THE COMBINED EFFECT OF LIGHT TOUCH AND COGNITIVE TASK DIFFICULTY ON POSTURAL CONTROL

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ABSTRACT

THE COMBINED EFFECT OF LIGHT TOUCH AND COGNITIVE TASK DIFFICULTY ON POSTURAL CONTROL

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Studies investigating combined effects of light touch and cognitive task are limited and available results are inconsistent regarding effects of cognitive task on postural control. Therefore, this study investigated the combined effects of light touch and cognitive task difficulty on postural control. Participants performed cognitive task and light touch individually and simultaneously. Results indicated that both light touch and cognitive task improved postural sway individually. The cognitive task difficulty moderately improved postural control. The simultaneous performance of cognitive task and light touch improved postural control and this improvement was more effective than individual performances of cognitive task and light touch.

Keywords: Postural Control, Light Touch, Cognitive Task, Dual-Task Paradigm, Cognitive Task Difficulty

ÖZ

HAFİF DOKUNMA BİLİŞSEL GÖREV ZORLUĞUNUN POSTÜR KONTROLÜ ÜZERİNE KOMBİNE ETKİSİ

ÇELİK, Tuğba
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Hafif dokunuş ve bilişsel görevin kombine etkisini araştıran çalışmalar sınırlıdır ve bilişsel görevin postür kontrolü üzerine etkilerine ilişkin çelişkili sonuçlar mevcuttur. Bu çalışma, hafif dokunuş ve bilişsel görev zorluğunun postür kontrolü üzerindeki etkilerini araştırmayı amaçlamıştır. Katılımcılar bilişsel görev ve hafif dokunuşu tek başına ve eş zamanlı olarak gerçekleştirmiştir. Sonuçlar hem hafif dokunuşun hem de bilişsel görevin tek başına postür kontrolünü artırdığını göstermiştir. Bilişsel görev zorluğu, postür kontrolünü orta derecede artırırken, bilişsel görev ve hafif dokunuşun eşzamanlı performansı, postür kontrolünü geliştirmiştir. Bu gelişme ise hafif dokunuş ve bilişsel görevin tekil performanslarından daha fazla bulunmuştur.

Anahtar Kelimeler: Postür Kontrolü, Hafif Dokunma, Bilişsel Görev, İkili Görev Paradigması, Bilişsel Görev Zorluğu.

To humanity

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LIST OF ABBREVIATONS

COP	Center of Pressure
COM	Center of Mass
COG	Center of Gravity
CMI	Cognitive Motor Interference
LT	Light Touch
CT	Cognitive Task
AP	Anteroposterior
ML	Mediolateral
QS	Quiet Stance

CHAPTER I

INTRODUCTION

This introduction chapter will provide an overview about the issues of attention and dual-task paradigm, postural control mechanism, and light finger touch. All these issues will be discussed furthermore in Literature Review Chapter.

1.1. An Entrance

Understanding human movement has been an interest of human beings dating back to ancient times. People tried to analyze and make plausible explanations to the movements that are executed in every single minute of our lives from sitting to walking, quadrupling to running, and standing to climbing stairs. Every diverse movement is executed with a certain postural position. Regardless of the movement's type, aim, or level of difficulty, without posture, movement is not possible.

A certain level of postural control is required for the maintenance of our lives, especially for daily tasks. There are several kinds of postural actions that we perform during the day either consciously or unconsciously. From childhood to the elderly, we need postural control to move no matter how well it is. An individual with a disorder which may result in a significant loss in strength or an elite athlete who runs a marathon requires postural control at different levels of modifications. Even reaching to a glass of water from the standing position needs to be supported by sufficient postural control of the neck and the trunk.

Human postural control has been a subject of research since ancient Greece (Ivanenko & Gurfinkel, 2018) and it is defined as the ability to maintain equilibrium and orientation in a gravitational environment (Horak & Macpherson, 1996). According to Horak & Macpherson (1996), postural control has two behavioral aims: postural orientation and postural equilibrium. Postural orientation can be defined as the positioning of the body segments with respect to each other and the environment; while postural equilibrium is a condition in which all the internal and external forces acting on the body are in balance to maintain the desired position. Human bipedal standing posture is not stable, even in a quiet stance position, the postural control system remains active to accomplish the erect posture. This complex sensorimotor task requires the functioning of various neurological structures that involve the spinal cord, the brain stem, the cerebellum, and the cortex (Rougier & Bonnet, 2016). During human upright stance, achieving an equilibrium state does not only depend on the commands from the CNS, but also the integration of visual, somatosensory, and vestibular inputs and these systems' adaptation in response to environmental changes (Shumway-Cook & Woollacott, 2000).

Postural control is not an isolated task that humans should execute during their daily lives. There are many other tasks either motor or cognitive that need to be performed for normal living: talking on the phone while walking, trying to figure out a problem while standing, or grasping a glass of water while walking. Most of our daily tasks involve the combination of a cognitive task and a postural task having varying level of difficulty such as maintaining body position in a stationary or dynamic environment. As a form of multitasking, dual-tasking is the performance of more than one task simultaneously (Lee & Taatgen, 2002) and is commonly used during our daily lives (Wickens, 2008; Lee & Taatgen, 2002). It has been well known that the attentional capacity of a human is limited to perform two or more tasks concurrently (Abernethy, 1988). This limitation brings about following questions: Does human postural control require a specific attention to be allocated or is it controlled only by automatic processes without certain attention?

Although postural control is thought to be maintained through automatic processes that require minimal information processing, a body of research demonstrates that postural control requires considerable information processing (Woollacott & Shumway-Cook, 2002). When attention is divided between tasks in a way that exceeds the total capacity, increased errors or delayed responses occur in one or more tasks (Singer, Hausenblas, & Janelle, 2001). In this case, the dual-task paradigm arises.

The dual-task paradigm is a methodology to assess performance in the existence of the simultaneous performance of two tasks (a primary task and a secondary task). As attention must be divided into multiple channels (Abernethy, 1988), dual-task performance is linked to deteriorations in time sharing-ability (Wickens, 2008). Performing a dual task with cognitive and motor demands leads to varying interferences between simultaneously executing tasks, from no response to a response that results in facilitation or deterioration of one or both task performances (Leone et al., 2017; Laessoe & Voigt, 2018).

Many researchers claim that dual-task leads to a decreased postural control because of the limited attentional capacity (Donker,2007; Polskaia & Lajoie,2016; Murillo et al.,2012), while some others indicate that dual-task interference improves postural control since it facilitates the automatization of postural control (Bergamin et al., 2014; Pellecchia, 2003; Swan, Otani, & Loubert, 2007; Stevens, Barbour, Meredith, & Timothy, 2016). While maintaining postural stability as a primary task, directing attention to a concurrently performed secondary task which requires a cognitive function, promotes the automatic postural control processes (Lajoie, Jehu, Richer, & Chan, 2017).

Another factor that affects postural control is “light touch” which is a mechanical stimulus that somatosensory system processes with the conscious perception of touch and pressure. Usually, a very small part of the body (e.g., index finger) is in contact with a stationary surface (Lackner & Dizio, 2000) It is widely accepted phenomenon that a light voluntary touch with a fingertip on a fixed surface improves postural stability. Through light contact, somatosensory information results in enhanced postural control and decreased body sway (Jeka, 2006). Light touch has been shown to cause a tactile sensory input but not to provide mechanical support (Kouzaki and Masani, 2008). Many studies demonstrated that light touch is an important reference for improved control of human upright stance (Baldan, 2014; Lee, 2018; Chen, Chen, Tu, & Tsai, 2015).

The positive effects of light touch on human postural control have been observed in various populations. For instance, the relationships between light touch and postural control were investigated in people with multiple sclerosis (Kanekar, Lee, & Aruin, 2012), down syndrome (Gomes & Barela, 2007), autism (Chen & Tsai, 2015), developmental coordination disorder (Chen & Tsai, 2016) and in people diagnosed with peripheral neuropathy (Dickstein, Shupert, & Horak, 2001). All the aforementioned studies reported the positive effect of light touch on postural control.

Studies investigating the combined effect of the light touch and the cognitive task on postural control provide useful findings to have the following interpretations. Cognitive task and the light touch compete for the same limited capacity processor (Soto-Faraco et al. (2002). Based on this idea, unless the overall demands of these three tasks (postural task, cognitive task, and light touch) don't exceed the available processing capacities, simultaneous performance of the light touch and the cognitive task may lead to an enhancement in postural control (Chen, Chen, Tu, & Tsai, 2015). Chen et. al. (2015) also demonstrated that light touch significantly reduced the postural sway and improved cognitive task performance in comparison with the condition without light touch. Similar results were found in another study.

The simultaneous performance of light touch and cognitive task (visual search accuracy task) improved postural stability. Furthermore, either cognitive task or light touch task individually reduced postural sway (Dos Santos et al., 2019).

1.2. Postural Control Mechanism

The human standing posture is an essential topic of motor control since it deals with the complex mechanism involved in the maintenance of the static posture as well as stability during locomotor movements (Gurfinkel V., Ivanenko, Levik, & Nabakova, 1995). Proper postural control is an important perquisite when an individual requires to perform various static and dynamic activities including sitting, standing, kneeling, quadruped, crawling, walking, and running. In response to changes in position and environment, responsible muscles contract to execute the intended movements while posture is maintained by making required postural adjustments (Massion, 1994).

It's a complex developmental task for humans to maintain the erect posture when the relatively small support surface and the high position of the center of gravity are considered. The presence of the perturbations (sudden exposure to changing conditions that leads to a displacement of the body away from its equilibrium) makes postural control even more challenging. These perturbations may arise from both internal (e.g., visual, vestibular, and somatosensory) or external (e.g., a push to a body segment) sources (Horak, Henry, & Shumway-Cook, 1997). Postural control system consists of two parameters including the tonic muscle activity to maintain "posture", and the compensations of internal and external perturbations to achieve the state of "equilibrium" (Ivanenko & Gurfinkel, 2018). Firstly, it resists gravity and enables the postural balance to be maintained. Secondly, it fixes the orientation and position of body segments (Massion, 1994). The environment surrounding us is not stationary and predictable, meaning that conditions might change, and unexpected perturbations might occur (Dietz, Trippel, & Horstmann, 1991). The postural control mechanism enables humans to adapt to these environmental changes by maintaining equilibrium state. These two parameters (posture and equilibrium) are related to each other, however, from different perspectives they have distinctive features. Postural control is explained by the presence of the inverted pendulum and the center of pressure (COP) oscillations. In this mechanism, which is called as simplified inverted pendulum model, the center of the body mass (COM) is the single controlled variable (Winter, Patla, Ishac, & Gage, 2003). During quiet stance, COP oscillates on both sides of COM to keep it stable between the two feet. COM is located approximately 1 m above the ankles and corresponds the length of the inverted pendulum. The presence of the oscillations and the relatively small base of support make posture inherently unstable. However, this biomechanical feature is not enough to explain observed postural behavior. For instance, a similar oscillation pattern was observed in horses as well despite standing on four feet and the lower COM location (Clayton & Nauwelaerts, 2014) meaning that the COM location is not the only variable affecting the stability of posture. Postural tone provides antigravity support by the tonic activation of the muscles. This support is provided by the contribution of both passive bone-on-bone forces in joints, stretched ligaments, and muscles and active connection of lower limb, trunk, and neck extensors (Ivanenko & Gurfinkel, 2018). This mechanical act is executed by the continuous feedback from the sensory system that organizes the information collected by visual, vestibular, and somatosensory receptors (Peterka, 2002; Maurer, Mergner, & Peterka, 2005; Mergner, Maurer, & Peterka, 2003). The facility of the CNS builds the link between the mechanical properties of the postural control system and the somatosensory system (Maki & Mcllroy, 2007; Hwang, Agada, Kiemel, & Jeka, 2016). According to the changing environmental conditions and constraints, the information from the somatosensory system from multiple sources including visual, vestibular, and proprioceptive systems are transmitted to the CNS and are interpreted, so that the neuromuscular system initiates the process and mechanical components of the body can execute the required movement.

On the other hand, concurrent performance of a motor and a cognitive task, frequently referred to as “the dual task paradigm”, states that the introduction of a second task during a cognitive or motor performance results in different types of interferences in either task. These could be either the facilitation or interference or the combination of both as well as no changes in motor and cognitive tasks (Leone et al., 2017). Indeed, the literature doesn’t provide consistent findings regarding the effects of dual task on the motor and cognitive task performance (Laessoe & Voigt, 2018). In line with the limited attentional capacity model of the human information-processing system (Norris & Colman, 1993), some researchers show that the dual-task results in a decreased postural control performance. On the other hand, some others indicate that the dual-task interference enhances postural control by facilitating the automatization of the postural control mechanism. Additionally, it is crucial to determine the attentional demands of the cognitive task since directing attention more to a cognitive task might affect the postural stability (Polskaia & Lajoie, 2016). For instance, a study has shown that with the increasing cognitive task demands, a deterioration occurred in postural control (Estevan, Gandia, Villarrasa-Sapina, Luis Bermejo, & Garcia-Masso, 2018).

1.3. Problem Statement

The positive effect of light touch on postural control is investigated in diverse populations (Chen, Chen, Tu, & Tsai, 2015). Light touch is defined as the touch of the index finger on a stable and firm surface with a force less than 1N so that it provides additional sensory information (Baldan A., Alouche, Aroujo, & Freitas, 2014). The consequences of performing three tasks simultaneously – 1) Postural Task, 2) Cognitive Task, 3) Light Touch, are not well known since the effect of cognitive task on postural control is not well documented.

Lee et al., (2018) conducted a study with healthy adults and investigated the effect of the light touch and concurrent cognitive task on postural control. The results showed that the body sway during quiet stance wasn't not significantly affected by the simultaneous performance of this dual task. It's suggested that the positive effect of light touch on body sway could be diminished due to the negative effect of cognitive task on body sway.

Given the findings of the literature, this study aims to investigate the combined effects of the light touch and the cognitive task on the postural control by modifying the level of the cognitive task difficulty. It is the argument that directing attention to the cognitive tasks at two different levels of difficulty may affect postural control differently and thus, would also have different effects on postural control when performed in combination with the light touch.

1.4. Research Questions

This study was designed to investigate the effects of the cognitive task difficulty on postural control with or without concurrent light touch.

Accordingly, the research questions are:

1) Does increased level of cognitive task difficulty have a positive effect on postural control?

2) Does light touch have a positive effect on postural control?

3) Is there an interaction between cognitive task difficulty and light touch on postural control?

1.5. Hypotheses

1. Increased level of cognitive task difficulty would have a positive effect on postural control.

2. Light touch would have a positive effect on postural control.

3. There would be an interaction between cognitive task difficulty and light touch on postural control.

1.6. Significance of the Study

The study contributes to the existing literature by re-testing the dual-task paradigm, to examine the effects of a cognitive task with two difficulty levels on a postural task. Assuring standardized cognitive task levels for each participant is believed to strengthen experimental design. The cognitive task levels are chosen to make a difference in the degree of directed attention between trials. Thus, while directing attention to the cognitive task, personal differences, abilities, and past experiences aimed to be eliminated as much as possible. Besides, this study is the first to our knowledge, which aims to reveal the light touch effect on postural task, in combination with a secondary cognitive task having different difficulty levels.

1.7. Limitations

This study has potential limitations. Such as:

- The sample size was kept limited due to the inconveniences caused by Covid-19 pandemic.

- A wide range of age limit (between 18-40 years) was set.

1.8. Operational Definitions

Center of Pressure (CoP, COP): The center of pressure is the point at which the ground reaction force vector is applied. During posture or gait, CoP measurements usually gathered using force plate (Benda, Riley, & Krebs, 1994).

Center of Gravity (CoG, COG): The center of gravity (CoG, COG) is the point at which the total body mass can be assumed to be concentrated without altering the body's translational inertia properties (Benda, Riley, & Krebs, 1994).

Postural Control: Postural control is the way of producing adequate motor output to maintain a controlled, upright posture through the several systems working in cooperation. The CNS regulates sensory information including the visual, vestibular, and somatosensory systems and thus, the postural control is maintained (Ivanenko & Gurfinkel, 2018; Alcock, O'Brien, & Vanicek, 2018).

Cognitive Task: Cognitive task is an undertaking that requires an individual to process new information (Sweller, 1988). In this study, the use of attentional resources was aimed by introducing cognitive task to the participants, to understand the possible interference between the motor and cognitive task. A visual-verbal Stroop test was chosen as the cognitive task.

Light Touch: Light touch is defined as slightly touching to a stable and firm surface with the index finger with a force no more than 1N (Holden, Ventura, & Lackner, 1994). According to Lackner J. (1988), any part of the body which is in contact with a stationary external surface has an influence on the perception of body orientation.

CHAPTER II

LITERATURE REVIEW

2.1. Postural Control

Postural control is a term that describes how our Central Nervous System (CNS) regulates sensory information from other sources to execute a motor output for the maintenance of a controlled, upright posture. The somatosensory, visual, and vestibular systems are the main three contributors to establish postural control and balance (Ivanenko & Gurfinkel, 2018; Alcock, O'Brien, & Vanicek, 2018). Postural control is adjusted adaptively as a response of static and dynamic conditions and perceived postural configuration. If any problem occurs in one of the three aforementioned components of postural control, the other two might be used a compensation mechanism to a certain extent. However, if more than one system is affected or in the case of motor impairment, postural control will be disrupted to a greater extent (Horak F., 2006).

Postural orientation and equilibrium are two main outcomes of postural control (Gandolfi et al., 2018). Postural orientation is the body's alignment and adequate muscle tone regarding gravity, support surface, visual environment, and internal references. Equilibrium refers to the stabilization of the body's Center of Mass (COM) (Horak F., 2006). The environment surrounding us is not stationary and predictable, meaning that both internal and external conditions might change and unexpected perturbations to upright posture might occur (Dietz, Trippel, & Horstmann, 1991).

The development of postural control in human takes many years as it is a complex and distributed task (Schmitz, Martin, & Assaiante, 2002). Adaptation to body weight becomes the main task of the sensorimotor system after birth (Van der Fits, 1998). This adaptation requires an antigravity vector to resist gravitational forces. Postural organization is formed beginning from the head to lower body segments (Massion J., 1998). During the initial half-year of life, ability to adapt to changes in environmental conditions is limited. From 6 months of age, proficiency in adapting to those changes increases (Hadders-Algra, 2005). Development of head control as the first sign of maintaining an erect posture is accomplished by the end of the first year (Assaiante & Amblard, 1995). Anticipatory postural adjustments which are defined as the ability to the integration of feedforward control into postural management emerge at around 13-14 months of age (Hadders-Algra, 2005). The last acquisition in the developmental process, postural control, is accomplished by the distribution of the body segments mass with respect to the supporting surface area (Massion J., 1998).

The ability of postural control maintenance differs by aging (Tinetti, Speechley, & Ginter, 1988). The changes in the neural, sensory, and musculoskeletal systems with aging might result in impairments in balance that could have a considerable impact on mobility and daily task routines. Deterioration in postural control system which results in reduced stability is associated with the increased risk of falls in elderly (Alexander, 1994). As abovementioned, postural control aims to maintain the correct relationship between the COM and the base of support. The control of the base of support is provided by the compensatory leg and/or arm movements. Studies demonstrated that there is a deterioration in the control of compensatory stepping movements in elderly. This impairment is associated with an increased risk of fall (Brian, Maki, William, & McIlroy, 1996). Furthermore, elderly people tend to rely on visual inputs due to the age-related losses in proprioceptive and vestibular losses. Also, decreased muscle strength, power, and joint mobility contribute to poor postural control in elderly (Kanekar & Aruin, 2014).

Postural stability, or balance, is measured by several ways including both qualitative and quantitative methods (Panjan & Šarabon, 2010). These methods include Clinical and Simple Field Tests, Laboratory Tests of Static Balance, and Laboratory Tests of Dynamic Balance. Clinical and Simple Field Tests (e.g., Flamingo Test, Romberg and Sharpened Romberg Test, Tinetti Balance Test, Berg Balance Test) require none-or little equipment. Subjects are given number of tasks which are based on standardized test protocols. Their reliability is low since they are based on the observational criteria of the examiner (Pérennou et al., 2005). Laboratory tests of static balance measures static balance (the ability to maintain specific posture). It is measured with devices which detect the movements of the body, its center of gravity (COG), and center of pressure (COP). The dynamic balance (the ability to maintain balance while moving) is assessed by laboratory tests (e.g., The Star Excursion Balance Test, The Bruininks-Oseretsky Test of Motor Proficiency, Functional Reach Test, The Jump-landing test, and Computerized Dynamic Photography) (Panjan & Šarabon, 2010).

2.1.1. Postural Control Mechanisms

An extensive comprehension of postural control systems is very crucial for understanding postural control mechanisms. Regarding the literature findings, this chapter will discuss the components of the postural control mechanisms: 1) biomechanical and musculoskeletal properties, 2) sensory system, 3) CNS.

2.1.1.1. Biomechanical and Musculoskeletal Properties of Postural Control

There are three main tasks of postural control as a behavior: 1) alignment of body segments, 2) postural equilibrium, 3) postural orientation. Firstly, the alignment of body posture is maintained and reacted to the gravitational forces regarding the appropriate vertical relationship between body segments. The vertical stance is maintained primarily with the existence of the postural tone. By the achievement of this alignment, the position of the body's COM must be maintained within the base of support. This consists of the second part of the postural task; postural equilibrium (Bronstein, Brandt, Woollacott, & Nutt, 1996). Postural equilibrium is defined as a condition in which all the internal and external forces acting on the body are in balance to maintain the desired position (Horak & MacPherson, 1996). Lastly, the postural task involves maintaining bodily orientation in relation to the environment. Once these tasks are accomplished, posture provides mechanical support for actions by organizing the interaction between the different segments and adjusting the joint stiffness during the movement (Bronstein, Brandt, Woollacott, & Nutt, 1996).

