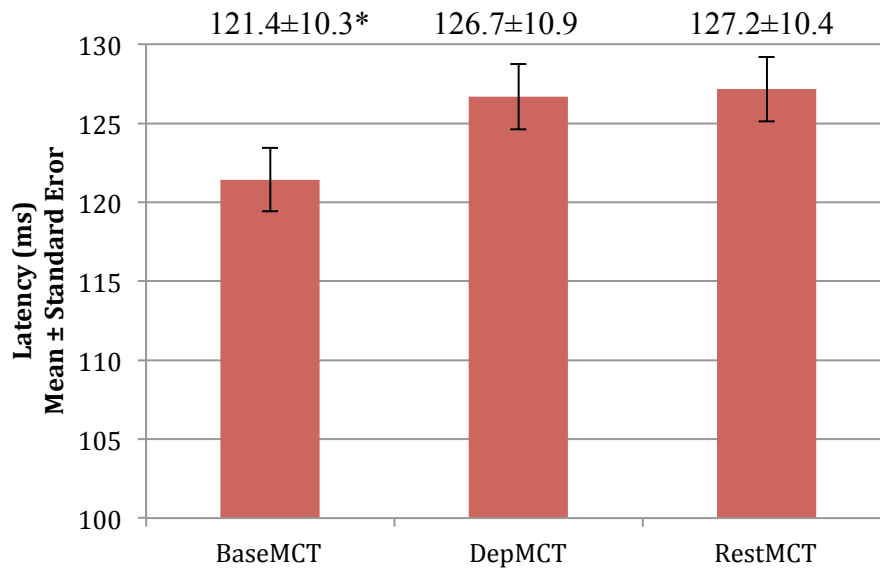
Figure 9. MCT composite latency score (ms) (n=19). *There was a statistically significant different in MCT composite latency scores between baseline (Base MCT) and rest period (RestMCT) conditions (p<0.05). There was not a statistically significant difference in scores between sleep deprivation (DepMCT) and rest period (p>0.05).

**Adaptation Test**

One-way ANOVA with pair wise comparisons indicated a statistically significant difference in ADT toes up condition scores when comparing the main effects of the three test conditions (df= 1.838; F= 10.321; p= 0.000). Post hoc analysis using Bonferroni correction method indicated a significant difference between the rest period vs. base line and vs. sleep deprivation, with p= 0.001 and p= 0.002, respectively (Table 2) (Figure 10). There was not a statistically significant difference in ADT toes up condition scores when comparing base line vs. sleep deprivation, with p=1.000.

| (I) factor1 | (J) factor1 | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -.063 | 1.950 | 1.000 | -5.210 | 5.083 |
| | 3 | 6.716* | 1.546 | .001 | 2.636 | 10.796 |
| 2 | 1 | .063 | 1.950 | 1.000 | -5.083 | 5.210 |
| | 3 | 6.779* | 1.622 | .002 | 2.499 | 11.059 |
| 3 | 1 | -6.716* | 1.546 | .001 | -10.796 | -2.636 |
| | 2 | -6.779* | 1.622 | .002 | -11.059 | -2.499 |