According to Winter et al. (2003), human erect posture is explained by the idea of the existence of an inverted pendulum model and center of pressure (COP) oscillations. This single segment inverted pendulum at which the center of body mass is regulated mainly by muscles around the ankle joint based on sensory feedback while others base on passive muscle properties (Saffer, Kiemel, & Jeka, 2008). In a quiet stance, the human body is not free from the forces. These external forces acting on the body results in the body reacting with an equal and opposite force. The point at which this force is exerted is COM of the body, also called the center of gravity. It can be summarized as the point at which the body generates a force that passes through the COM against gravitational force. The position of COM may alter according to the configuration of the body segments. While the body is in movement such as locomotion; the projection of COM is not always within the base of support. COP refers to the origin of the ground reaction force and reflects the acceleration of the body. The COM and the COP are not equivalent in the horizontal plane, while COP is related to force, COM is a position (Horak & Macpherson, 1996). In the inverted pendulum model, the whole body can be moved around the ankle joint to adjust the COP position that is located at the level of the pelvis. However, these oscillations are very slow (frequency around 0.2 Hz) due to the high inertia of the body. Quick corrections are required when there are fast perturbations. Body segments such as the trunk around the hip, thigh around the knee that have lower inertia moves for sudden corrections (Horak & MacPherson, 1996). When the postural stance is disturbed, two strategies are selected to restore the balance: hip strategy (torques and movement at the hip joint), ankle strategy (torques and movement at the ankle joint). The reaction for restoring the balance depends on the level and the intensity of constraints (Horak, Diener, & Nashner, 1989).

The postural tone is the first parameter that consists of antigravity posture (Sherrington, 1947). The postural tone which is often associated with antigravity support is explained as the presence of the tonic activation of muscles providing a specific postural attitude and exerting force against the ground to keep the limbs extended. Antigravity support is provided by both passive bone-on-bone forces in joints, stretched ligaments, and joints and by the active contraction in lower limb, trunk, and neck extensors (Ivanenko & Gurfinkel, 2018; Bronstein, Brandt, Woollacott, & Nutt, 1996). The main muscles are erector spinae, abdominal muscles in the trunk, iliopsoas, gluteus medius, biceps femoris, gastrocnemius, tensor fascia latae, tibialis anterior, and soleus muscle in the lower limb (Kendall & McCreary, 1984).

Even though, activity of postural muscles is rather smaller than that of other skeletal muscles during locomotor movements, it is important to emphasize that postural activity is not a passive mode of response. The specific and slight activities of the neck, trunk, and limb muscles play a crucial role in determining the resting tension, axial tone, and individual postural attitudes (Gurfinkel et al., 2006; Caneiro et al., 2010). Skeletal muscles enable the body to execute a wide range of activities including rapid production of forces and long-lasting maintenance of body segment orientation relative to gravity. Furthermore, functionally skeletal muscles are composed of different types of muscle fibers to execute task-specific time-activation profile (Knight, 2016).

Maintenance of the long-term postural activity is related to the low energy expenditure. This is because of the preferentially activation of slow-twitch muscle fibers during long-lasting muscle activities as they are highly fatigue resistant (Ivanenko & Gurfinkel, 2018). The constant activity of axial muscles enriched with fatigue-resistance biochemical properties helps to maintain postural stability for long. Thus, distal movements of the body parts can be compensated (Gurfinkel, Ivanenko, & Levik, 1994).

2.1.1.2. Sensory System and Postural Control

Understanding the physiological mechanisms underlying the postural control has begun to be investigated with systematic experimental studies a century ago by Sherrington (1906, 1915) and were further developed by Magnus (1912, 1924) and Rademaker (1931). The sensory system is a component that plays a significant role in postural control by sending information to the CNS with the integration of sensory systems including visual, vestibular, somatosensory, and proprioceptive systems (Massion, 1994).

During human upright stance achieving an equilibrium state doesn't only depend on the commands from the CNS, but also the integration of information from the somatosensory, visual, and vestibular inputs (Horak, 1996; Collins, 1993). According to the task and the environmental context requirements, the contribution of the visual, vestibular, and somatosensory systems may vary.

The visual system plays a role in the identification of the body position and orientation in relation to the environmental cues (Watson & Black, 2008). Mohapatra et al. (2011) claim that the visual information constitutes one-third of the orientational information. It is also known that the absence or lack of visual information leads to a deterioration in postural control (Watson & Black, 2008).

the vestibular system is an important part of the sensory system, and it provides information including motion, equilibrium, and spatial orientation and thus helps the maintenance of postural balance. There are two main apparatus located in each ear: otolith organs (the utricle and saccule) and semicircular canals (lateral, anterior, and posterior). The vertical orientation of the body and linear positioning are perceived by otolith organs whereas the rotational movements are perceived by semicircular canals by the movement of fluid inside of the inner ear (Watson & Black, 2008). With the changes in the movement of the head such as rotation and acceleration, the vestibular system is stimulated (Lackner & Dizio, 2000). In the absence of somatosensory or visual information, the vestibular system provides the information of self-motion (Mergner, Maurer, & Peterka, 2003). In brief, the vestibular system transmits the information about forces of gravity and inertia to the motor system. Thus, required adjustments in orientation of head such as gaze stabilizations and balance control can be done automatically (Cengiz, 2017).

The somatosensory system consists of nerve cells that sense and response information about the external object touching our skin, and also about our body itself. Several body parts such as skin, skeletal muscles, bones and joints, internal organs, and the cardiovascular system include somatosensory receptors. The main role of the somatosensory system is to perceive touch, pressure, position, temperature, vibration, and movement (Brodal, 1969). The somatosensory system is responsible for providing information about the forces and properties of the contact surface, and the relative configuration of the body segments (Horak &

MacPherson, 1996). Compelling evidence state that the somatosensory system is very crucial in estimating the orientation of upright standing posture (Ceyte, 2007).

Based on sensory information on relative configuration of the body segments, proprioception is considered as a subsystem of the somatosensory system (Peterka, 2002). In brief, the proprioceptive system is responsible for taking information from each part of the body and transmitting them to CNS, consciously or unconsciously, to control posture. This information is provided by proprioceptors located in the muscles, joints, ligaments, tendon, and skin (Kavounoudias, Gilhodes, Roll, & Roll, 1999). In the lack of proprioceptive input, movements would be impaired and the dependency on other sensory information such as visual inputs would likely to increase (Fortier & Basset, 2012).

2.1.1.3. Somatosensory System and Light Touch

Somatosensory information provided by the contact of the feet with the support surface in combination with proprioceptive inputs from the legs and ankles is helpful in maintaining upright stance (Diener, Dichgans, Guschlbauer, & Mau, 1984). Furthermore, Lackner (1988) stated that not only somatosensory information from feet in contact with a surface improves postural stability, but also any part of the contact with a stationary external surface has an influence on the perception of body orientation. However, it's not a necessity for this touch contact to be physically supportive (Marsden, Mertton, & Morton HB, 1981).

Light finger touch is defined as slightly touching to a stable and firm surface with the index finger with a force no more than 1N. Holden et al. (1994) demonstrated that fingertip contact on a stable surface can improve postural control, although the contact forces are not big enough to provide mechanical support. Somatosensory cues are a crucial orientation reference for the organization of postural control (Jeka, Schoner, Dijkstra, Ribeiro, & Lackner, 1997). Given the characteristics of light finger touch, how does it improve postural control without providing mechanical support? There are two possible explanations to it. First one is that the touch contact may trigger the additional postural muscles; especially the trunk muscles, which are not active without the touch contact. Light touch contact may provide a reference point to activate these muscles. Thus, these muscles can counteract sway (Jeka J. J., 1997). Second one is explained by the presence of additional sensory information that is obtained by the cutaneous mechanoreceptors and kinesthetic mechanoreceptors (Baldan, Alouche, Araujo, & Freitas, 2014; Diener, Dichgans, Guschlbauer, & Mau, 1984). Even though almost the entire body surface is covered with the cutaneous mechanoreceptors, their density is the greatest on hands and on fingertips (Philips, 1986). Two-point discrimination studies revealed that fingertip can detect differences as small as 2 mm (Jeka, Schoner, Dijkstra, Ribeiro, & Lackner, 1997). On the other hand, the sensitivity of two-point discrimination studies concerning the bottom of the foot is around 8 to 10 mm. During the touch with the index finger, cutaneous mechanoreceptors detect the changes in body sway by the skin surface or skin stretch prior to the sensory information provided by feet or ankle (Srinivasan, Whitehpuse, & LaMotte, 1990). Because of this feedback, body sway is perceived and required adjustments are made by the CNS. Also, the information regarding the arm configuration provides proprioceptive feedback (Matthews, 1988; Baldan et al., 2014). Rabin et al. (2008) found that position of contact surface was most effective at the point of greater instability (i.e., anterior touch for anterior-posterior instability, lateral touch with mediolateral instability). In other studies, the improving effect of light finger touch on postural control was demonstrated in people with vestibular loss (Lackner, Rabin, & Dizio, 2000) and people with lower extremity sensory deficits (Dickstein, Shupert, & Horak, 2001). In a further study of Lackner et. al. (2000) it was found that the light touch substitutes for impaired cutaneous information from the feet due to diabetic peripheral neuropathy.

The effect of light touch on postural control has been tested in different experimental conditions such as: one leg stance (Holden, Ventura, & Lackner, Stabilization of posture by precision contact of the index finger, 1994), natural feet position (Dickstein, 2005), or tandem stance (Rabin, Dizio, Ventura, & Lackner, 2008) and it was demonstrated that its supportive effect was independent from these conditions.

Tandem Romberg stance of 5 healthy subjects aged between 20-50 years was tested with eyes open and closed under three conditions: no contact, touch contact (slightly touching), and force contact (touching as strong as wanted) (Jeka & Lackner, 1994). The subjects stood on a force platform with tandem stance, and they were asked to maintain their balance and not to sway as much as possible. The duration of each trial was 24 s. The force of the touch contact was limited to 0.98 N and when the subjects exceeded this force, they were warned by alarm and the trial was repeated. Results indicated that touch contact was as effective as force contact in decreasing body sway; and this effect was comparable with the contribution provided by vision. Both touch and force contact attenuated postural sway when the vision is not available in comparison with no touch and no vision condition. Also, the attenuation in sway due to the touch contact and force contact occurred less when the vision was available. This is explained by the sensory information about the body orientation provided by touch contact and the anticipatory innervation of muscles. On the other hand, force contact was reported to have a counteracting effect on body sway (Jeka & Lackner, 1994).

Jeka and Lackner (1995) also found that the properties of the surface (roughness-slipperiness) don't affect the positive effect of light touch on postural control. Five healthy subjects aged between 20 to 30 years stood on the force plate in the tandem Romberg stance with three contact conditions: 1) light touch contact, 2) force contact, 3) no contact. The surface of the touch plate was altered as "rough" and "slippery". EMG surface electrodes were placed on both peroneus muscles. Force plate data was collected regarding the center of pressure (COP) and medio-lateral (ML) body sway. Mean sway amplitude was reduced by over 50% with both touch and force contact of the fingertip, in comparison to standing without fingertip contact. However, there was no difference when touching different surfaces. The EMG activity in the peroneal muscles and the timing relationships between fingertip forces demonstrated that light touch or the force contact on a surface activated long-loop reflexes including postural muscles for stabilization. On the other hand, when force contact was applied, mean sway amplitude decreased due to the physical support.

Dickstein (2001) investigated the effectiveness of light touch in subjects with somatosensory loss in the feet from diabetic peripheral neuropathy. 8 patients and 8 healthy subjects as a control group participated in the study. Postural sway of the groups was compared in three touch conditions (light, heavy, and none) and two surfaces (firm and foam) while eyes open or closed. In the light touch condition, the force exerted on the surface was limited to 1 N, while in heavy touch condition participants were allowed touch to apply as much as force they wished. In no touch condition, participants hold their index finger just above the plate as if they were touching. Antero-posterior (AP) and medio-lateral (ML) root mean square (RMS) of center of pressure (COP) sway and trunk velocity were greater in subjects with somatosensory loss than in control subjects, especially when standing on the foam surface. There was no significant difference between the effects of light touch in somatosensory loss and control groups. On the foam surface, heavy touch was more effective than light touch for the decrease in COP sway. Overall results demonstrated that light finger touch was as effective as heavy touch in decreasing trunk velocity, but, less effective in decreasing COP sway. Also, the results support the idea of feedforward mechanism in which finger touch contact activates postural muscles, thereby controlling body sway (Dickstein, Shupert, & Horak, 2001).

A systematic review compared the light touch effect on postural control during quiet standing between healthy people and people with balance problems due to an aging, a brain lesion, or other motor or sensory deficits. According to the results, the individuals with balance problems took more advantage of the light touch effect compared to healthy individuals. This is explained as the result of a greater sensory loss in people with balance problems. When these systems are not fully functional, the degree to which people benefit from additional somatosensory information increase. Thus, it can be concluded that light touch provides additional somatosensory information for postural control (Baldan et al., 2014).

In recent years light touch effect has been investigated in combination with the secondary task, cognitive task. Fu-Chen Chen (2015) conducted a study with 42 young adults (22 women and 20 men, mean age; 21.182±1.775 years) investigating the combined effect of light touch and visual search accuracy task. Results demonstrated that the light touch on a stationary surface with a force not more than 1N improved postural stability significantly. The accuracy of the visual search task improved as well when performed with light touch. A further study was investigated by the same researchers among young and older adults (Chen, Chu, Pan, & Tsai, 2018). The same study design was conducted for 22 young and 22 older adults. The positive light touch effect on postural control was more significant in older adults when compared to the young adults. Additionally, visual search accuracy improved in both groups and these effects were equivalent between groups.

Similar results were confirmed by another study conducted by Daniel Gonçalves dos Santos (2019). Light finger touch (±1 N) was performed in combination with a cognitive task (visual search accuracy task) with 13 healthy adults (7 women and 6 men, mean age; 23 ± 3.1 years). They stood on a force platform quietly and performed visual search accuracy task. Each trial lasted 70 sec. Participants performed both cognitive task and light finger touch individually and simultaneously. The results demonstrated that both cognitive tasks and light touch reduced postural sway when they were performed individually. Also, simultaneous performance of light touch and cognitive tasks improved postural stability due to a decrease in postural sway. Furthermore, it was confirmed that light finger touch provided additional somatosensory cue, thereby, reducing postural sway.

The effectiveness of light touch studies on postural control was investigated in various populations. The light touch and postural control relationship were investigated in people with multiple sclerosis (Kanekar, Lee, & Aruin, 2012), in people with down syndrome (Gomes & Barela, 2007), in people with autism (Chen & Tsai, 2015), in people with developmental coordination disorder (Chen & Tsai, 2016) and in people diagnosed with peripheral neuropathy (Dickstein, Shupert, & Horak, 2001) and the positive effect of light touch on postural control was reported. Besides, researchers investigating the combined effect of the light touch and the cognitive task on postural control exist in the literature. According to Soto-Faraco et al. (2002) cognitive tasks and the light touch compete for the same limited capacity processor. Based on this idea, unless the overall demands of these three tasks (light finger touch, cognitive task, and postural task) don't exceed the available processing capacities, simultaneous performance of the light finger touch and the cognitive task may lead to an enhancement in postural control (Chen, Chen, Tu, & Tsai, 2015). Chen et al. (2015) conducted a study with 42 subjects (22 women and 20 men, mean age; 21.182±1.775 years) to investigate the combined effects of the light finger touch and the visual search accuracy task. It was demonstrated that light touch significantly reduced the postural sway and improved cognitive task performance in comparison to the condition without light touch. Similar results were found in another study in which 13 participants were included. It was concluded that the simultaneous performance of light touch and cognitive task (visual search accuracy task) improved postural stability. Furthermore, the individual performance of both the cognitive task and the light touch task reduced postural sway.

2.1.1.3. The Central Nervous System (CNS) and Postural Control

Posture is defined as the intense interaction of sensorimotor processes and internal representations of these processes rather than being a simple static condition (Horak & Macpherson, 1996). The CNS receives different types of information from both external (environmental constraints) and internal (visual, vestibular, and, proprioceptive systems) sources (Lee & Lishman, 1975). Using this information, the CNS plays a role in organizing the sensory information and planning the execution of the required reaction (McCollum, Shupert, & Nashner, 1996).

The CNS comprises of several parts including the spinal cord, the brainstem, the cortex, basal ganglia, and the cerebellum. The spinal cord maintains antigravity support and locomotor patterns; however, it is not sufficient for ensuring balance (Macpherson & Fung, 1999). Different parts of the CNS play diverse roles in postural organizations. Somatosensory information about limb orientation is carried in sensory pathways in the spinal cord. Integration of sensory information for postural orientation is regulated at the level of the brainstem. The cerebellum is important for the programming of normal automatic and anticipatory postural adjustments (Horak & Diener, 1994) and orientation of the body with reference to gravity or visual references by using vestibular and visual information (Horak, 2009). The role of the basal ganglia is to provide quick changes in postural strategies, regulation in muscular tone, and anticipatory and reactive postural responses for postural orientation (Horak & Frank, 1996). Lastly, the cerebral cortex is responsible for changing postural reactions with modifications in the cognitive state, sensory-motor conditions, previous experience, and an estimation of a perturbation (Horak F., 2009).

Posture comprises a basis on which the movements can be executed and organized (Jeannerod, 1988). That’s why during the performance of movement it is important to preserve postural functions (Massion, 1998). The CNS preserve functions of posture during movement by two strategies: (1) postural reactions (i.e., compensatory postural adjustments), (2) anticipatory postural adjustments. First, when a disturbance caused by the movement, postural reactions occur regarding the sensory information. These reactions are regulated in CNS, and they are executed after the disturbance. Second, anticipatory postural adjustments occur before the disturbance of movement so that they can prevent further disturbances. Anticipatory postural adjustments are used when the perturbation is anticipated or when the previous experiences help the estimation (Kanekar & Aruin, 2014). The anticipatory postural adjustments are helpful in minimizing postural disturbances, postural preparation for movement, and, assisting the movement (Bouisset, 1992; Massion, 1998). Aruin & Neeta (2014) made a kinematic analysis of anticipatory and compensatory postural adjustments. Eight participants were exposed to external predictable and non-predictable perturbations while standing. It was found that the CoM and CoP displacements were larger when subjects were exposed to an unpredictable perturbation. When the perturbation was predicted, anticipatory postural adjustments were used to restore balance, thereby leading to smaller displacements of the CoP.

When the stance is disturbed by external forces, the CNS regulates the reaction to restore the balance. The type of reaction strategy (ankle strategy, hip strategy, and stepping strategy) is chosen according to the direction and the magnitude of the perturbance. Ankle strategy is opted when the perturbation is low and slow and the control in sway in antero-posterior direction is required. When the torque exerted around the ankle is not sufficient, hip strategy is used. Hip joint has a greater range of motion than the ankle joint in medio-lateral direction. If the perturbation necessitates to restore stability in medio-lateral direction, hip strategy is chosen to restore the balance. If both the ankle and hip strategies are insufficient to maintain balance or the COM suddenly moves away from the base of support, stepping strategy occurs (Moore, Rushmer, Windus, & Nashner, 1988). All these changes in internal and external environment are sent to the CNS, so that it can analyze and interpret the current situation to generate a motor command according to the sensory environment (McCollum, Shupert, & Nashner, 1996).

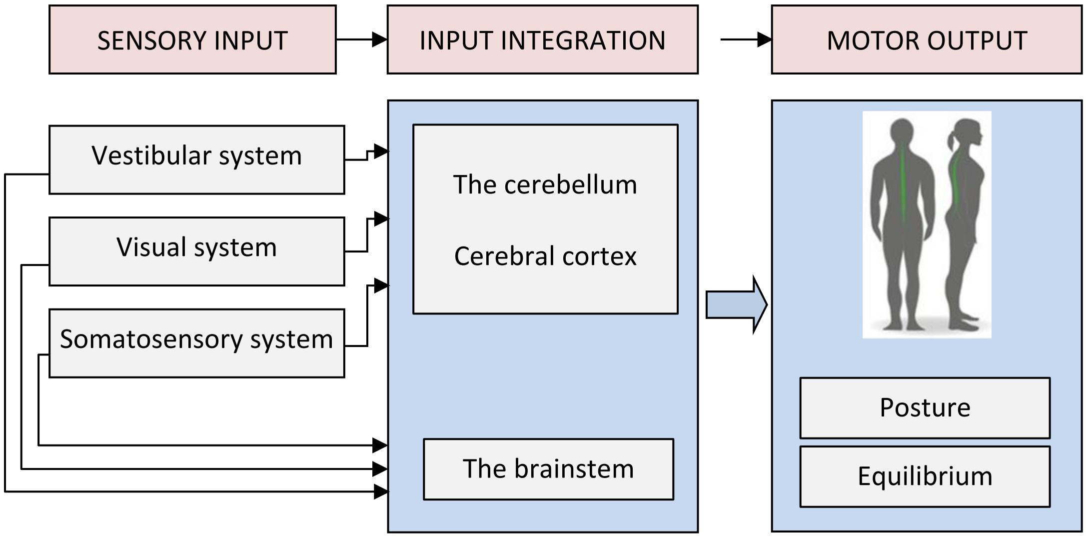


Figure 2.1. Relationship of the postural control systems

McCollum, Shupert, & Nashner (1996) conducted a study to investigate how does the CNS regulate sensory information even if the information is distorted. 20 healthy adults and 69 patients with peripheral vestibular disorder participated in the study. It was hypothesized that a single small cue from the environment could result in a change in sensory state. To exemplify; changing the property of the surface (e.g., from rigid to a compliant surface) will result in changes in the relationship between ankle position and both visual and vestibular information about body sway. Subjects stood on a movable force platform. Both the platform and the visual surround could be rotated independently. Six different sensory conditions were introduced to the subjects and the duration of each trial was 20 s. They were instructed to stand still with as minimum sway as possible. In conditions 1 and 2, they stood on a fixed platform with eyes open and eyes closed. In other 4 conditions visual surround or the platform were rotated to interfere with sensory feedback. In condition 3, the visual surround was rotated. In conditions 4 and 5 the platform was rotated with eyes open, and ayes closed. In condition 6, both the platform and the visual surround was rotated. After the experiment, the patients with peripheral vestibular disorder were grouped under three categories: category 1 (swayed within normal limits in conditions 3 and 4 but abnormal in conditions 5 and 6), category 2 (excessive sway in conditions 3 and 6), and category 3 (abnormal sway in conditions 3, 4, 5 and 6 and little more sway in conditions 1 and 2 in comparison with healthy subjects). Besides, three different sensory stages were defined: A, B, and C. In state A (at which the conditions 1,2, and 3 were included), the CNS is able to make use of all of the sensory information including vestibular (when available), visual (when available), and somatosensory systems. In sensory states B and C (at which the conditions 4, 5, and 6 were included), the nervous system cannot make use of somatosensory information from the legs and feet about the orientation of the body with respect to surface, however, it can utilize somatosensory information about the orientation of body segments with respect to each other and also vestibular system. The sway measurements indicated that the sway amount of people with peripheral vestibular dysfunction was comparable to the healthy subjects while standing on a rigid surface with eyes open or eyes closed. It was observed in healthy subjects that when a mismatch between vestibular and somatosensory information occurs, a transition is made from sensory state A to B, if the eyes are open. The similar transition mechanism was observed in patients with vestibular disorder as well. However, they showed a greater amount of sway. This was explained by two possible mechanisms. First, they might have relied on vestibular input which was reduced in amplitude or dynamic range. Second, they might have used the information from visual and somatosensory sources, but, since the platform and visual surround was altered by the experimenter, the visual and somatosensory information were sway-referenced. This study explains how the nervous system uses a transition mechanism to regulate the sensory input to maintain balance.

2.2. Attention

In the previous sections, the mechanism involved in human postural control was elaborated. The role of biomechanical and muscular properties, sensory systems and CNS was mentioned. But is the combination of all these systems processed completely automatically without any attention, or is the human consciousness factor could affect these processes? In this case, understanding the role of "attention" becomes crucial.

2.2.1. Theory of Attention

Attention has been investigated for years to understand its nature and principles and its function, and interestingly its definition. Yet, the theory of attention is not clear to elucidate these questions completely.

In several attention theories, attention is considered as the connection between perception and memory (Kihlstrom, 2018). William Jones is the first to define attention as the "Taking possession by the mind…. of one out of what seem simultaneously possible objects or trains of thought." (James, 1890). This definition is remarkably close to the current understanding of attention defined as the "selective prioritization of neural representations that are most relevant to one's behavioral goals." (Buschman & Kastner, 2015)

The theories of attention will be introduced under 3 categories: early theories of attention (1), capacity theory of attention (2), multiple resources theory of attention (3). Firstly, early theories of attention comprise early, and late selection theories proposed by Broadbent, (1958); Deutsch and Deutsch, (1963); Keele, (1973); Treisman, (1964). These theories are similar in general view; however, they have some distinctive features. According to these theories, attention is conceptualized as single-channel or "bottleneck." The name of "bottleneck" describes the occurrence of information processing. The level of the "neck" determines whether the information would reach short-term memory, and thus it can reach "higher-level" information processing (Kihlstrom, 2018). So, it acts as a control point. Early selection theories refer to an attentional filter that operates after sensory processing but prior to meaningful semantic processing. Late selection theories refer to an attentional filter that operates after semantic analysis but prior to response preparation. The most well-known early selection theories are Broadbent's, (1958) filter theory and Treisman's (1964) attenuation model. Broadbent's (1958) filter theory suggests that the sensory system can identify only one stimulus at a time. All the stimulus reaches to a certain point into the system (bottleneck). A filter determines which stimuli will be processed further and stimuli will not. A very similar but slightly different theory proposed by Treisman (1969) claims that the filter lowers the strength of the sensory signal on the unattended channel. The degree of perceptual analysis received by an input depends on the signal intensity of the input. When it comes to late selection theories, Keele's (1972) late-filter theory explains that all stimuli are recognized (semantically analyzed), but they are narrowed to the most relevant ones during response preparation. As a result, only the most relevant stimulus is responded.

Secondly, in the early 1970s Kahneman (1973) proposed a view for the theory of attention in terms of mental capacity. According to this view, there is a fixed capacity of attention. Cognitive activities differ in terms of their attentional requirements. For instance, when two tasks are performed simultaneously, they might interfere with each other by exceeding the individual's capacity if both tasks are attention demanding. However, if they are not attention-demanding, and do not exceed the individual's capacity, interference does not occur. On the other hand, it's assumed that it's possible to process multiple stimuli at the same time. This occurs through parallel processing (Posner & Snyder, 1975; Navon & Gopher, 1979. In this case, the trade-off between tasks might occur. According to the importance, difficulty, and other factors of the tasks, this trade-off is determined.

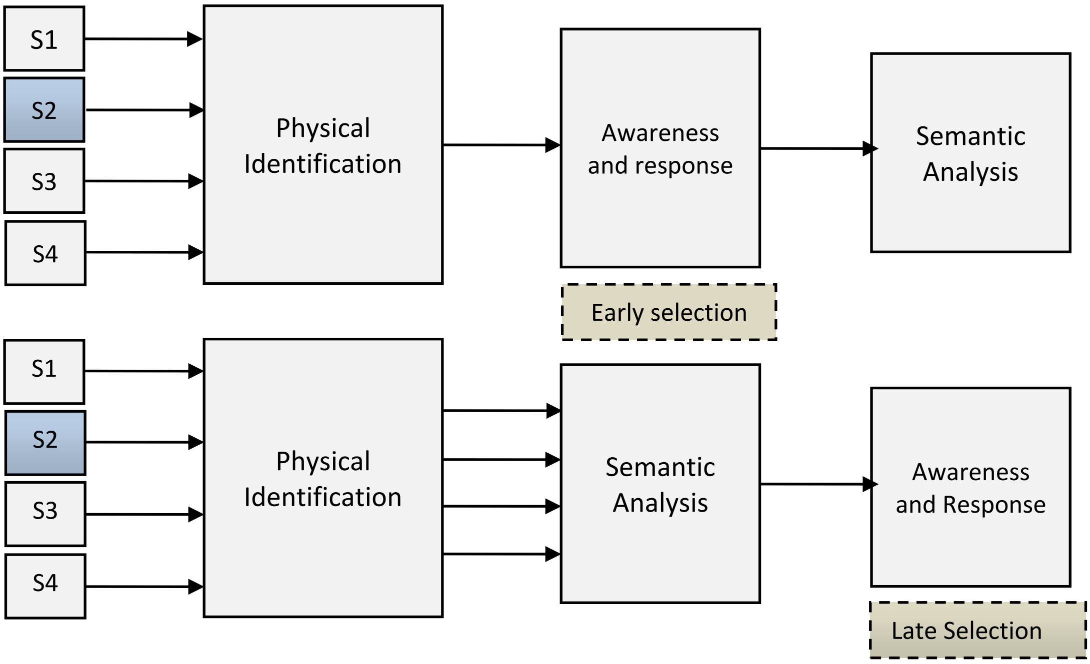


Figure 2.2. Description of Early and Late Selection theories.

Note. The identity of both the attended stimulus (S2) and the unattended stimuli (S1, S3, and S4) are computed alike. In early selection model, the attended stimulus (S2) is selected after the physical identification and before the semantic analysis, however, in late selection model, the attended stimulus (S2) is selected after the semantic analysis.

Lastly, it is supported that attention doesn't have a single resource, instead, it has multiple resources. For mental processing only a limited set of resources are available. These resources are first pooled and then allocated to variety of operations. Based on this theory, it can be understood that how a demanding single-task can be difficult to process and how some dual-tasks can be performed without any interference. According to this view, each resource has its own capacity, and the information is processed goal directed. Thus, during the simultaneous execution of two tasks, they could be performed well without any interference (Wickens, 1976; Navon & Gopher, 1979; Wickens, 2002). Allport states that the main mechanism of the multiple resources theory is to accomplish the completion of a task. Each resource has its own capacity, and the information is processed goal directed.

Therefore, separate tasks can be performed simultaneously, and complex tasks can be executed successfully (Allport, 1989).

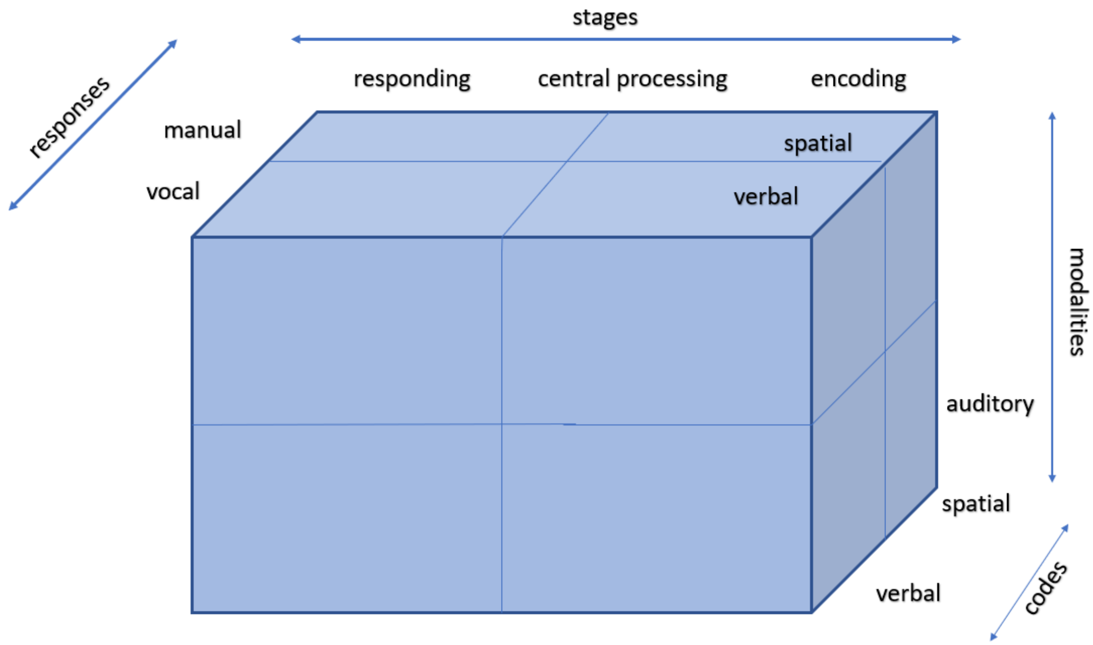


Figure 2.3. Multiple Resource Model (Wickens, 1992)

Attention is a fundamental aspect of cognitive function, and it has a broad domain (Dux & Marois, 2009). It is a multifaceted concept which involves switching, dividing, selecting, orienting, searching and sustaining (Redick & Engle, 2006). There are number of ways to measure the attention. Various methods are utilized to evaluate each parameter of attention. Posner's test, Reaction-time paradigms (Stroop paradigm, Simon paradigm, and Navon Paradigm), Priming test, Oddity paradigm, and Das' test are the most common batteries used in practice. This study will utilize Stroop paradigm to differentiate attentional demands (Towey, Fabio, & Capri, 2019). In the next part the Stroop paradigm will be explained in detail.

2.2.1.1. Stroop Effect and Attention

“Stroop Effect” or “Stroop Test” phenomenon was first identified by the psychologist John Ridley Stroop in the 1930s (Stroop, 1935). In general terms, the Stroop test involves color words both congruent (e.g., the word "red" written in a red color ink) and in incongruent mode (e.g., the word "red" written in a "yellow" color ink). Participants are instructed to name the color in which the word is written. The different information received by the brain -the incongruent word color and the real color in which they are written- causes an interference. Word reading and color reading are processed parallel, thus, while generating an output response this interference occurs (Arthur & William, 1966). This is because of the increasing difficulty of remaining focused and the difference in the speed of processing of words and colors. It is stated that word recognition processing occurs much faster than color recognition processing. Thus, confusion occurs at the time of decision making (Imbrosciano & Berlach, 2006). When the congruent word color is presented, the time to respond to the name of the color is very fast, however, when the incongruent word color is presented, delayed response time and a high possibility of error occurs (Harvey, 1984). But isn't it possible to simply focus on the color of the ink ignoring the word itself? Different views are explaining the possible mechanism of this interference. The first explanation is the difference between the processing speeds of color and word as explained above (Fraisse, 1969). On the other hand, there is another experiment that proposes a different view to this explanation. Dunbar & MacLeod (1984) conducted the Stroop test differently. The names of the words were presented in reverse order like seen in a mirror. In this experiment identification of the name of the word was much slower than naming the color. Therefore, the explanation of the difference in speed of processing is insufficient to explain the Stroop effect. The irrelevant signal (color name) and the relevant signal (ink color) are processed in parallel with the possibility without any interference in the early stages of processing (Schmidt, Lee, Winstein, Wulf, & Zelaznik, 1999).

2.2.2. Attention and Postural Control

According to the traditional view, postural control requires minimal consciousness for information processing and reflexively controlled. In other words, postural control is considered to be automatic (Kerr, 1985; Pellecchia, 2003). However, there are opposing views to it suggesting that attentional resources play a role in the organization of postural control.

Pellecchia (2003) examined the postural control in response to the difficulty of concurrent cognitive tasks. 20 healthy adults participated in the study. Digit reversal, digit classification, counting backward by 3 seconds were introduced to subjects during quiet stance and results showed that the increase in the attentional demands of the cognitive tasks resulted in an increase in sway during postural stance. This result may indicate that task integration becomes more challenging with the increasing level of attentional demands. However, a similar study conducted by Blanchard et al. (2005) to determine the attentional demands of concurrent cognitive on postural control with children showed different results. 19 fourth-grade students performed three different tasks on the force platform: quiet stance, counting backward, and reading second-grade level sentences. Results revealed that children were able to adjust their postural stance by decreasing sway range and sway variability with the increasing attentional demands. This might be due to the different strategies adopted by children, as the author explained.

On the other hand, the findings of Shumway-Cook and Woollacott (2000), demonstrates that postural control is not only a reflexive response to the sensory information. 18 young adults and 36 elderlies (18 with a history of fall or balance impairments and 18 without a history of fall) participated in the study and performed a choice reaction time auditory task. They performed the auditory task in six different sensory conditions. These conditions altered the availability of accurate visual and somatosensory cues required for postural control. Results showed that the performance of auditory task did not affect the postural stability in young adults in any of the sensory context. However, the situation was different in older adults. As the sensory information decreased, the attentional demands of postural control increased. Additionally, this increase was present in all sensory contexts for the elderly with balance impairments, while for healthy elderly it was present when both visual and somatosensory cues were removed.

2.3. Dual Task Methodology and Postural Control

Dual-task methodology in which participants perform two or more concurrent activities has been investigated to assess the attentional demands of postural control, mental load, as well as the automaticity (Abernethy, 1988; O. Neumann, 1996). When a secondary task is performed in addition to the postural task, the dual-task paradigm arises. Within dual-task paradigm the degree of sharing information-processing requirements is investigated. So, how are the attentional requirements determined or how is it explained? To understand this issue, it's important to focus on cognitive function. In literature, dual-task studies are performed with various tasks that assess different cognitive functions. Al-Yahya et al. (2011) classified cognitive tasks based on their behavioral and cognitive level. According to this study, three types of cognitive tasks which require 1) executive function, 2) working memory, and 3) attention. Executive function involves higher cognitive processes which are not routine, and goal directed. Producing words spontaneously (e.g., reciting words with or without specific letters) under pre-specified search conditions can be defined as a task of executive function. Working memory is a part of cognitive function that can hold information temporarily and the ability to manipulate and use the information to complete complex cognitive tasks when required. Serial subtractions, repeating a series of digits forward, and counting how many times predefined words appeared in a text read aloud are some examples of working memory tasks (Baddeley, 2003). Attention, as abovementioned, has four components: sustained (e.g., counting backwards, push-button simple reaction time), selective (e.g., The Stroop paradigm, auditory choice reaction time task), divided (e.g., talking on the phone while walking), and set-shifting (cognitive flexibility) attention and in brief terms it can be defined as individual's information processing capacity during the performance of a task (Woollacott & Shumway-Cook, 2002).

In dual-task situations, the ability to allocate attention between the two relevant tasks is very essential for both tasks to be performed optimally (Shumway-Cook & Woollacott, 2000). In literature, the underlying mechanism of the dual-task interference is not yet clear. When a motor and cognitive task are performed simultaneously, these performances may be affected by these simultaneous execution (Leone et al., 2017). When two different tasks are performed simultaneously, the performance of one or both tasks may deteriorate. This is called as "dual-task interference." When one of these tasks is a cognitive task and the other is a motor task, it is called as cognitive-motor interference. Provided that the single task condition is a reference, any deviation from this reference point during the performance of dual-task is named as dual-task cost (Friedman, 1982). A study (Plummer et al., 2013) has proposed nine possible scenarios in dual situations. These possible outcomes are: 1) no interference (performance of either task does not change relative to single-task performance), 2) cognitive-related motor interference (cognitive performance remains stable while motor performance deteriorates), 3) motor-related cognitive interference (motor performance remains stable while cognitive performance deteriorates), 4) motor facilitation (cognitive performance remains stable while motor performance improves), 5) cognitive facilitation (motor performance remains stable while cognitive performance improves), 6) cognitive-priority trade off (cognitive performance improves while motor performance deteriorates), 7) motor-priority trade off (motor performance improves while cognitive performance deteriorates), 8) mutual interference (performance of both tasks deteriorates), or 9) mutual facilitation (performance of both tasks improves) (see Table 2.1).

Table 2.1. The nine potential outcomes of cognitive-motor interference proposed by Plummer et al. (2013)

Motor Performance	**Cognitive Performance**		
	No Change	**Improved**	**Worsened**
No Change	No dual-task interference	Cognitive facilitation	Motor-related cognitive interference
Improved	Motor facilitation	Mutual facilitation	Motor-priority trade-off
Worsened	Cognitive-related motor interference	Cognitive priority trade-off	Mutual interference

2.3.1. Underlying Mechanisms to Explain Dual-task Paradigm

In literature, there are different approaches explaining the underlying mechanism of the dual-task paradigm (see Figure 2.4).

– **Capacity sharing model***,* points out that – n resources are divided into "to-be-performed" tasks, in other words, one can voluntarily allocate capacity sharing to a specific task. Due to the limited-capacity parallel processor cognitive-motor interference occurs (McLeod, 1977; Tombu & Jolicoeur, 2003). To add, in this model, it's also possible to perform multiple tasks without interference unless they require common limited sources (Navon & Gopher, 1979; Wickens C., 1980).

– **Time sharing model**, suggests that two tasks can access resources, but time has to be shared between two tasks. This model suggests that the brain areas that are responsible for only one task are less activated during a dual-task condition. The greater the resources overlap, the greater the level of interference (Nijboer, Borst, van Rijn H., & Taatgen, 2014).

– **Cross-talk model**, adopts the idea of the use of similar domains or neural processors. If two tasks use similar domains or neural processors, they don't interfere with each other. Also, due to the use of less attentional resources, efficiency of processing (i.e., facilitation) might increase (Navon & Miller, 1987).

– **Bottlenecks theory,** as mentioned earlier, claims that when two tasks need the same neural processors or networks or when the required networks overlap, serial processing occurs. Since certain processors act only on one task at a time, a delay or impairment of one or both tasks occur (Pashler, 1994; Tombu & Jolicoeur, 2003).

Other than these attention theories, some theories handle dual-task paradigm within the postural control scope.

– **The non-linear interaction model** (U-shaped relationship between postural control and cognitive demand), proposes that postural control improves when performing a relatively easy concurrent task, while it deteriorates with the increasing demands of a concurrent cognitive task (Bonnet & Baudry, 2016; Riccio & Stoffregen, 1988). However, there is a lack of clarity in determining the demands of concurrent cognitive tasks. In other words, at which point of difficulty does concurrent cognitive task result in a diminished postural control? The literature doesn’t explain the inflexion point explicitly at which cognitive demands create enough difficulty to diminish postural control (Legrand et al., 2013).

– **The task prioritization model** is an another common idea which explains dual-task paradigm. Since there is a limited attentional source, postural task is often prioritized over the cognitive task. This behavior is widely observed in elderly population rather than young population. Elderly subjects tend to preserve their postural stance when confronted with a secondary task (Lacour, Bernard-Demanze, & Dumitrescu, 2008).

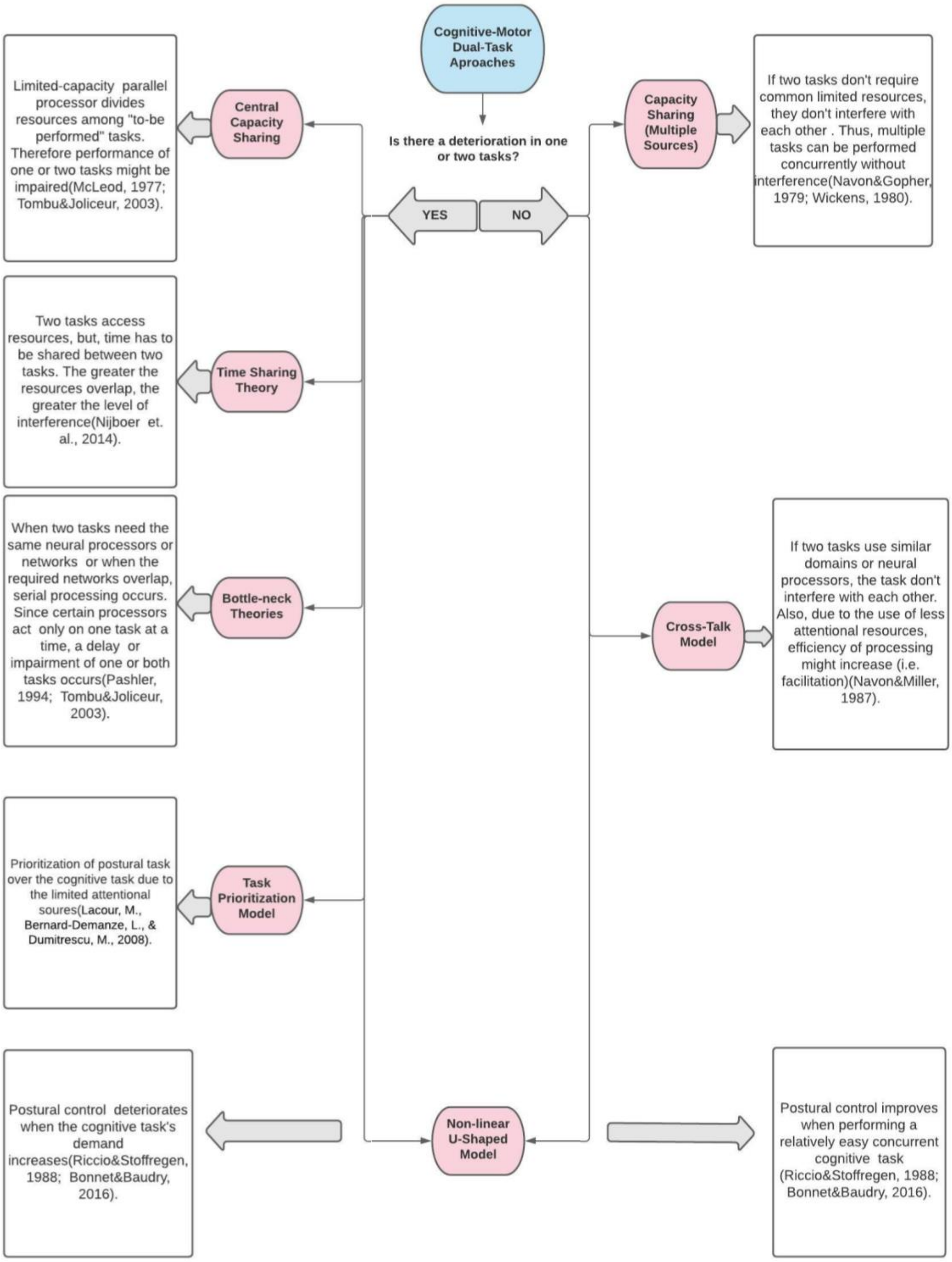


Figure 2.4. Proposed mechanisms to explain dual-task paradigm for concurrent "cognitive and motor" dual-task performances

2.3.2. Interference in Postural Task Under Dual Task Conditions

Dault et. al. (2001) examined the postural control in dual-task conditions. 24 healthy individuals, 12 males and 12 females (aged between 20-40 years) participated in the study. The individuals who have highly developed balance skills (more than average) were excluded from the study. The varying difficulty levels for cognitive task were added to increase attentional interference. As a cognitive task, Stroop task was chosen and modified using three shortened versions with 25 items including word card, color card, and the word-color card. Each version of the Stroop task was expected to last in 22 seconds. Postural stance difficulty was also modified, and seesaws were utilized to create difficulty. Three types of postural task were established and performed on a force plate: Task-1) shoulder-width stance, Posture Task-2) shoulder-width stance while each foot placed on two individual seesaws, and Task-3) tandem stance on the seesaw. Three different postural tasks and four different cognitive tasks (in total 12 different combination including no task situation) were presented to the participants in a random order. According to the results, there was a slight effect of cognitive task on Posture 1. This was interpreted as the decreased attentional requirement for Task 1 as a very-well learned task. However, cognitive tasks led to a deterioration in the postural tasks which were performed on seesaws (Task 2 and 3), especially in tandem stance. Increased level of postural task difficulty resulted in reduced postural stability in frontal plane, like the addition of cognitive tasks with increasing difficulty levels. These results can be interpreted as quiet stance requires a very little attention; thus, addition of a concurrent cognitive task doesn't make a considerable interference. However, since the more challenging postural tasks were considerably more attention demanding, addition of a concurrent cognitive task had a detrimental effect on postural control.