Table 2. Post hoc analysis for tests of within-subject effects.  Pairwise omparisons for BaseADT-UP (factor 1), DepADT-UP (factor 2), and RestADT-UP (factor 3) (n=19).
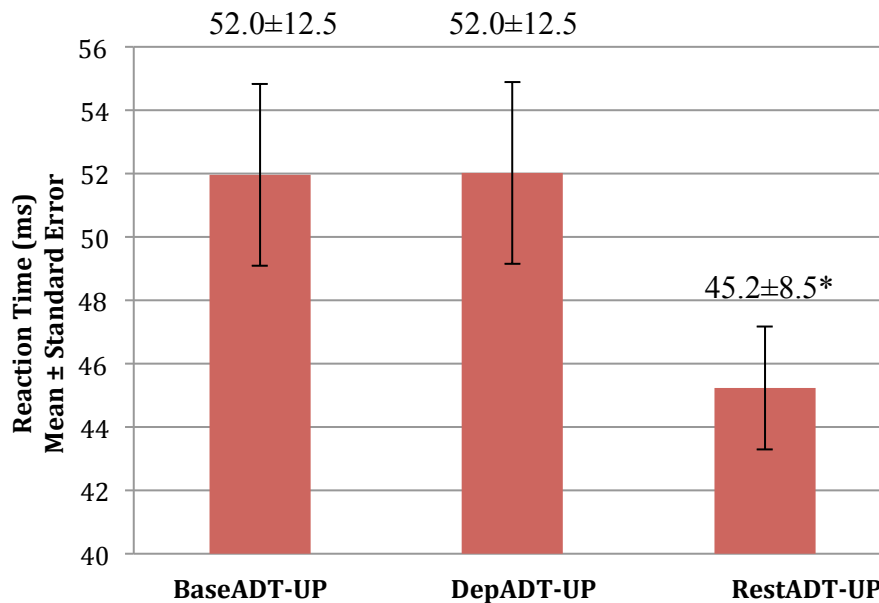


Figure 10. ADT toes up reaction time latency (ms) (n=19).  *There was a statistically significant difference between rest period (RestADT-UP) and base line (BaseADT-UP) toes up condition (p<0.05) as well as between rest period and sleep deprivation (DepADT-UP) toes up condition (p<0.05).

One-way ANOVA with pair wise comparisons the main effects of the three test conditions (df= 1.647; F= 1.562; p= .227) indicated no statistically significant difference in ADT toes down condition scores (Figure 11).
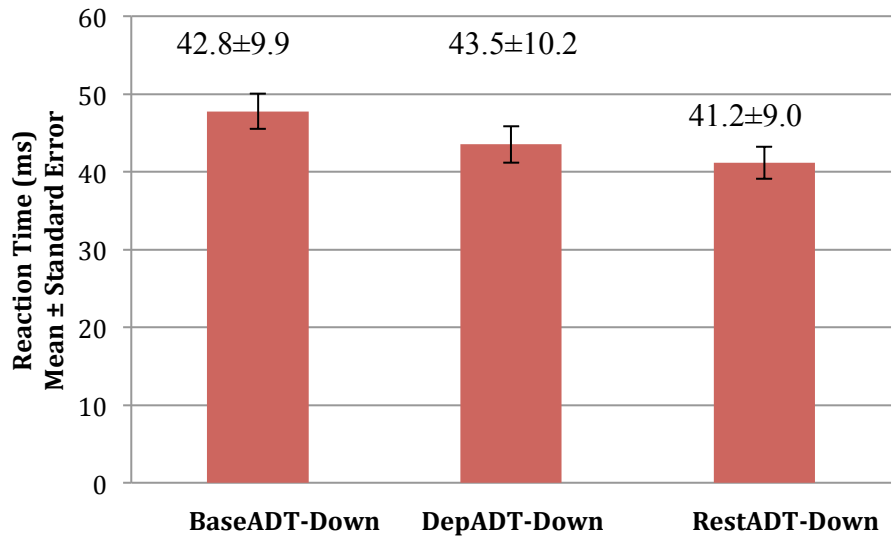
31

Figure 11. ADT toes down reaction time latency (ms) (n=19). There was a not a statistically significant difference between the three test conditions base line (BaseADT-Down), sleep deprivation (DepADT-Down), and rest period (RestADT-Down) toes down condition (p>0.05).

**DISCUSSION**

Sleep deprivation has been shown to decrease postural control and to impair multiple aspects of cognition including, alertness, vigilance, attention, emotion, long-term memory processes, and sensory perception (Killgor, 2010).   However, investigation into the possible ability of a rest period following 24-hours of sleep deprivation to restore some of these abilities has been limited.  This study examined the effects of a 110-minute rest period on postural control in healthy young adults after 24- hours of sleep deprivation.