Another study addressed the dual-task paradigm by comparing the young and older adults (Bergamin et al., 2014). Thirty young adults (15 men and women, aged between 18 to 28 years) and 30 older adults (15 men and women older than 64 years) were recruited. Individuals who have health problems or physical limitations were excluded from the study. Different types of cognitive tasks were introduced during Romberg test, a single postural task, in which the participants were required to stand with their eyes open and feet together. Cognitive tasks involved spatial-memory brooks test (SMBT), counting backwards aloud test (CBAT), and mental arithmetic task (MAT). The velocity of Center of pressure (COP), sway area, anterio-posterior and medio-lateral oscillations as extents of postural sway were measured. Results indicated that the types of cognitive tasks differently affected postural sway variables regardless of age, inducing an increase in CBAT, and a decrease in SMBT and in MAT in COP velocity and sway area.

Ceyte et al. (2014) examined the influence of visual cues and the stability of support surface on body sway during a cognitive task on 71 healthy young adults (36 women and 35 men: mean age = 24.1 ± 2.5 years). The participants performed Sensory Organization Test with and without the presence of cognitive task. Each dual task was repeated for three visual conditions (V—vision, NV—no vision, MV—moving visual surround) and two support conditions (fixed or moving support surface). Cognitive task involved two versions of MAT with two difficulty levels as backward counting by three or thirteen. When visual cues were available, addition of MAT resulted in an increase in body sway during quiet stance. Also, a similar effect on body sway parameters were observed during standing on an unstable support surface. Furthermore, there was no significant difference in body sway parameters between the two calculation tasks independently from the visual context and the stability of the support surface. The authors ground these findings by the theory of limited attentional capacity. This theory postulates that postural control and simultaneous cognitive activities compete for a limited capacity of central processing resources, thus, performing a postural and a cognitive task together generate a “double-task” instead of a “dual-task”.

Taesdela et al. (2001) examined how the integration of sensory information perturbs postural stability and whether it requires additional attentional demand within the scope of dual-task paradigm. Eight healthy young (5 men and 3 women, mean age: 24.8 years) and eight healthy elderly (6 men and 2 women, mean age: 68 years) subjects performed a postural task on a force platform with and without a secondary cognitive task. The postural task involved three conditions: 1) the reinsertion of proprioceptive information when vision is available, 2) the reinsertion of proprioceptive information when vision is absent, and 3) the reinsertion of vision when proprioception is perturbed. Secondary task was a probe-reaction time (P-RT) task at which participants were instructed to respond verbally "top" as quickly as possible to the unpredictable auditory stimulus presented before or after a sensory reintegration and in control conditions. Attentional demands for the postural system were evaluated by using the reaction times to the auditory stimuli. Results indicated that in both vision and no-vision conditions reintegration of proprioception resulted in a faster COP velocity for both young and elderly, and this effect was more significant in elderly. When vision was not available, attentional demands increased for both groups, while reintegrating the proprioceptive information.

Another study is undertaken by Pellecchia (2003) to understand the effect of difficulty of the cognitive dual-task on postural control. 20 healthy subjects (10 men and 10 women, aged between 18-30 years) performed three different cognitive tasks; 1) digit reversal, 2) 2-bit classification, and 3) counting backwards by three. A 10 cm dense foam pad was placed on the force platform in order to create a more compliant surface to eliminate low task difficulty to limit possible interference effect. Results demonstrated that an increased postural sway during standing was observed as the difficulty of cognitive task increased. This finding is in line with the capacity theory of attention. According to this theory, the requirements of information processing increase as the difficulty level of a cognitive task increases.

Thus, task integration becomes more challenging when the secondary task is more attention demanding (Pellecchia, 2003).

2.3.3. Facilitation of Postural Control Under Dual-Task Conditions

Donker et al. (2007) examined the influence of focus of attention on the dynamical structures of postural control and recruited 30 healthy young adults (10 men and 20 women: age between 19–30 years). It was hypothesized that i) an increase in cognitive involvement would result in an increase in COP regularity, and ii) directing attention away from the postural control would result in a decreased COP regularity. In order to test these hypothesis, four different experimental conditions were presented: 1) upright stance with eyes open (EO-ST), 2) upright stance with eyes closed (EC-ST), 3) upright stance with eyes open while performing a dual task (EO-DT) and 4) upright stance with eyes closed while performing a dual task (EC-DT). These conditions were performed in a random order and once in reverse order by each participant. COP dynamics were quantified in terms of sample entropy (regularity), standard deviation (variability), sway-path length of the normalized posturogram (curviness), largest Lyapunov exponent (local stability), correlation dimension (dimensionality) and scaling exponent (scaling behavior). The cognitive task involved reading a word backward (e.g., ‘‘Simon’’ had to be read as ‘‘nomis’’). As hypothesized, COP regularity significantly increased during standing with eyes closed, standing with eyes open resulted in less COP irregularity and smaller variability. These findings suggested that the amount of attention directed to postural control was positively correlated with sway regularity. Standing with eyes-closed led to an increase in COP regularity. However, performing a cognitive task while standing with eyes-closed resulted in greater COP irregularity and smaller variability as observed in standing with eyes open condition. The authors explained this finding with the increase of automaticity of postural control when a cognitive task is presented additionally.

Polskaia and Lajoie (2016) investigated the cognitive task demand and the postural control. 17 young adults (mean age: 23.71 ± 1.99 years) were asked to stand upright on a force platform and perform concurrent cognitive tasks (visual and auditory) at three different difficulty levels, as easy, moderate, and difficult. Visual task was counting the occurrence of one or two numbers. Auditory task was counting the occurrence of the letters and repeating a string of words. The increase in cognitive task difficulty resulted in reduction in 95% confidence ellipse area and ML sway variability. However, there was a difference between the effects of visual and auditory task. While auditory task led to an increase in COP irregularity, the visual task led to a decrease in ML sway variability. These results explained by the view that withdrawing attention away from the postural control facilitates the automatic control processes.

In a study, authors (Swan, Otani, & Loubert, 2007) investigated dual-task condition by modifying difficulty level of the cognitive tasks as well as the balance requirements of the postural task. Due to the differences in stabilizing COP location between genders, 98 healthy and women-only participants (aged between 18-27 years) were recruited in the study. The difficulty levels of motor task included 1) standing with feet together (Easy), 2) standing with feet together with the stimulation of concurrent vibration of the bilateral gastrocnemius muscles (medium), and 3) tandem stance (difficult). Brooks working memory task with spatial and nonsense sequences were chosen as the cognitive task. In the spatial Brooks' task, participants were instructed to listen to a series of sentences in which the location of numbers in a 4x4 grid were described. In the nonsense part of the Brooks' task, the words of direction: right, left, up, and down were replaced with good, bad, quick, and slow. The Brooks' tasks were modified to have two levels of difficulty. Postural tasks were performed either concurrently with Brooks' tasks or without a cognitive task. As a result, performing a difficult cognitive task concurrently with motor task led to a decrease in postural sway regardless from the difficulty of postural task. This is explained by the consequence of directing attention away from the postural balance. Thus, an individual becomes less responsive to the balance-related cues and prevents over corrections (Swan, Otani, & Loubert, 2007).

Batistela et al. (2019) examined the effects of cognitive task on postural task performance in combination with haptic information. Cognitive tasks involved; 1) control, 2) visual-Stroop task, and 3) auditory digit-monitoring while postural task involved standing upright with the feet shoulder width apart on a wood balance beam placed on a force platform 1) with the use of anchors, 2) without the use of anchors. Twenty healthy young adults (10 male and 10 females; aged between 24.0 ± 3.0 years participated in the study. They performed three trials of six experimental conditions each one lasting 40 s, with minute rest period between trials. Results demonstrated that not only the use of anchors but also the cognitive tasks individually reduced COP ellipse area. The positive effect of anchor use on postural control was explained as the presence of haptic information provided by the tactile receptors. Thus, postural orientation was improved with the additional sensory information. There was no significant difference between the effects of auditory and visual cognitive tasks on postural sway. There was no correlation between the effects of anchors and the cognitive task on sway parameters. Even during the execution of a challenging postural task, cognitive tasks reduced the postural sway possibly by facilitating functional integration.

Lajoie et al. (2017) investigated the effect of discrete and continuous cognitive tasks in older adults. Twenty heathy older adults (4 men and 16 women; mean age: 69.9 ± 3.5 years) participated in the study. They performed postural task which consisted of standing still on the force platform with feet together. In addition to the postural task, participants were asked to perform a total of four cognitive tasks, including two discrete and two continuous tasks. Discrete cognitive tasks involved a single reaction task (SRT) and go/no-go reaction time (GO/NG) task. The continuous cognitive tasks involved the sequence and equation tasks. SRT task and sequence task was designed to be “easy” tasks, whereas GO/NG task and equation task designed to be “challenging”. Each trial lasted 60 sec and were repeated for each condition in random order. According to the results, there was a significant decrease in sway amplitude and sway variability while performing challenging discrete and continuous cognitive tasks in comparison to a standing only task. The finding of no significant differences between standing only and simple discrete tasks is likely to be attributed to the simplicity of the task. These results suggest that a challenging discrete and continuous task were enough to direct attention away from the postural control. Furthermore, SRT task had no effect on sway parameters, the attention is likely to be intermittently drown away from the postural control. It can be concluded that the type and level of the difficulty of cognitive tasks differently affect postural control in elderly adults.

The existing literature was reviewed and elaborated by focusing on postural control mechanisms, attention theories and dual-task paradigm. Postural control mechanisms highlight the interactions among biomechanical and musculoskeletal properties, as well as the function of peripheral and CNS. Human upright stance is inherently unstable and requires the continuous feedback from the sensory system. In this mechanism, CNS interprets the changing information from both internal and external sources and regulates the motor task accordingly (Hwang, Agada, Kiemel, & Jeka, 2016; Maki & Mcllroy, 2007). Since, the literature review indicates a discrepancy in findings about the underlying mechanism of postural control, it brings about two main questions; 1) whether the postural control is a result of automatic processes entirely or 2) does consciousness play a role in postural control processes? Several theories on attention allocation are linked to the postural control mechanisms to understand the underlying mechanisms. At this point, dual-task paradigm arises which is broadly defined as the concurrent performance of two or more tasks. While performing multiple tasks simultaneously, interference, facilitation, or none of both might occur in one or both tasks. However, the level of difficulty and the nature of each task are both crucial for the possible interference, facilitation, or no response effect. This study is, therefore, concerned with the understanding the role of secondary cognitive task difficulty on postural control within the dual-task paradigm.

On the other hand, effect of light touch (LT) condition was discussed in relation with the input from the sensory system. LT condition was provided by the contact of the index finger with a load cell on a stationary surface while force did not exceed ± 1 N. Thus, it allowed an additional somatosensory cue through the cutaneous receptors, without acting as a mechanical support. It has been reported in several studies that slightly touching on a stable surface is effective in the attenuation of postural control. The effectiveness of LT was proven to have positive effects on postural control in diverse populations (Chen & Tsai, 2015; Chen & Tsai, 2016; Gomes & Barela, 2007; Dickstein, Shupert, & Horak, 2001; Kanekar & Aruin, 2014).

Another issue that this study investigates is the changes in postural control during the simultaneous execution of cognitive task and light touch during. Few studies investigated the combined effects of light touch and cognitive task above mentioned. However, there are not many studies in literature adopting dual-task paradigm and light finger touch in combination. The studies undertaken mostly investigated the same type of cognitive task models (visual search accuracy /or counting backwards) without noticing the cognitive task difficulty. Therefore, this study aims to contribute to the literature by adjusting difficulty levels of cognitive task in combination with light touch.

CHAPTER III

METHOD

3.1. Subjects

18 voluntary participants were included as listed below in Table 1 (mean age: 29.33±5.20 years; mean height: 172.81±7.16 cm; mean weight: 73.26±11.04 kg). Age limit was set between 18-40. 10 men and 8 women took place in the experiments (see Table 3.1). The sample size was chosen based on an estimated effect size of 0.31, which was averaged from three similar studies [0.42 (Lee, 2018), 0.31 (Dos Santos et al., 2019) and 0.43 (Chen, Chu, Pan, & Tsai, 2018). Using G*Power software (GPower 3.1), an estimated sample size of 18 people was recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.8. Ethical approval was obtained from the Research and Ethics Committee of Middle East Technical University and subjects gave written consent before participation. The study's data was collected in NMLab in Hacettepe University Department of Biomechanics and Motor Control.

3.2. Data Collection Procedures and Apparatus

While subjects performed cognitive test (visual-verbal Stroop tests in pre-determined random sequences and in different difficulties) with or without light touch, they stood in quiet stance on a force plate to perform postural task. A customized data collection software was prepared in LabVIEW (version 7.1, National Instruments Corporation, Austin, TX) to simultaneously perform the following experimental processes; 1) measurement, monitoring and recording force plate data 2) randomized presentation of cognitive test via computer screen, 3) measurement, monitoring and recording pressure data during light touch with index finger (when available). Stored data were used for post-processing in MATLAB (The MathWorks, Inc). The measurement methods and analyzed parameters were explained in detail below.

Table 3.1. Descriptive Statistics of Participants

Subject Number	Age (Years)	Height (cm)	Weight (kg)
1	34	182,5	90,4
2	34	156,5	47
3	32	169	61
4	31	175	83,5
5	29	167	79,5
6	35	180	81
7	29	172	70
8	25	172,5	72,5
9	31	177	70,5
10	29	171	79
11	33	179	84,5
12	29	166,5	63,5
13	21	179	67,5
14	40	184	88,5
15	21	169	74
16	21	160,5	59,5
17	31	178	81,5
18	23	172	65,3
Mean	29.33	172.81	73.26
Standard Deviation	5.20	7.16	11.04

3.2.1. Measurement of Ground Reaction Forces

Ground reaction forces in 3 orthogonal axis (Fx, Fy, Fz) and moments (Mx, My, Mz) were measured via a Force Plate (AMTI OR-6-7) (Figure 3.1). The data were acquired for 50 sec at a sampling rate of 2000 Hz by using DAQ card (NI, USB-6225 Mass Termination) which was connected to a PC. Before each trial, force plate data was demeaned to ensure that the data had a zero drift. The amplified, digitized data were monitored and recorded using customized data collection software LabVIEW and stored for further post processing in MATLAB.

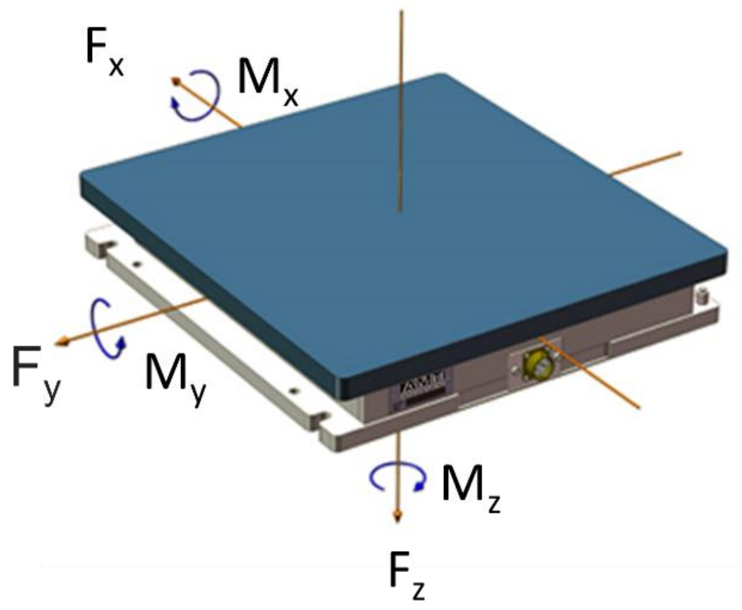


Figure 3.1. 6-dof force plate

3.2.2. Analysis of Sway Parameters During Quite Stance

COP positions were calculated from the relevant forces and moments (collected from the force plate) by using below formula, where h is the height of the sensor over the force plate (h = 4.1 cm).

$$COPx = -(My + Fx \bullet h) / Fz$$

$$COPy = (Mx - Fy \bullet h) / Fz$$

(Formula 1)

Data corresponding to the first 10 sec of the 50-sec trials were discarded to avoid adaptation transients related to the initiation of the trial (Carpenter, Frank, Winter, & Peysar, 2001), leaving 40 sec for further analysis. The mean value was subtracted from each time series and the second order low pass Butterworth filter with a cut-off frequency of 10 Hz was used for filtering the COP.

Postural sway was investigated through calculating COP Velocity (COP_{VEL}), COP Ellipse Area ((COP_{EA}), root mean square (rms) values in Anterio-Posterior (rms_{AP}) and Medio-Lateral (rms_{ML}) directions and COP Range in AP (COPrange AP) and ML (COPrange ML) for each trial (Carpenter, Frank, Winter, & Peysar, 2001).

Overview of the calculation of the postural sway parameters were summarized below.

- COP velocity: sway-path normalized to signal duration.
- COP ellipse area: the area of the exact 95% prediction ellipse (Marcos & Watanabe, 2021; Duarte, 2015)
- COP range: maximal deviation of COP in AP and ML directions.
- Rms COP: root mean square COP displacement relative to the mean COP location.

3.3. Dual Task Configurations: Cognitive and Postural Tasks

3.3.1. Cognitive Tasks and Difficulty Levels

A modified visual-verbal Stroop tests with congruent and incongruent stimuli was chosen as the cognitive task with two levels of difficulty (easy and difficult). Subjects performed 50-s visual-verbal Stroop tests with 20 events of congruent and incongruent color words. The time interval between the word colors was set between 0.8 s to 1.2 s randomly. The visual-verbal Stroop test has four different colors including "BLUE", "YELLOW", "RED", and "GREEN" written by capital letters in Turkish language. The easy part of the Stroop Test includes congruent color words, whereas the difficult part of the Stroop Test includes incongruent color words (e.g., the word "BLUE" presented in green letters). Participants had to name the color of the font verbally in which the words were written but not the actual word written by the letters. For instance, when the word of "RED" presented in yellow letters, the true answer should be "YELLOW".

In both easy and difficult cognitive tasks, there were 6 different versions of Stroop test to avoid any learning effect. The first version was used to introduce the test during a familiarization trial to be make sure that the test was understood correctly by the participant. The following three versions were designed to be used during the experimental trials. The remaining two versions were designed to be used in case the test had to be repeated.

3.3.2. Motor Tasks

Motor task configurations involved a postural task by performing Quiet Stance (QS) trials with and without Light Touch (LT).

During the QS task the subject was required to maintain a quiet, comfortable upright position whilst standing barefoot on the force platform, with the lower limbs are aligned in parallel about shoulder width apart and arms kept hanging comfortably at their sides.

LT task required subjects to maintain QS while merely touching with index finger of the preferred arm to a flat instrumented surface. Subject kept one arm relaxed with 90° elbow angle. Their forearm was in prone position with the index finger extended and the other fingers were flexed while touching the load cell affixed on a wooden plate. The plate mounted top of a tripod could be adjusted in height and position to allow subjects to keep the requested and comfortable arm position while touching its surface with their index finger.

The load cell signals were amplified and calibrated in units of force (Newtons) and triggered visual feedback to let the researcher terminate the trial when an adjusted threshold force of 1N was reached. Load cell signals were digitized in real time with a data acquisition board and simultaneously recorded with force plate data.

Both postural task conditions (QS only and QS+LT) were performed with and without Easy or Difficult cognitive tasks. The eyes were open during the trials. The visual stimuli were presented via computer screen placed at the eye level at a distance of 2-m from the center of the force plate.

3.3.3. Experimental Tasks: Single and Dual Tasks

Postural tasks were performed separately both with and without the cognitive tasks. The order of the six experimental conditions were randomized for each subject. Experimental conditions consisted of (see Table 3.2):

<u>Single Tasks (motor tasks only):</u>

- QS: Quiet Stance
- QS+LT: Quiet Stance + Light Touch

Dual Tasks (combined motor and cognitive tasks):

- QS with ECT: Quiet Stance with Easy Cognitive Task,
- QS with DCT: Quiet Stance with Difficult Cognitive Task,
- QS+LT with ECT: Quiet Stance + Light Touch with Easy Cognitive Task
- QS+LT with DCT: Quiet Stance + Light Touch with Difficult Cognitive Task

All task trials repeated in a random order until the subject successfully completed three trials per each task.

The test was repeated if one of the following criteria was met; i) if the subject failed to name the words over two consecutive times during a trial, ii) if finger force exceeded threshold value, if) if the posture was not held constant during the trials. Each subject completed 18 trials and none of the subject had to repeat the test. The trials were observed and recorded by the video camera in order to calculate the number of correct answers precisely after the experiments. There was a 1-minute rest between each trial to assume to eliminate the effect of fatigue.

Table 3.2. Description of Experimental Procedures

Factor	*Light Touch (No LT/LT)*	*Cognitive Task Difficulty (None/Easy/Difficult)*
Level 1	No LT	None
Level 2	No LT	Easy
Level 3	No LT	Difficult
Level 4	LT	None
Level 5	LT	Easy
Level 6	LT	Difficult

3.4. Experimental Protocols

Postural tasks were performed separately with or without the cognitive tasks. The order of the six experimental conditions were randomized differently for each subject. Experimental protocols consisted of Quiet Stance (QS), Light Touch (LT), Quiet Stance and Easy Cognitive Task (QS and ECT), Quiet Stance and Difficult Cognitive Task (QS and DCT), Light Touch and Easy Cognitive Task (LT and ECT), and Light Touch and Difficult Cognitive Task (LT and DCT).

All experiments were executed with eyes open and repeated in a random order until the subject successfully completed three trials per each task. The trials were recorded by the video camera in order to calculate the number of correct answers precisely after the experiments. There was a 1-minute rest between trials to eliminate the effect of fatigue.

3.4.1. Protocol 1: Single Task (Quiet Stance Only)

Quiet Stance (QS) experiment was performed with three repetitions. Quiet Stance (QS) measures without Cognitive Task (CT) and Light Touch (LT) were taken to form a baseline for the other conditions. The participants stood still on the force platform with feet shoulder wide open and were instructed to flex their both elbows to the 90° in the prone position, extend their index finger and flex the other four fingers as if they were touching a metal surface. This position was chosen as same as in the Light Touch (LT) to provide the same postural stance and the body symmetry.

3.4.2. Protocol 2: Dual Task (Quiet Stance and Cognitive Task Trials)

Cognitive Task (CT) trials were performed separately for both difficulty levels with and without the Light Touch (LT) conditions. Each experiment lasted 40s and the series of the cognitive tasks were chosen with a random order. Each trial was completed after three successful repetitions.

3.4.3. Protocol 3: Light Touch Trials (Quiet Stance with/without Cognitive Task)

Light Touch (LT) trials were performed with and without Cognitive Task (CT). Each experiment lasted 40 sec and after three successful repetitions a trial was completed.

Figure 3.2. Experimental Set-Up

3.5. Statistical Analysis

In order to link findings to the research questions, a number of analyses were performed to examine interactions among quite stance, light touch and cognitive tasks with different difficulty. Six COP measures determined as dependent variables were: COP mean velocity (COP_{VEL}), COP ellipse area (COP_{EA}), COP range (COPrange AP and COPrange ML), rms COP values in AP (rms_{AP}) and ML (rms_{ML}) directions. All

COP measures were calculated for each trial. Difficulty Levels of Cognitive Task (3 levels; none, easy, difficult) and presence of Light Touch (two levels; yes, no) were included as factors. Each entry corresponds to an average of three identical trials to eliminate the effect of within-subject inter trial variability. The alpha level of significance was set to $p<0.05$. Since all subjects were measured multiple times for the same factors, a within-subjects design (two-way repeated measures ANOVA) was conducted for each COP parameter, separately.

The main assumptions underlying two-way repeated measures ANOVA were met; 1) one dependent variable that is measured at continuous level (all COP parameters are measured at continuous level); 2) presence of two within-subject factors (cognitive task & light touch); 3) no significant outliers (no significant outliers in any combination of levels of the two within-subjects factors); 4) normal distribution (the dependent variable is normally distributed in the population for each level of the within subjects factor); 5) sphericity (variance of the differences between any levels of a within-participants factors are equal across all the groups in the population).

CHAPTER IV

RESULTS

The purpose of this thesis was to investigate the individual and combined effects of light touch and cognitive task difficulty on postural control. The current chapter presents detailed information about the results of this thesis in two sections. In the first section, descriptive statistics are presented; in the second section, main findings are presented under three categories (cognitive task + light touch interaction, the main effects of cognitive task, and the main effects of light touch, respectively) in relation with the hypotheses.

4.1. Descriptive Statistics

In the experiment, 18 voluntary participants (10 males & 8 females) aged between 18-40 years were included. The sample size was chosen based on an estimated effect size of 0.31, which was averaged from three similar studies [0.42 (Lee, 2018), 0.31 (Dos Santos et al., Combined effects of the light touch and cognitive task affect the components of postural sway, 2019) and 0.43 (Chen, Chu, Pan, & Tsai, 2018). Using G*Power software (GPower 3.1), an estimated sample size of 18 participants were recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.8.

Participants performed six experimental conditions consecutively in a randomized order: (1) No Cognitive Task + No Light Touch, (2) Easy Cognitive Task + No Light Touch, (3) Difficult Cognitive Task + No Light Touch, (4) No Cognitive Task + Light

Touch, (5) Easy Cognitive Task + Light Touch, (6) Difficult Cognitive Task + Light Touch. Each experiment consisted of three trials, and the average value of the three trials was considered. The means and standard deviations of six experimental conditions are presented in table below (Table 4.1).

Table 4.1. The means and SD of COP Parameters in Light Touch (LT) and No Light Touch (No LT) Conditions

COP Parameters		**No Cognitive Task**		**Easy Cognitive Task**		**Difficult Cognitive Task**	
		Mean	SD (±)	Mean	SD (±)	Mean	SD (±)
LT	COP_{EA}	10.70	.717	16.15	.803	17.03	.71
	COPVEL	4.92	1.21	5.08	1.34	5.31	1.22
	COPrange AP	11.24	3.80	10.16	3.38	9.74	2.36
	COPrange ML	7.62	1.77	6.61	1.76	6.96	2.60
	RMSAP	2.32	.83	2.00	.63	1.81	.40
	RMSML	1.59	.42	1.36	.42	1.46	.62
No LT	COP_{EA}	22.54	1.50	17.45	.996	16.60	.61
	COPVEL	6.81	1.66	6.50	1.29	6.71	1.30
	COPrange AP	22.54	6.37	17.46	4.23	16.60	2.58
	COPrange ML	10.48	3.53	8.38	2.57	8.91	3.60
	RMSAP	4.89	1.57	3.50	.81	3.24	.55
	RMSML	2.12	.77	1.67	.59	1.66	.65

4.2. Main Findings

Two-way repeated measures ANOVA were run to determine the effect of light touch and cognitive task difficulty on six COP measures (COP ellipse area, COP mean velocity, COP range in AP direction, COP range in ML direction, COP rms in AP direction, COP rms in ML direction). Analysis of the studentized residuals showed that there was normality, as assessed by the Shapiro-Wilk test of normality and no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations for all five two way repeated-measures ANOVA. Cognitive task x Light touch interaction was found in four COP parameters (COP range AP, COP range ML, COP rms AP, COP rms ML). The findings of interaction are presented table below (see Table 4.2).

Table 4.2. Repeated measures Analysis of Variance for CT x LT Interaction

COP Parameters	*SS*	*df*	*MS*	*F*	*p*	η^2
COPVEL	10.410	1.718	6.058	6.225	.008	.268
COPrange AP	1137.75	1.630	697.79	76.586	‹.001	.489
COPrange ML	94.038	2	47.019	14.252	‹.001	.456
RMSAP	67.987	17.000	52.603	75.295	‹.001	.816
RMSML	3.912	2	1.956	11.226	‹.001	.398

4.2.1. Cognitive Task x Light Touch Interaction

COP Mean Velocity: Mauchly's test of Sphericity indicated that the assumption of sphericity has been violated, Mauchly's W=.431, $\chi^2(2) = 13.454$, $p < .05$. Hence, the sphericity violations were corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between light touch and cognitive task on COP mean velocity, $F\,(1.275, 21.675) = .937$, $p = .367$, partial $\eta^2 = .052$ (see Figure 4.1 and Table 4.3). Therefore, main effects were run.

Table 4.3. Repeated measures Analysis of Variance for Cognitive Task (CT) x Light Touch (LT) Interaction and Main Effects of CT and LT for COP Mean Velocity

COP range AP	*SS*	*df*	*MS*	*F*	p	η^2
CT x LT	1.435	1.275	1.126	.937	.367	.052
CT	.876	1.629	.537	.555	.545	.032
LT	66.357	1	66.357	78.959	<.001	.823

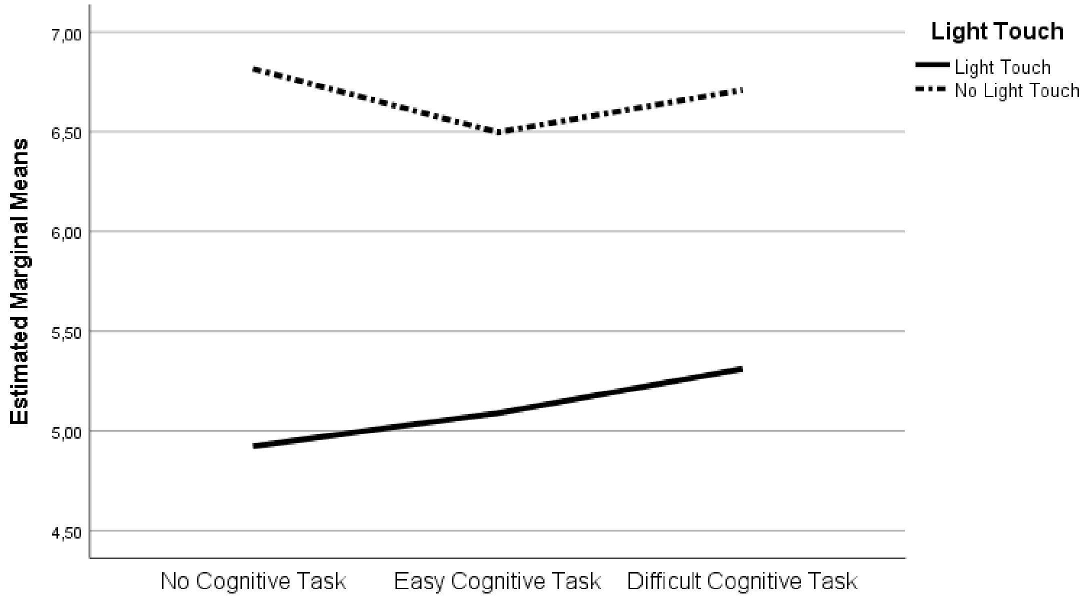


Figure 4.1. Interaction Graph for COP Mean Velocity

<u>COP Ellipse Area:</u> Mauchly's test of Sphericity indicated that the assumption of sphericity has been violated, Mauchly's W=.679, $\chi2(2) = 6.197$, $p < .05$. Therefore, the sphericity violations were corrected by the Huynh-Feldt estimation. There was a statistically significant interaction due to the cognitive task difficulty between light touch and cognitive task on COP ellipse area, F (1.630, 27.718) = 76.586, p <.001, partial η2=.818 (see Figure 4.2 & Table 4.4). Therefore, simple main effects were run.

Table 4.4. Repeated Measures Analysis of Variance for Cognitive Task (CT) x Light Touch (LT) Interaction and Simple Main Effects of CT and LT for COP Ellipse Area

	COP rms ML	*SS*	*df*	*MS*	*F*	*p*	η^2
Interaction	CT x LT	1137.74	1.275	1.13	76.586	<.001	.818
Simple Main Effects of Cognitive Task	No LT	371.80	1.302	285.47	11.198	.002	.397
	LT	21.64	2	10.82	2.183	.128	.114
Simple Main Effect of Light Touch	No CT	1148.54	1	1148.54	39.018	<.001	.697
	Easy CT	478.98	1	478.98	74.091	<.001	.813
	Difficult CT	422.72	1	422.72	84.875	<.001	.833

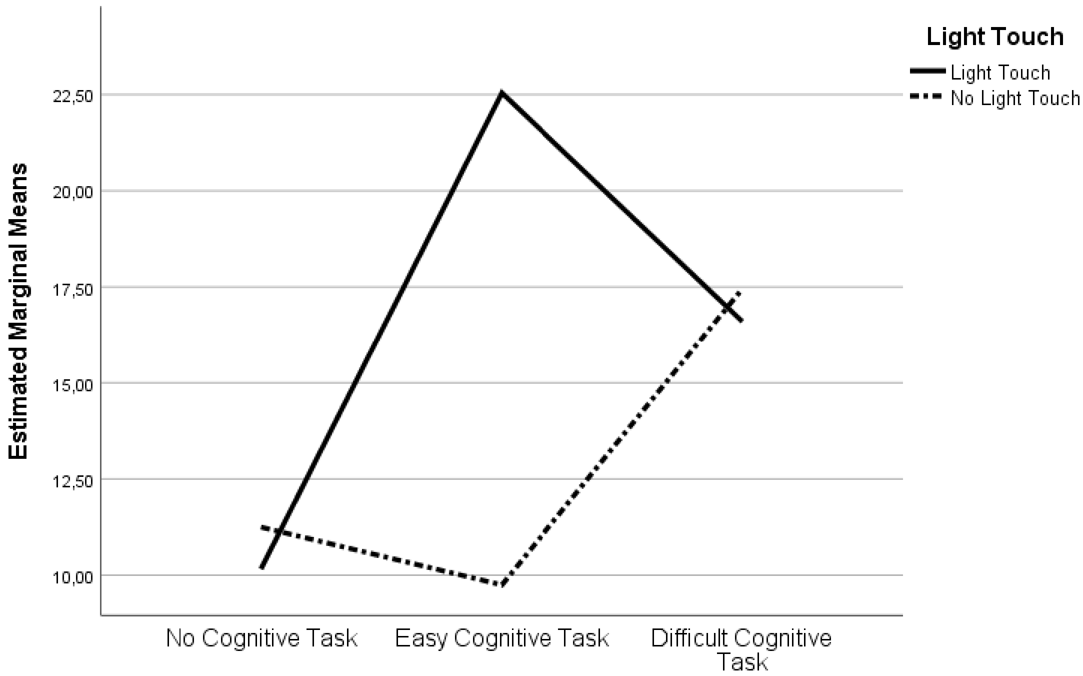


Figure 4.2. Interaction Graph for COP Ellipse Area

<u>COP Range in AP Direction;</u> Mauchly's test of Sphericity indicated that sphericity assumption has been violated, Mauchlys W=.414, $\chi^2(2) = 14.122$, $p < .05$. Sphericity

violations were corrected by Greenhouse-Geisser estimation. There was a statistically significant interaction due to cognitive task difficulty between light touch & cognitive task on COP range in AP direction F (1.261, 21.433) = 4.129, p = .047, partial η^2 =.195 (see Figure 4.3 & Table 4.5). Hence, simple main effects were run.

Table 4.5. Repeated Measures Analysis of Variance for Cognitive Task (CT) x Light Touch (LT) Interaction & Simple Main Effects of CT & LT for COP Range in AP Direction

Interaction	COP range AP	*SS*	*df*	*MS*	*F*	p	η^2
	CT x LT	107.85	1.315	82.03	4.129	.044	.195
Simple Main Effects of Cognitive Task	No LT	371.80	1.302	285.47	11.198	.002	.397
	LT	21.64	2	10.82	2.183	.128	.114
Simple Main Effect of Light Touch	No CT	1148.54	1	1148.54	39.018	‹.001	.697
	Easy CT	109.90	1	478.98	74.091	‹.001	.813
	Difficult CT	422.72	1	422.72	84.875	‹.001	.833

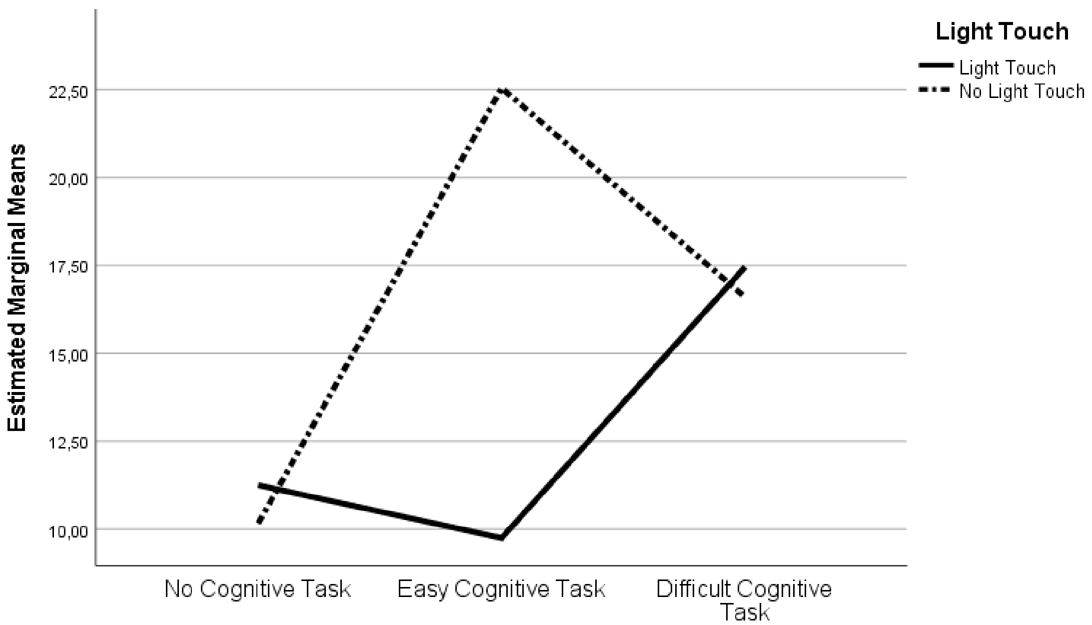


Figure 4.3. Interaction Graph for Range in AP Direction

COP Range in ML Direction: Mauchly's test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, Mauchlys W=.853, $\chi^2(2) = 2.540$, p=.281. There was a statistically significant interaction between light touch and cognitive task on COP range in ML direction due to the cognitive task difficulty, F (2, 34) = 14.452, p <.001, partial η^2 =.456 (see Figure 4.4 & Table 4.6). Therefore, simple main effects were run.

Table 4.6. Repeated Measures Analysis of Variance for CT x LT Interaction and Simple Main Effects Simple Main Effects of CT and LT for COP Range in ML Direction

Interaction	COP range ML	*SS*	*df*	*MS*	*F*	*p*	η^2
	CT x LT	94.038	2	47.019	14.252	<.001	.456
Simple Main Effects of Cognitive Task	No LT	371.80	1.302	285.47	11.198	.002	397
	LT	21.641	2	10.820	2.183	.128	.114
Simple Main Effect of Light Touch	No CT	73.884	1	73.884	15.267	.001	.473
	Easy CT	28.025	1	28.085	10.572	.005	.383
	Difficult CT	33.107	1	33.107	5.714	.029	.252

COP RMS in AP Direction: Mauchly's test of Sphericity indicated that the assumption of sphericity has been violated, Mauchlys W=.679, $\chi^2(2) = 6.197$, p <.05. Hence, the sphericity violations were corrected by the Huynh-Feldt estimation. There was a statistically significant interaction between light touch and cognitive task on COP rms in AP direction due to the cognitive task difficulty F (1.630, 27.718) = 76.586, p =<.001, partial η^2 =.818 (see Figure 4.5 & Table 4.7). Therefore, simple main effects were run.

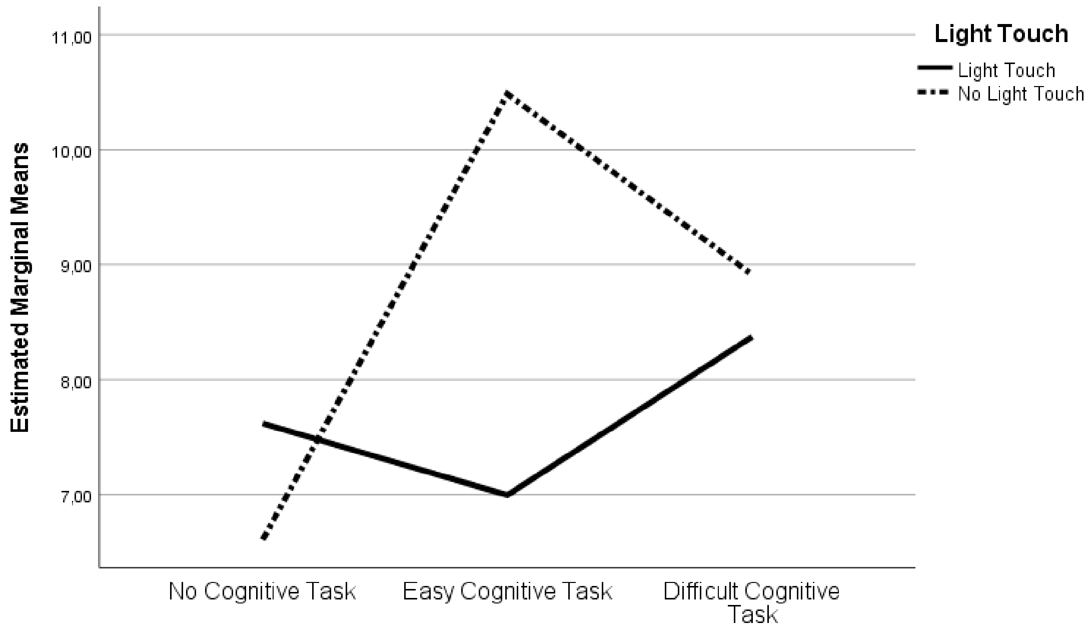


Figure 4.4. Interaction Graph for COP Range in ML Direction

Table 4.7. Repeated measures Analysis of Variance for CT x LT Interaction and Simple Main Effects of CT and LT for COP Rms in AP Direction

Interaction	COP rms AP	*SS*	*Df*	*MS*	*F*	*P*	η^2
	CT x LT	1137.74	1.630	697.792	76.586	<.001	.818
Simple Main Effects of Cognitive Task	No LT	371.80	1.302	285.47	11.198	.002	.397
	LT	21.641	2	10.820	2.183	.128	.114
Simple Main Effect of Light Touch	No CT	59.235	1	59.235	41.115	<.001	.707
	Easy CT	19.940	1	19.940	60.634	<.001	.781
	Difficult CT	18.377	1	18.377	91.716	<.001	

<u>COP RMS in ML Direction</u>**:** Mauchly's test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, Mauchly’s W=.853, χ2(2) = 2.540, p=.281. There was a statistically significant interaction between light touch and cognitive task on COP rms in ML direction due to the cognitive task difficulty, F

(2, 34) = 14.252, p <.001, partial η2 =.456 (see Figure 4.6 and Table 4.8). Therefore, simple main effects were run.