In the current work, the SOT composite score indicates there is no significant difference in the sensory organization abilities of a participant who has been subject to 24-hours of sleep deprivation compared to after the participant receives a 110-minute rest period following the sleep deprivation.  Contrary to expected findings, the current study demonstrated an increased MCT latency following a 110-minute rest period compared to base line latencies.  Additionally the poor MCT latency following the rest period was comparable to MCT latency following 24-hours of sleep deprivation.  Interestingly, this study noted a decrease in ADT reaction time latency following a 110-minute rest period compared to base line and sleep deprived latencies; however, the improvement was only found in the toes up test condition.  While this finding supports the hypothesis of the study, it should be interpreted with caution as the same improvement was not noted in the toes down test condition.

Based on current literature, it was expected that the 110-minute rest period would restore the participant's postural control abilities close to base line.  There are several

limiting factors that could contribute to a decline of certain postural control abilities rather than an improvement.

One factor was no EEG recordings were obtained to determine if the study participants were clinically asleep during the 110-minute rest period. Our study indicated a 110-minute rest period provided an improvement of SOT scores towards baseline, which approached significance. Perhaps if the participants were able to benefit from the restorative properties of actual sleep, there would have been a significant shift of scores following sleep towards baseline scores.

A second contributing factor is sleep inertia. Sleep inertia is defined as transient hypovigilance, drowsiness, and diminished performance immediately after awakening. Sleep inertia is dependent on the quality and length of the nap, sleep stage upon waking from nap, timing of nap, and duration of wakefulness prior to the nap (Muzet et al., 1995). There are differing opinions as to how long sleep inertia lasts. Naitoh (1981) found that sleep inertia lasts for several hours after 50 or more hours of sleep deprivation. Conversely, Dinges et al. (1987) reported that after 56 hours of sleep deprivation, sleep inertia does not exceed 30 minutes. In the current study, participants were awake for approximately 15-20 minutes before being tested after the 110-minute rest period. The effects of sleep inertia may have been demonstrated in our study when participants performed significantly poorer during the MCT condition after having a 110-minute rest period compared to their baseline scores. Scores may have improved towards baseline if it was certain the participants were not being tested during the sleep inertia phase.

A third contributing factor may have to do with the sensitivity of the equipment used in the current study. Natus's clinical interpretation guide (2009) breaks the SOT

Composite Equilibrium Score into several categories. Scores are considered normal if they fall within the 95th percentile. Abnormal scores, those below the 95th percentile compared to their age-matched values, are further broken into sub-categories. A Composite Score of 38 or below is associated with a risk for falling. A Composite Score 15 points below the age-matched normative performance values is associated with a risk of falling and injury. A Composite Score greater than two standard deviations or eight points is considered significant. By examining the latencies for the MCT, some information can be gained as to the possible location of the central nervous system lesion. The interpretation guide provides ways to distinguish between an extra-vestibular, central nervous system or a musculoskeletal pathology. One particular study cited in the interpretation guide utilized the CPD equipment in the current study to distinguish between diabetic patients with and without peripheral neuropathy. A second study used the CPD equipment in the current study to distinguish between various sub-types of Parkinson's Disease. Participants in these studies were suspected of having a pathology or had a known pathology, whereas individuals with a pathology were excluded from participating in the current study. Given the aforementioned examples, it is possible that the CPD system used in the current study is not sensitive enough to detect minor balance changes in healthy young adults.

# FUTURE DIRECTIONS

The current study utilized a CPD system that has been used to track the progress of individuals undergoing therapy for nerve or musculoskeletal disorders or to distinguish between different sub-types of nerve pathologies. In the future, the study should be repeated using more sensitive equipment that is able to pick up on smaller disturbances in balance in healthy individuals.

A shortcoming of the current study was the inability to call the rest period sleep. Per participant report, it was unclear if all of the participants fell asleep during the rest period. Some participants reported being too tired to sleep or unable to sleep in an unfamiliar room. Future studies like the current one should obtain an EEG to ensure the participants are truly sleeping during their rest period. By obtaining an EEG, investigators could also avoid the risk of testing during the sleep inertia phase. Further investigation needs to be done regarding the effect of sleep inertia on the variables measured in the current study by testing during the sleep inertia phase and after the effects of sleep inertia have worn off.

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