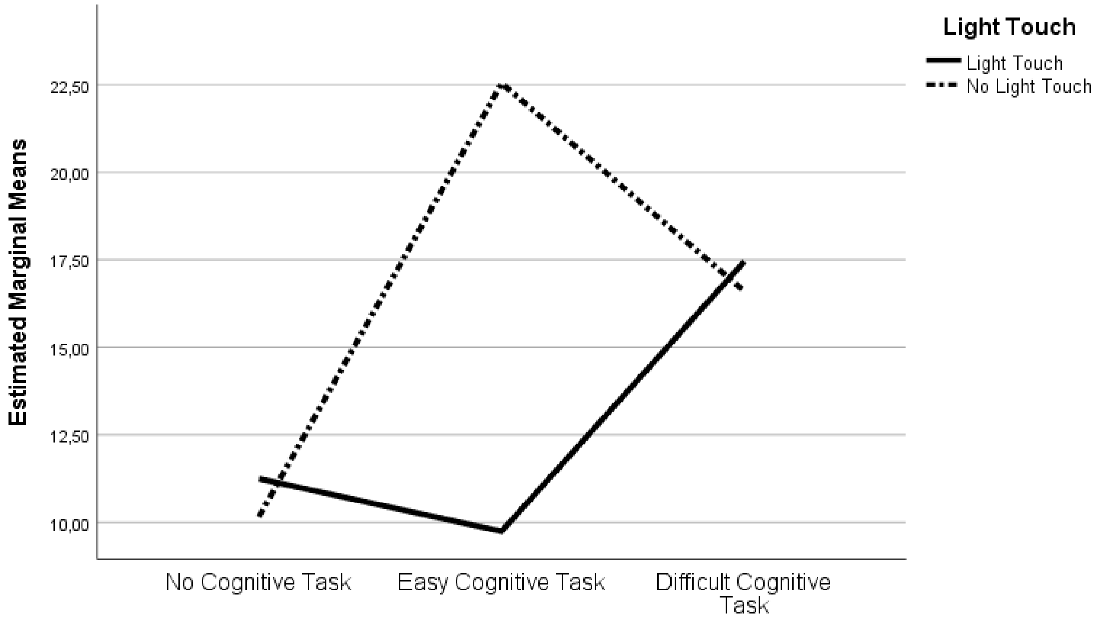


Figure 4.5. Interaction Graph for COP RMS in AP Direction

Table 4.8. Repeated measures Analysis of Variance for CT x LT Interaction and Simple Main Effects of CT and LT for COP Rms in ML Direction

Interaction	COP rms ML	*SS*	*df*	*MS*	*F*	*p*	η^2
	CT x LT	3.912	2	1.956	11.226	<.001	.398
Simple Main Effects of Cognitive Task	No LT	2.485	2	1.243	6.106	.005	.264
	LT	21.641	2	10.820	2.183	.128	.114
Simple Main Effect of Light Touch	No CT	2.485	1	2.485	12.250	.003	.419
	Easy CT	2.134	1	.876	6.980	.017	.291
	Difficult CT	.359	1	.359	1.187	.291	.065

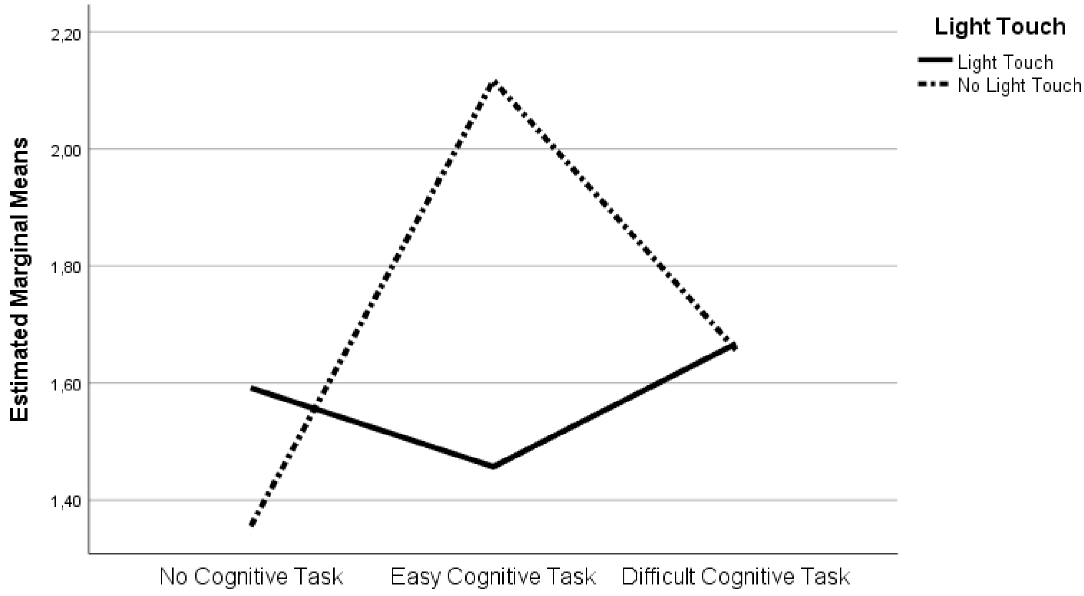


Figure 4.6. Interaction Graph for COP RMS in ML Direction

4.2.2. Main Effects of Cognitive Task

<u>COP Ellipse Area</u>**:** During no light condition, the effect of cognitive task was statistically significant, $F\ (1.302,\ 22.141) = 11.198$, $p = .002$, partial $\eta 2 = .397$, however, during light touch condition, the effect of cognitive task not statistically significant, $F\ (2, 34) = 2.183$, $p = .128$, partial $\eta 2 = .114$ (see Figure 4.7).

<u>COP Mean Velocity</u>**:** The main effect of cognitive task showed that there was no statistically significant difference in COP mean velocity between touch conditions, F (.876, 26.818) =.555, p =.545 (see Figure 4.8).

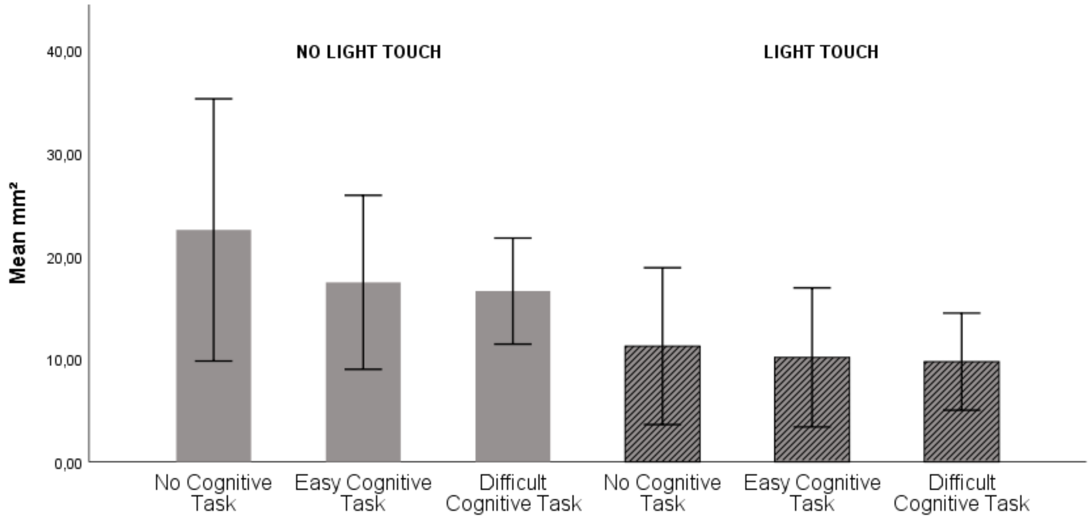


Figure 4.7. Mean COP Ellipse Area in Cognitive Task Conditions

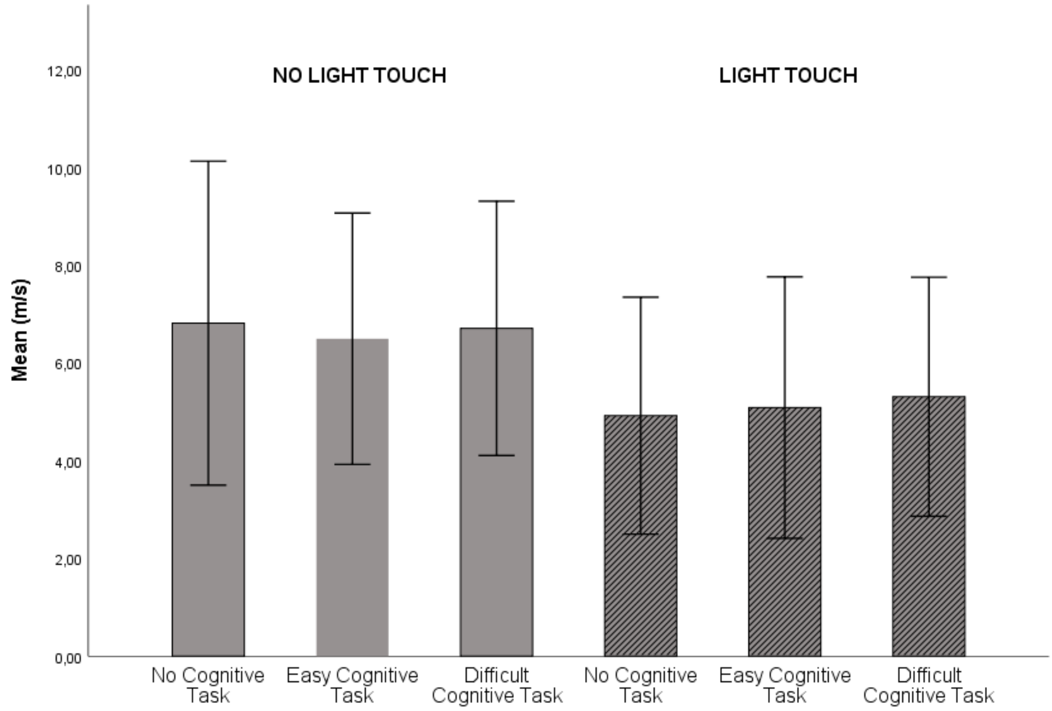


Figure 4.8. Mean COP Mean Velocity in Cognitive Task Conditions

COP Range in AP and ML in Direction: During no light condition, the effect of cognitive task was statistically significant both in AP direction, F (1.366, 23.222) = 11.198, p = .001, partial η^2 = .367, and in ML direction, F (1.302, 22.141) = 11.198, p = .002., η^2 = .397. During light touch condition, however, the effect of cognitive task was not statistically significant in AP direction, F (1.701, 28.925) = .137, p = .145, partial η^2 = .114 (see Figure 4.9), and in ML direction, F (2, 34) = 2.183, p =.128., η^2 =.114 (see Figure 4.10).

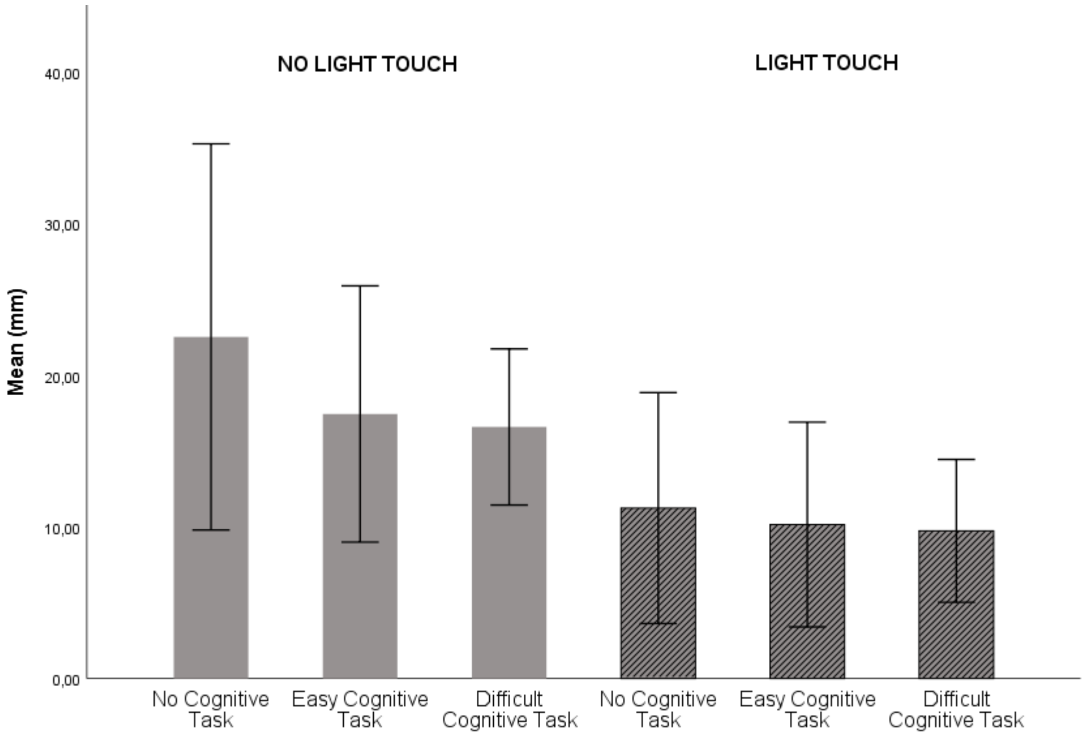


Figure 4.9. Mean COP Range in AP Direction in Cognitive Task Conditions

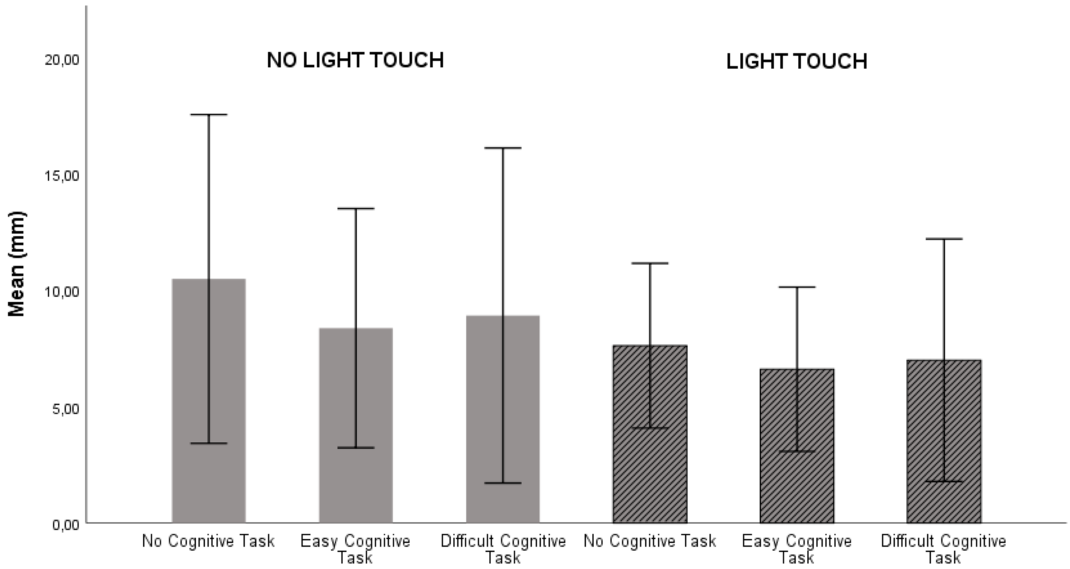


Figure 4.10. Mean COP Range in ML Direction in Cognitive Task Conditions

<u>COP Rms in AP and ML Direction:</u> During no light condition, the effect of cognitive task was statistically significant both in AP direction, F (1.302, 22.141) = 11.198, p=.002, partial η^2 =.397, and in ML direction, F (2, 34) = 6.106, p=.004, partial η^2 =.264. During light touch condition, however, the effect of cognitive task was not statistically significant both in AP direction, F (2, 34) = 2.183, p=.128 (see Figure 4.11), partial η^2 =.114, and in ML direction, F (2, 34) = 2.183, p=.128, partial η^2 =.114 (see Figure 4.12).

4.2.3. Main Effects of Light Touch

<u>COP Ellipse Area</u>**:** During all cognitive task situations COP ellipse area was greater in no light condition than light touch condition and the results indicated that they were statistically significant.

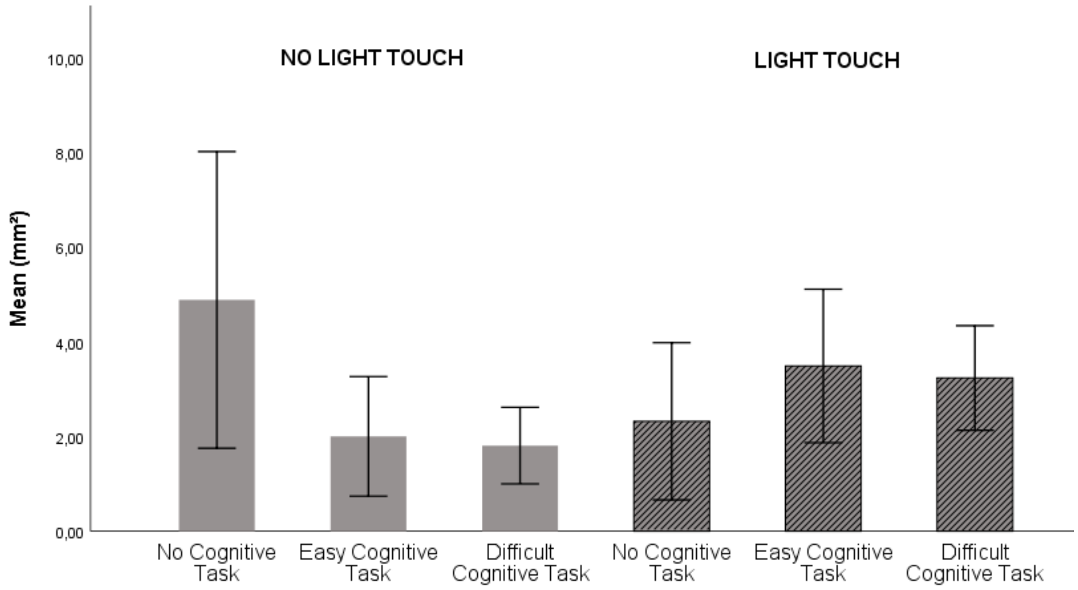


Figure 4.11. Mean COP Rms in AP Direction in Cognitive Task Conditions

Mean differences for COP ellipse area were 11.297 mm^2, 95% CI [7.481 to 15.112], $F(1, 17) = 39.018$, $p < .001$, $\eta^2 = .697$; 7.295 mm^2, 95% CI [5.507 to 9.083], $F(1, 17) = 74.091$, $p < .001$, $\eta^2 = .813$; 6.853 mm^2, 95% CI [5.284 to 8.423], $F(1, 17) = 84.875$, $p < .001$ $\eta^2 = .833$, during no cognitive task, easy cognitive task, and difficult cognitive task conditions, respectively(see Figure 4.13).

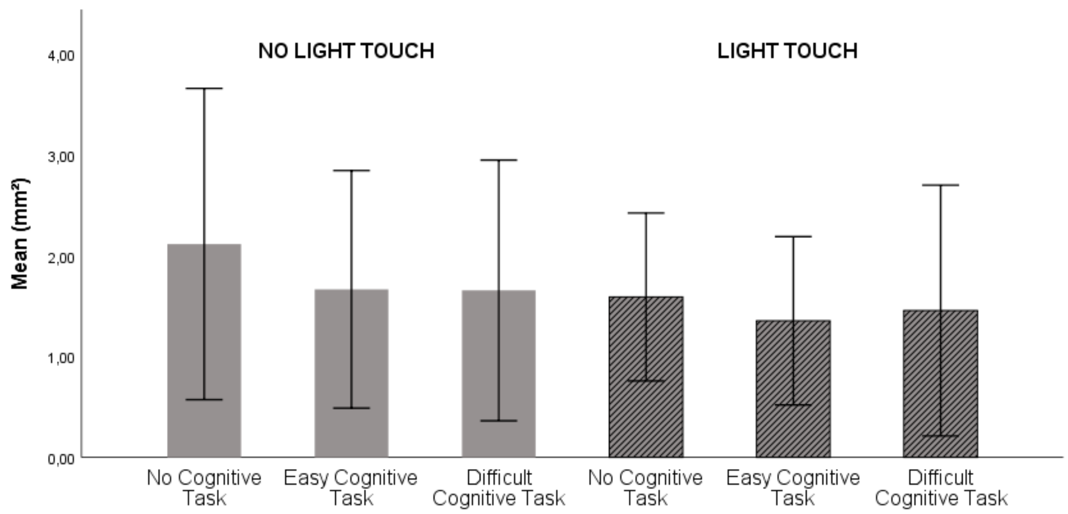


Figure 4.12. Mean COP Rms in ML Direction in Cognitive Task Conditions

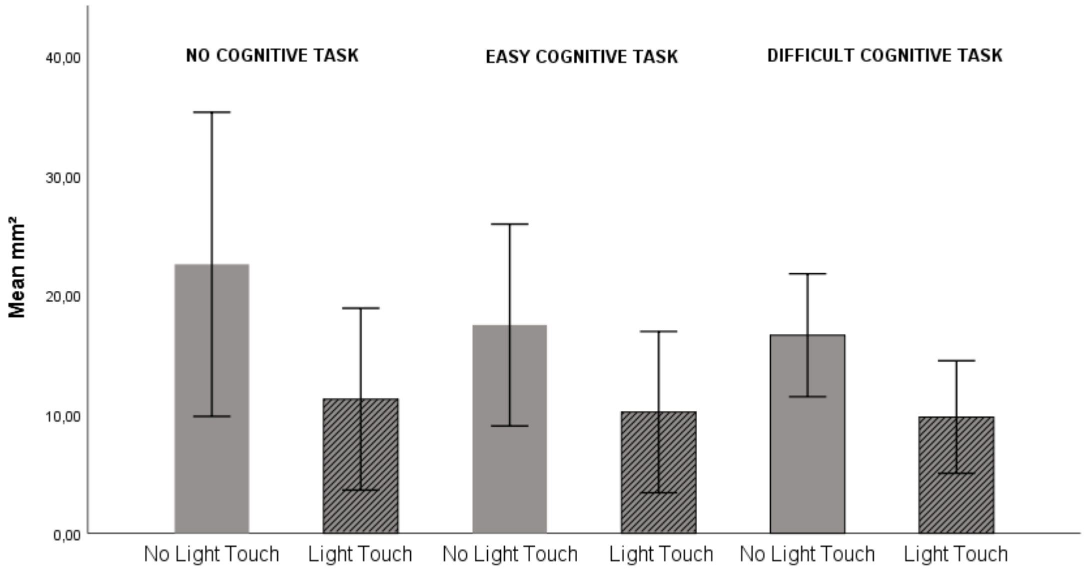


Figure 4.13. Mean COP Ellipse Area in Light Touch Conditions

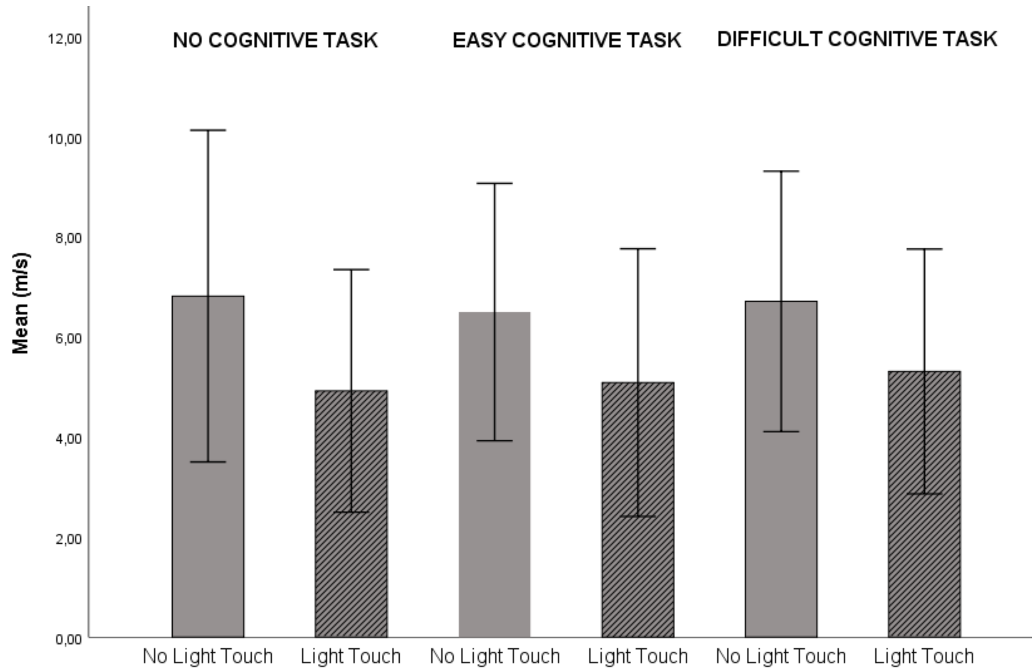


Figure 4.14. Mean COP Mean Velocity in Light Touch Conditions

COP Mean Velocity: Mean COP mean velocity was 1,57 m/s, 95% CI [1.195 to 1.940] higher at the no light condition as opposed to the light touch condition, a difference that was statistically significant, F (1, 17) = 0.40, p <.001 (see Figure 4.14).

COP Range in AP and ML Direction: During all cognitive task situations both COP Range in AP and ML direction was greater in no light condition than light touch condition, which was statistically significant.

Mean differences for COP range in AP direction were 11.297 mm, 95% CI [7.481 to 15.112], $F(1, 17) = 39.018$, p <.001, $\eta^2 = .697$; 7.295 mm, 95% CI [5.507 to 9.083], $F(1, 17) = 74.091$, p <.001, $\eta^2 = .813$; 6.853 mm, 95% CI [5.284 to 8.423], $F(1, 17) = 84.875$, p <.001 $\eta^2 = .833$, during no cognitive task, easy cognitive task, and difficult cognitive task conditions, respectively (see Figure 4.15).

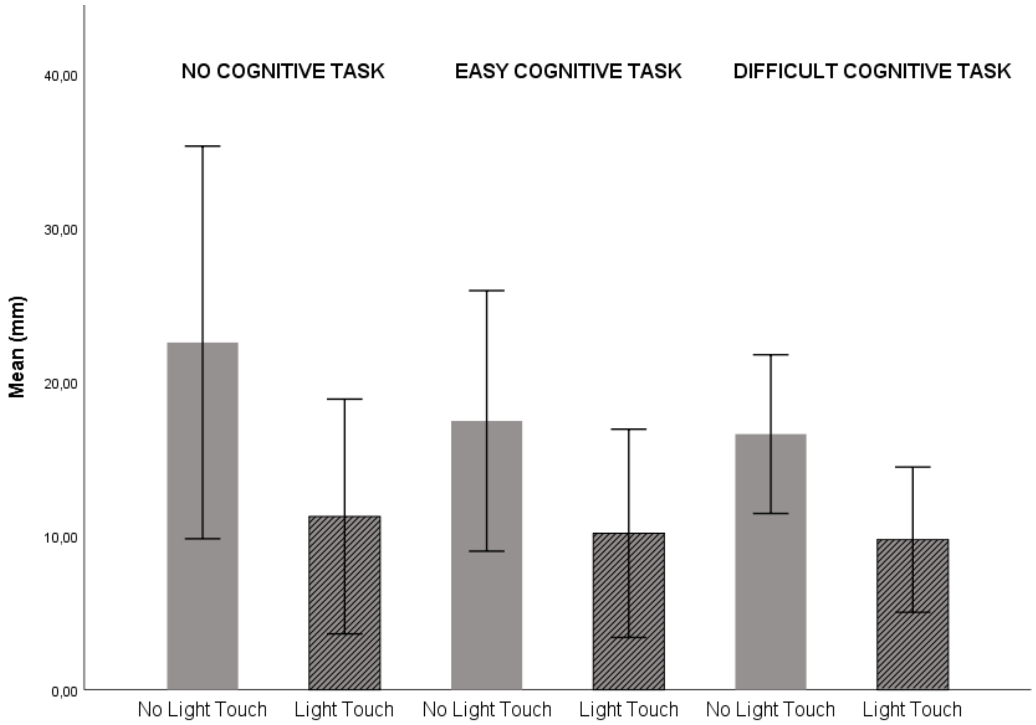


Figure 4.15. Mean COP Range in AP Direction in Light Touch Conditions

Mean differences for COP range in ML direction were 2.865 mm, 95% CI [-1.318 to 4.412], *F* (1, 17) = 15.267, *p* =.001., η^2 = .473; 1.765 mm, 95% CI [.620 to 2.910], *F* (1, 17) = 10.572, *p* =.005., η^2 = .383; 1.918 mm, 95% CI [.225 to 3.611], *F* (1, 17) = 5.714, *p* = .029., η^2 = .252, during no cognitive task, easy cognitive task, and difficult cognitive task conditions, respectively (see Figure 4.16).

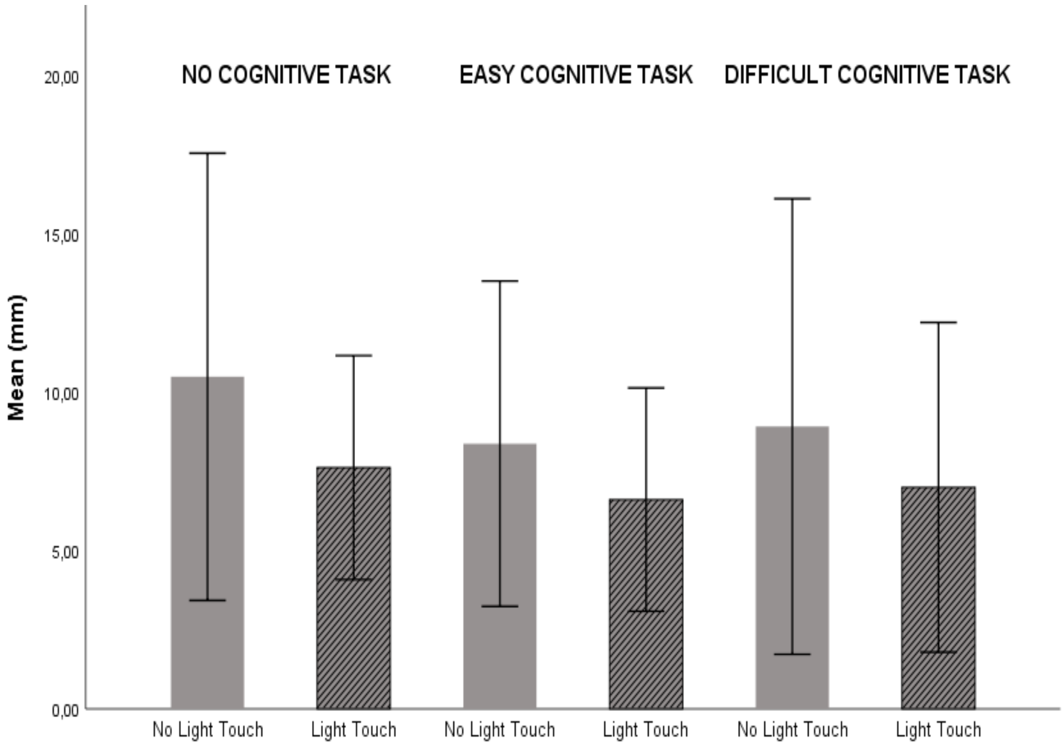


Figure 4.16. Mean COP Range in ML Direction in Light Touch Conditions

<u>COP Rms in AP and ML Direction</u>**:** During all cognitive task situations both COP Rms in AP and ML direction was higher in no light condition than light touch condition, which was statistically significant.

Mean differences for COP rms in AP direction were 2.565 mm^2, 95% CI [1.721 to 3.410], F (1, 17) = 41.115, *p* <.001, η^2 = .707; 1.488 mm^2, 95% CI [1.085 to 1.892], *F* (1, 17) = 60.634, *p* <.001, η^2 = .781; 1.429 mm^2, 95% CI [1.114 to 1.744], *F* (1, 17) =

91.716, p <.001 η^2 = .844, during no cognitive task, easy cognitive task, and difficult cognitive task conditions, respectively (see Figure 4.17).

Mean differences for COP rms in ML direction were .525 mm^2, 95% CI [.209 to .842], F (1, 17) = 12.250, p =.003, η2 = .419; .312 mm^2, 95% CI [.063 to .561], F (1, 17) = 6.980, p =.017, η2 = .291; .200 mm^2, 95% CI [.187 to .586], F (1, 17) = 1.187, p =.291 η2 = .065, during no cognitive task, easy cognitive task, and difficult cognitive task conditions, respectively(see Figure 4.18).

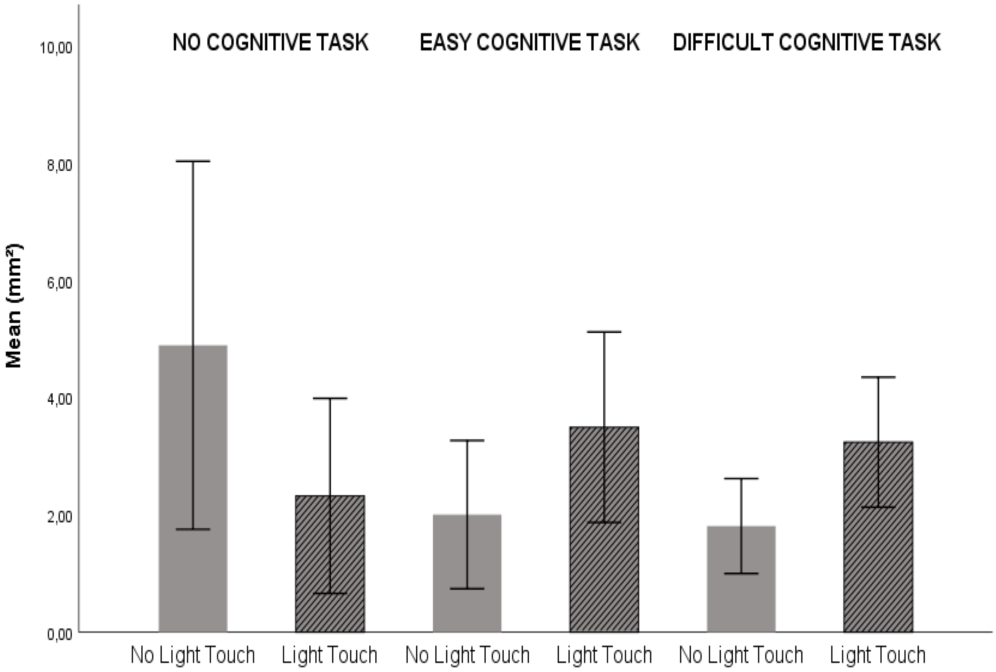


Figure 4.17. Mean COP Rms in AP Direction in Light Touch Conditions

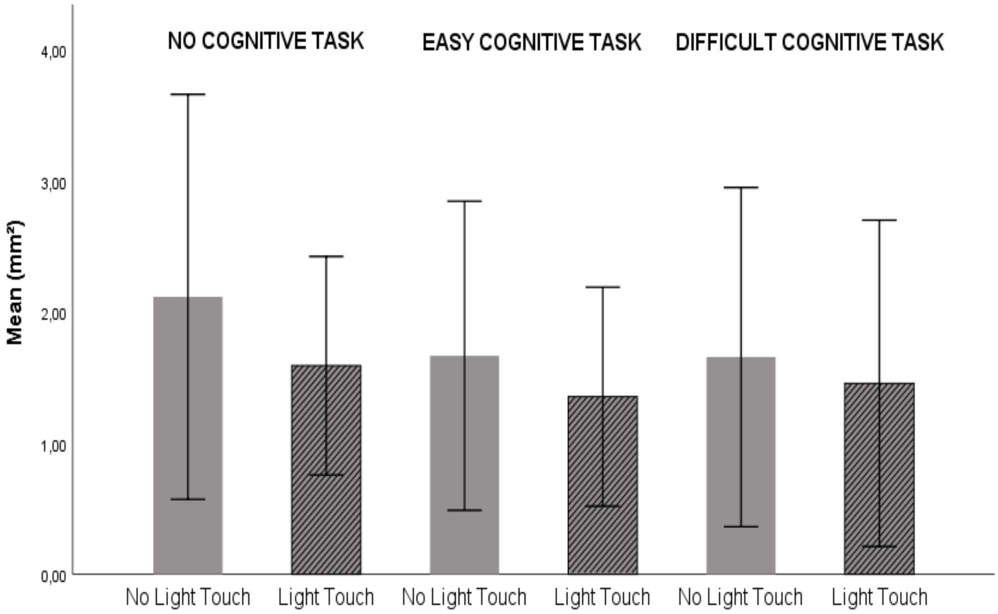


Figure 4.18. Mean COP Rms in ML Direction in Light Touch Conditions

Overall results indicated that there was an interaction between cognitive task and light touch on all COP parameters except for COP mean velocity. The statistically significant effect of cognitive task was present in all COP parameters (except for COP mean velocity) only during no light touch condition. In addition, difficult cognitive task was more effective than easy cognitive task in reducing postural sway. The presence of light touch had a statistically significant effect on postural control.

CHAPTER V

DISCUSSION

This study was conducted to understand the combined effects of light touch (LT) and cognitive task (CT) difficulty on postural control. We investigated how the postural task would be affected by the presence of light finger touch and none/easy/difficult cognitive task. As stated in the problem statement part, the literature indicates concordant results about the positive effect of light touch on postural control, while there's no consensus on the effect of concurrent cognitive tasks' effects on postural control. On the other hand, there's a limited number study concerning the combined effects of cognitive tasks and light touch. Therefore, this thesis aimed to create two levels of difficulty of the cognitive task (modified Stroop test) which was used to a lesser degree in dual-task studies, and investigate its individual and combined effects with a light touch on postural control.

5.1. The Individual Effects of Cognitive Task

The first hypothesis was that the increased level of cognitive task difficulty would have a positive effect on postural control. The first part of the experiment was to quietly stand with no cognitive task, then with an easy cognitive task, and then with a difficult cognitive task. During these experiments, it was observed whether there were significant changes in the trajectories of CoP. It was expected that the difficulty of cognitive tasks would significantly affect postural control, by enhancing postural control. As expected, cognitive task difficulty resulted in significant differences in all

COP parameters except for COP mean velocity during quiet stance. This was one possible outcome of dual-task performance proposed by Plummer et al., (2013). As stated earlier, there are nine possible scenarios in dual-task situations. The possible outcomes are: (1) no interference, (2) cognitive-related motor interference, (3) motor-related cognitive interference, (4) motor facilitation, (5) cognitive facilitation, (6) cognitive-priority trade-off, (7) motor-priority trade-off, (8) mutual interference, or (9) mutual facilitation (also see Table 2.1). In our results, motor facilitation (cognitive performance remains stable while motor performance improves) was observed. In other words, there was no dual-task interference. Furthermore, it was demonstrated that performing a difficult concurrent cognitive task resulted in a decrease in postural sway in comparison with easy cognitive task. These results are concordant with many studies in the literature.

Why there was no significant difference observed in COP mean velocity unlike other COP parameters? In literature there are studies which indicate similar results Roerdink et al., (2006); (Lajoie, Richer, Jehu, & Tran Ylan, (2016); Lee Y. G., (2018). Roerdink et al., (2006) investigated the recovery of balance in stroke patients by assessing COP trajectories. COP velocity in the sagittal plane was higher during the dual task, which was regarded as an indicator that patients ‘stiffened up' to some degree, maybe because of enhanced alertness. Therefore, the increase in COP mean velocity is correlated with stiffening strategy. Lajoie, Richer, Jehu, & Tran Ylan, (2016) argues that increased frequency values are due to the usage of a more automated postural control system (McNevin &Wulf, 2002). Greater joint or muscle stiffness was observed during an external focus compared to an internal focus and was interpreted as a posture improvement. Likewise, in our study, the increased level of cognitive task difficulty resulted in increased COP mean velocity.

Polskaia & Lajoie (2016) investigated cognitive task demand and postural control. Seventeen young adults (23.71 ± 1.99 years) were asked to stand feet together on a force platform and perform concurrent cognitive tasks (visual and auditory) at three different difficulty levels: easy, moderate, and difficult. The visual task was counting the occurrence of one or two numbers. The auditory task was counting the occurrence of the letters and repeating a string of words. The increase in cognitive task difficulty resulted in a reduction in 95% confidence ellipse and ML sway variability. However, there was no significant difference between the moderate and difficult level tasks. Also, there was a difference between the effects of visual and auditory tasks. While auditory tasks led to an increase in COP irregularity, the visual tasks led to a decrease in ML sway variability. The results obtained are consistent with our findings. These results are explained by the view that withdrawing attention away from the postural control facilitates the automatic control processes. The external emphasis (cognitive task) may have helped automatic processes to control sway more efficiently by diverting conscious attention away from sway and toward movement consequences (Wulf, McNevin, & Shea, 2001).

A study was undertaken to investigate dual-task conditions with modifying the difficulty level of the cognitive task as well as the balance task. 98 healthy women (aged between 18-27 years) participated in the study. The reason why only women were included was due to the difference in average center of pressure (COP) location among genders. The levels of motor tasks include (1) standing with feet together(easy), (2) standing with feet together with the stimulation of concurrent vibration of the bilateral gastrocnemius muscles (medium), and (3) tandem stance (difficult). Brooks' tasks with spatial and nonsense sentences were chosen as cognitive tasks. In the spatial Brooks' task, participants are instructed to listen to a series of sentences in which the location of numbers in a 4x4 grid is described. In the nonsense part of the Brooks' task, the words of direction: right, left, up, and down were replaced with good, bad, quick, and slow. The Brooks' tasks were modified to have two levels of difficulty. Balance tasks were performed concurrently with Brooks' tasks and without a cognitive task. As a result, performing a difficult cognitive task concurrently with a balance task led to a decrease in postural sway regardless of the difficulty of the balance task. These results are in line with the findings of this thesis; however, we didn’t modify the difficulty level of the postural task. Swan, Otani, & Loubert, (2007) created three levels of motor task as abovementioned unlike in our study (only quiet stance as the motor task). An important question that exists is why postural sway reduced when people perform a difficult motor task in combination with difficult cognitive task. This is explained because of directing attention away from the balance task. Thus, an individual becomes less responsive to the balance-related cues and prevents overcorrections (Swan, Otani, & Loubert, 2007). Also, this might be explained by the view proposed by Beilock, Carr, MacMahon, & Starkes, (2002). They claimed that focusing on motor skills was found to disrupt the performance of skilled performers but did not affect beginners and concluded that when a motor skill becomes automatic, focusing on the skill may undermine the performance of the skill.

Bustillo-Casero, Villarrasa-Sapiña, & García-Massó, (2017) compared the dual-task performance of adolescents and young adults. The postural task consisted of three different conditions 1) bipedal stance, 2) tandem stance and 3) unipedal stance while the cognitive task consisted of a backward digit span test at three different difficulty levels: (i.e., backward digit span test with 3, 4, and 5 digits). In these tasks, subjects were asked to memorize the sequence of numbers and then repeat the number in reverse order. The results indicated that cognitive task difficulty affected adolescents and young adults differently. Adolescents prioritized postural tasks during a difficult cognitive task. Furthermore, they reduced their postural control during easy postural tasks, whereas they didn't reduce their postural control during difficult postural tasks as the difficulty of cognitive tasks increased. This indicates that there is a competition for attentional resources between the two tasks at the low-difficulty postural task. Adolescents seem to focus on postural control when performing difficult postural tasks and prioritize postural tasks to avoid falls. On the other hand, young adults showed no difference in postural task conditions as the difficulty level of the cognitive task changed. However, a lower level of postural control in comparison to adolescents was observed in young adults with the increasing difficulty level of the postural task. The resources necessary to carry out cognitive and postural control tasks at the same time do not seem to be shared among young people. These results are not concordant with our study and there might be two explanations to it. First, the postural task adopted in this thesis is not modified in terms of the level of difficulty, and it is a relatively easier motor task. Increasing the difficulty level of motor task might have occupied the more of attentional sources thereby resulting in a decrease in postural control when dual-task was performed. Secondly, the attentional demands of the difficult cognitive task used in the study of Bustillo-Casero, Villarrasa-Sapiña, & García-Massó, (2017) might be higher than the difficult cognitive task used in our study. We can hypothetically claim that these concordant results are due to the difference in difficulty levels of cognitive tasks. Quiet stance is a well-learned daily task and doesn’t require too much of attentional sources (Bronstein, Brandt, Woollacott, & Nutt, 1996). Furthermore, as abovementioned, it’s not possible to objectively determine the attentional demands of diverse cognitive tasks.

Dault & Duysens, (2001) studied dual-task methodology by modifying the levels of difficulty of both motor task and cognitive task. The motor task involved (1) shoulder-width stance on the force plate, (2) shoulder-width stance while each foot was placed on the force plate, and (3) tandem stance on the seesaw placed on the force plate and cognitive tasks involved three different modified versions of Stroop test. The level of difficulty didn't result in any significant changes in all postural task situations, however, the addition of a cognitive task independent from their difficulty level, led to stiffness in tandem seesaw stance. These results are similar to our findings in some respects. We didn't observe any significant changes by altering the level of difficulty of the Stroop test either, however, during no light touch condition cognitive task had significant main effects on postural sway. Furthermore, the findings of this thesis demonstrated that increasing the difficulty level of the Stroop test resulted in moderate improvement in postural control. This might have resulted due to performing a relatively easier and well-learned motor task (quiet stance). In the study of Dault & Duysens, (2001), a challenging motor task might have occupied the more of attentional sources. When standing with the well-learned posture (shoulder width posture), the increase in cognitive tasks caused little changes, indicating that the posture might require only a minimum amount of attention. When the seesaws are added to this position, the addition of cognitive tasks resulted in an increase in stiffness as a commonly adopted synergistic adaptation to achieve more critical stable posture.

Pellecchia, (2003) examined the difficulty level of the cognitive task within the dual-task paradigm and showed that the rise in the level of difficulty increased postural sway. What might have caused the more different findings than in our study? There might be two possible explanations to it. First, in the study of Pellecchia (2003), a foam pad was used to create a more compliant surface. Since the motor task became more demanding, this might have caused dual-task interference by exceeding the limited capacity of attention. Secondly, the type of cognitive tasks used for the studies might have created different difficulty levels and their type might have resulted in different influences. In the study of Pellecchia, (2003) digit reversal, 2-bit classification, and counting backward by 3 (working memory and attention involved) were used unlike in our study (attention, planning and information processing involved). The type of cognitive task can deliberately influence the cognitive-motor interference in various populations (Ebersbach, Dimitrijevic, & Poewe, 1995). In literature it is not well established how the type of cognitive task effects cognitive-motor interference, however, there are studies comparing the cognitive demand of different type of cognitive tasks. For instance, it was suggested that Stroop test has higher complexity than simple reaction time task (Dalecki, Bock, & Hoffmann, 2013). On the other hand, Patel, Lamar, & Bhatt (2014) compared the effects of four different type of cognitive task in dual-task paradigm. Subjects performed (1) visuomotor reaction time, (2) word-list generation, (3) serial subtraction, (4) Stroop task while walking. Results indicated that during the performance of Stroop task, motor task's cost was the highest. It was inferred that

Stroop task required higher processing resources than other cognitive tasks did. It is not possible to determine and define the difficulty levels of the cognitive tasks due to the lack of clarity in the framework for the concept of difficulty level for the cognitive task in literature. However, one can only speculate that the cognitive tasks at different types or different difficulty levels might yield different results within the dual-task paradigm.

Unlike other studies, Zeren, (2019) created individualized difficulty levels for the cognitive task for each participant (zero/medium/high). Participants performed cognitive tasks with two different postural tasks concurrently: sway in accordance with metronome beat and quiet stance. Results indicated that cognitive task didn't have a significant effect on sway parameters during quiet stance whereas it had a significant effect on sway parameters during sway condition by decreasing postural control. This result supports the idea that creating enough difficulty in one or both tasks result in a dual-task cost (Plummer et al., 2013). Performing "quiet stance" did not create enough difficulty to cause a dual-task cost, whereas performing a relatively difficult postural task; "sway in accordance with the metronome" resulted in a deterioration in the postural task. This can be interpreted with the central capacity sharing model which suggests that there is a limited capacity of attention. Therefore, tasks are opted as "to be performed" tasks (McLeod, 1977; Tombu & Jolicoeur, 2003). In this case, the cognitive task didn't create enough difficulty to cause an interference during a relatively easier task (quiet stance), however, when the difficulty of the motor task was increased one of the tasks was chosen as "to be performed" task, and participants comprised postural task to achieve cognitive task successfully. The successful execution of goal-oriented actions required modifications to one of the actions to complete the entire action plan (Allport, 1989).

The findings of this study were in line with the findings reported by Riley, Baker, & Schmit, (2003). According to the attention literature, the results can be explained by several theories. First, it can be explained by shifting attention away from the body activates automatic control processes. Directing attention to a non-postural task may have been helpful in not monitoring postural tasks continuously. Also, the difficult cognitive task might have been more effective in reserving focus away from postural tasks due to the higher cognitive demand (McNevin & Wulf, 2002). In line with this view, concurrent cognitive task decreased postural sway, withal, increasing the difficulty level of the cognitive task decreased postural sway even more. Secondly, these results can be explained multiple sources theory of attention. According to this theory, if two tasks don't require common limited resources, they do not interfere with each other (Navon & Gopher, 1979; Wickens, 1980). In this study, no cognitive-motor interference occurred on none of the cognitive task situations, neither easy cognitive task nor difficult cognitive task. We may therefore assume that the cognitive task (Stroop test) and the motor task (quiet stance) do not require the common limited resources. However, this view is very hypothetical since we cannot evaluate precisely which attentional sources these tasks require. Lastly, the results can be interpreted by the view of Navon & Miller, (1987). They proposed that if two tasks use similar domains or neural processors, the efficiency of processing might increase by facilitation due to the use of less attentional resources. Although there is no clear evidence to support this theory, there is no opposing evidence either. If it is assumed that two tasks (cognitive task & motor task) use similar domains or neural processors, our results can be explained as a facilitation of the motor task by this theory.

5.2. The Individual Effect of Light Touch

The second hypothesis was that adding light finger touch to the postural control task would have a positive effect on postural control. The second part of the experiment comprised of touching/ or no touching on a stable metal surface with a force that does not exceed 1N in combination with cognitive task situations (none/easy/difficult). During these experiments, it was observed whether there were significant changes in the trajectories of CoP. As it was predicted, light touch had a significant effect on postural control by reducing sway. These results are concordant with the findings of previous studies in the literature.

Contribution of this study was to provide evidence to understand the effect of light touch in combination with various cognitive task situations (none/easy/difficult). It was observed that with the increasing level of task difficulty, the addition of light touch became less effective in terms of decreasing sway. These results are in accordance with the literature findings that touching a stationary surface with light finger touch decreases body sway (Jeka & Lackner, 1994; Jeka J. J., 1997; Tremblay, Mireault, Dessureault, Manning H, & Sveistrup, 2004). In this study, the magnitude of force applied by fingertip was no more than 1N which is considered as the magnitude which doesn’t provide mechanical support (Holden, Ventura, & Lackner, 1994; Jeka J. J., 1997). That's why the improvements in postural control cannot be associated with additional support. The effect of light finger touch on decreasing postural sway is explained by the presence of additional somatosensory information that is obtained by the cutaneous mechanoreceptors and kinesthetic mechanoreceptors (Baldan, Alouche, Araujo, & Freitas, 2014; Diener, Dichgans, Guschlbauer, & Mau, 1984). Another possible explanation for the effectiveness of light touch in improving postural control is that it triggers postural muscles, especially trunk muscles, which are not as much as active without finger touch (Jeka J. J., 1997). However, in this study, no evidence can be proved to support this explanation since there is no data collected regarding muscle activity. The methodology of this study cannot differentiate the mechanism of how light touch improves postural control due to the lack of muscle activation data and the use of different somatosensory conditions.

5.2.1. Cognitive Task Light Touch Interaction

The third hypothesis was that there would be a significant interaction between cognitive task difficulty and light touch on postural sway. It was expected that during simultaneous execution of the cognitive task and light touch, there would be a significant change in the trajectories of COP. To test this hypothesis, participants' postural sway was tested in a combination of light touch and the cognitive task at two levels of difficulty (easy/difficult). The results indicated that simultaneous performance of the cognitive task and light touch had a significant interaction on postural sway during quiet stance and this interaction was due to the cognitive task difficulty.

Lee, Goyal, & Aruin, (2018) also found a significant interaction between cognitive tasks and light touch. In this experiment, the cognitive task consisted of counting aloud backward subtracting by three from a randomly chosen three-digit number and the force applied to the surface by light finger touch was limited to 1N likewise in our study. Researchers found that while the individual performance of cognitive tasks led to an increase in postural sway, light touch caused a decrease in postural sway. However, their simultaneous performance neutralized each other's effect; no change was observed in postural sway. Differently, in this thesis, two levels of difficulty for the cognitive task were introduced. In contrast, it was observed that the presence of cognitive tasks improved postural control. Moreover, increasing the cognitive task difficulty improved postural control, although this increase was not significant. The light touch had a significant effect on postural control in all cognitive task situations (none/easy/difficult). The same author conducted a similar study by adding vision/no vision conditions among older adults who had a stroke (Lee, Curuk, & Aruin, 2021). Similarly, there was a significant interaction between cognitive task and light touch and their counteract effects neutralized each other. These conflicting results in terms of the effects of the cognitive task may be explained by the differences in cognitive tasks. The types of the cognitive tasks used in these studies are different from the ones used in this study and their difficulty levels cannot be compared as well. Therefore, one cannot differentiate between these cognitive tasks in terms of their cognitive demand. Cognitive demand, often known as cognitive load, is a multidimensional term that reflects the relationship between task-generated processing demands and learner skills (Bachman, 2002; Paas & van Merriënboer, 1994). In other words, depending on the extent of challenge individuals face during task completion, any measurement of cognitive load will be influenced by their individual characteristics. As a result, cognitive load evaluation does not allow for the measurement of task difficulty in isolation. Rather, it allows determining the degree of cognitive effort generated by a task complexity manipulation (Révész, Michel, & Gilabert, 2016)

Chen & Tsai, (2015) investigated the effects of light touch on postural sway and visual search accuracy and reached the result of interaction between cognitive task and light touch on head and torso sway. This thesis didn't investigate the changes in head and torso sway which would lead to more precise results. Also, it might be important to understand the changes sway in the head and torso as the participants were required to verbalize words during cognitive task situations. It would have provided more precise outcomes to interpret the results in more detail. Besides, it was observed that the presence of light touch improved cognitive task performance. The reason why the simultaneous execution of light touch and cognitive task improves the success of cognitive task can be explained by functional integration theory proposed by Riccio & Stoffregen, (1988). Functional integration theory supports the idea that postural sway can be modified to achieve and even improve a non-postural task. Stoffregen proposed a plausible explanation for the functional integration between postural control and the visual search task in terms of how reduced postural sway might improve visual search task performance. Because the eyes are placed on the head, postural sway would unavoidably shift their position in space. For these reasons, increased postural sway would create more vision disruptions, which would have a negative impact on the successful completion of tasks that require precise visual control. However, our study didn't aim to evaluate the effect of light touch on cognitive task performance because a different type cognitive was adopted.

Dos Santos et al. (2019) investigated the combined effects of the light touch and cognitive task on the components of postural sway. They computed COP, Rambling (the migration of reference points in which the body is momentarily in equilibrium) and Trembling (deviation of the COP trajectory from these equilibrium points) mean amplitude and found that there was an interaction between cognitive task and light touch on COP and rambling mean amplitude. The simultaneous performance of cognitive task and light touch reduced postural sway. Also, the independent effects of the LT or CT on postural sway were verified and extended to the circumstance in which both were done at the same time. Because of the varied combined effects of LT and CT on COP components, particularly the Rambling, postural sway was minimized.

Similar to this thesis, Batistela, Oates, & Moraes, (2019) created two types of cognitive task (visual and auditory), however, there was no difference in difficulty levels alleged. The visual task comprised of a modified Stroop test at which subjects were asked to mentally count the numbers of congruent displays of word-color while the auditory task was the digit-monitoring task where 22 random numbers between 1 and 9 were presented via headphones and participants were asked to count the numbers of target numbers determined in advance mentally. There was no interaction found between cognitive task and touch condition. What might have caused different results in terms of interaction? First, the postural task was to stand quietly on a wooden balance beam which was more challenging than standing on a flat surface. The presence of a more challenging task might have exceeded the attentional capacity. The resources are split into "to-be-performed" tasks in the capacity sharing paradigm; in other words, capacity sharing can be willingly allocated to a specific work. Cognitive-motor interference occurs as a result of the parallel processor's limited capacity. Secondly, in this thesis cognitive task involves verbalization whereas in the study of Batistela, (2019), cognitive tasks required mental evaluation. In other words, during the test, the subjects were not required to express cognitive task outcomes verbally. Verbalization while quietly standing can introduce biomechanical and respiratory artifacts (Madeleine, Nielsen, & Arendt-Nielsen, 2011). The internal activities of the body, like as respiration, have an impact on quiet stance (Jeong, 1991). Some researchers suggest that the addition of verbalization due to the increased respiration rate may affect postural control by increasing CoP frequency (Dault, Yardley, & Frank, 2003; Yardley, Gardner, Leadbetter, & Lavie, 1999; Pascal, Mogens, & Arendt-Nielsen, 2011). As the rate of respiration increases, so does body sway. However, we cannot evaluate the individual effect of verbalization in our study to document the differences in results. On the other hand, since the number of numbers expressed by the subjects remains stable, the errors introduced by these artifacts can be considered systemic regardless of the level of posture and cognitive difficulty.

CHAPTER VI

CONCLUSION

This study aimed to evaluate the combined effects of cognitive task difficulty and light finger touch on postural control. Simultaneous performance of light finger touch and cognitive task resulted in a decrease in CoP trajectories during quiet stance thereby improving postural control. Individual performances of light finger touch and cognitive tasks also resulted in a decrease on sway parameters during quiet stance. The presence of light touch decreased postural sway during quiet stance in all cognitive task situations (none/easy/difficult). The cognitive task difficulty did not have a significant effect on postural sway parameters in the presence of light touch conditions. However, when there was no light touch condition, difficult cognitive task was moderately more effective than the easy cognitive task in decreasing postural sway during quiet stance.

6.1. Further Studies

Further studies that investigate the combined effect of cognitive task difficulty and light finger touch should consider several issues. Firstly, the cognitive task type and difficulty should be determined within a more concise frame. The type of cognitive task (executive function, working memory, attention) or (visual/auditory) and the level of difficulty should be tested in various experimental designs. Secondly, not only data from the force platform on CoP but also the data from the head and torso sway should be obtained to have clearer conclusions. In this thesis, since the data from the head and torso was not obtained, the effect of verbalization on postural sway couldn't be differentiated. Thirdly, setting up a more significant difficulty level between the cognitive tasks might yield more precise results to interpret in terms of the dual-task paradigm. The results of this study revealed that cognitive tasks at two levels of difficulty (easy/difficult) did not show a significant difference in postural sway parameters. Creating the greater difficulty level gap between the cognitive tasks might have helped to increase attentional demands more. Lastly, evaluation of the cognitive task outcomes with and without the presence of light touch can provide information regarding the effect of light touch on cognitive task performance. Only the numbers of correct answers were calculated in this study, and it was found that there was no significant difference in the number of correct answers in all experimental conditions. Therefore, also the participants' response speed in Stroop test should be calculated to evaluate the performance of the cognitive task more elaborative.

REFERENCES

Abernethy, B. (1988). Dual-task methodology and motor skills research: Some applications and methodological constraints. *Journal of Human Movement Studies*, 14(3), 101-132.

Alcock, L., O'Brien, T., & Vanicek, N. (2018). Association between somatosensory, visual and vestibular contributions to postural control, reactive balance capacity and healthy ageing in older women. *Health care for women international*, 39(12), 1366-80.

Alexander, N. (1994). Postural Control in Older Adults. *Journal of the American Geriatrics Society*, 42(1), 93–108.

Allport, A. (1989). Visual attention. In M. I. (Ed.), *Foundations of cognitive science* (pp. 631–682). The MIT Press.

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev,* 35, 715-28.

Arthur, R. J., & William, D. R. (1966). The Stroop color-word test: A review. *Acta Psychologica*, (25), 36-93.

Aruin, A., & Neeta, K. (2014). Aging and balance control in response to external perturbations: Role of anticipatory and compensatory postural mechanisms. *Age*, 36(3), 9621.

Assaiante, C., & Amblard, B. (1995). An ontogenetic model for the sensorimotor organization of balance control in humans. *Human Movement Science*, 14(1), 13–43.

Baddeley, A. (2003). Working memory and language: an overview. *J Commun Disord*, 36, 189-208.

Baldan, A., Alouche, S., Araujo, I., & Freitas, S. (2014). Effect of Light Touch on Postural Sway in Individuals with Balance Problems: A systematic review. *Gait & Posture*, 40, 1-10.

Baldan, A., Alouche, S., Aroujo, I., & Freitas, S. (2014). Effect of Light Touch on Postural Sway in Individuals with Balance Problems: A systematic review. *Gait & Posture*, 40(1), 1-10.

Benda, B. J., Riley, P. O., & Krebs, D. E. (1994). Biomechanical relationship between center of gravity and center of pressure during standing. *IEEE Transactions on Rehabilitation Engineering*, 2(1), 3-10.

Bergamin, M., Gobbo, S., Zanotto, T., Sieverdes, J. J., Alberton, C. L., Zaccaria, M., & Ermolao, A. (2014). Influence of age on postural sway during different dual-task conditions. *Frontiers Aging Neuroscience*, 6, 271.

Bonnet, C., & Baudry, S. (2016). Active vision task and postural control in healthy, young adults: synergy and probably not duality. *Gait & Posture*, 48, 57-63.

Bouisset, S. D. (1992). Posturo-kinetic capacity assessed in paraplegics and parkinsonians. In M. W. Horak., *Posture and Gait: Control Mechanisms, Vol. II, ed.* (pp. 19-22). University of Oregon Books.

Brian, E., Maki, P., William, E., & McIlroy, P. (1996). Postural Control in the Older Adult. *Clinics in Geriatric Medicine*, 12(4), 635-658.

Broadbent, D. E. (1958). *Perception and Communication.* New York: Pergamon Press.

Brodal, A. (1969). *The Somatic Afferent Pathways. Neurological Anatomy. 2nd ed.* New York: Oxford University Press; 31-116.

Bronstein, A. M., Brandt, T., Woollacott, M. H., & Nutt, J. G. (1996). Posture and Equilibrium. In J. Massion, & M. H. Woollacott, *Clinical Disorders of Balance, Posture and Gait* (pp. 1-20). London: Arnold.

Buschman, T., & Kastner, S. (2015). From Behavior to Neural Dynamics: An Integrated Theory of Attention. *Neuron Perspective*, 88(1), 127-44.

Caneiro, J., O'Sullivan, P., Burnett, A., Barach, A., O'Neil, D., & Tveit, O. (2010). The influence of different sitting postures on head/neck posture and muscle activity. *Man. Ther.*, 15, 54–60.

Carpenter, M., Frank, J., Winter, D., & Peysar, G. (2001). Sampling duration effects on centre of pressure summary measures. *Gait Posture*, 13, 35–40.

Cengiz, B. (2017). Effect of the vestibular system on search and fall behaviour of human postural sway. (Master's thesis). Middle East Technical University, Ankara.

Ceyte, H. C.-A. (2007). Effect of Achilles tendon vibration on postural orientation. *Neuroscience Letters*, 416(1), 71–75.

Chen, F.-C., & Tsai, C.-L. (2015). A light fingertip touch reduces postural sway in children with autism spectrum disorders. *Gait & Posture,* (43), 137-140.

Chen, F.-C., & Tsai, C.-L. (2016). Light finger contact concurrently reduces postural sway and enhances signal detection performance in children with developmental coordination disorder. *Gait & Posture*, 45, 193-197.

Chen, F.-C., Chen, H.-L., Tu, J.-H., & Tsai, C.-L. (2015). Effects of light touch on postural sway and visual search accuracy: A test of functional integration and resource competition hypotheses. *Gait & Posture*, (42), 280-284.

Chen, F.-C., Chu, C.-H., Pan, C.-Y., & Tsai, C.-L. (2018). Not just a light fingertip touch: A facilitation of functional integration between body sway and visual search in older adults. *Gait & Posture*, 62, 105-110.

Clayton, H., & Nauwelaerts, S. (2014). Effect of blindfolding on centre of pressure variables in healthy horses during quiet standing. *Vet. J.*, 199(3), 365-369.

Collins, J., & Luca, C. (1993). Open-loop and closed-loop control of posture: A random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research*, 95(2), 308–318.

Dalecki, M., Bock, O., & Hoffmann, U. (2013). Inverse relationship between task complexity and performance deficit in 5 m water immersion. *Experimental Brain Research*, 227, 243-248.

Deutsch, J. A. (1963). Attention: Some theoretical considerations. *Psychological Review*, 70(1), 80-90.

Dickstein, R. (2005). Stance stability with unilateral and bilateral light touch of an external stationary object. *Somatosensory Mot. Res.*, 22(4), 319-25.

Dickstein, R., Shupert, C., & Horak, F. (2001). Fingertip touch improves postural stability in patients with peripheral neuropathy. *Gait and Posture*, 14(3), 238-247.

Dickstein, R., Shupert, C., & Horak, F. (2001). Fingertip touch improves postural stability in patients with peripheral neuropathy. *Gait Posture*, 14(3), 238-247.

Diener, H., Dichgans, J., Guschlbauer, B., & Mau, H. (1984). The significance of proprioception on postural stabilization as assessed by ischemia. *Brain Research*, 296(1), 103-109.

Dietz, V., Trippel, M., & Horstmann, G. (1991). Significance of proprioceptive and vestibulo-spinal reflexes in the control of stance and gait. *In Advances in Psychology*, 78, 37-52.

Dietz, V., Trippel, M., & Horstmann, G. (1991). Significance of proprioceptive and vestibulo-spinal reflexes in the control of stance and gait. V. Dietz, M. Trippel, & G. Horstmann *In Advances in Psychology* (s. 78: 37-52). North-Holland.

Dos Santos, D. G., Prado-Rico, J., Alouche, S., Barroso de Souza Costa Garbus, R., Barbosa de Freitas, P., & Ferreira de Freitas, S. S. (2019). Combined effects of the light touch and cognitive task affect the components of postural sway. *Neuroscience Letters*, 703, 99-103.

Dos Santos, D. G., Prado-Rico, J., Alouche, S., Barroso de Souza Costa Garbus, R., Barbosa de Freitas, P., & Ferreira de Freitas, S. S. (2019). Combined effects of the light touch and cognitive task affect the components of postural sway. *Neuroscience Letters*, 11(703), 99-103.

Dos Santos, D. G., Prado-Rico, J., Alouche, S., Barroso de Souza Costa Garbus, R., Barbosa de Freitas, P., & Ferreira de Freitas, S. S. (2019). Combined effects of the light touch and cognitive task affect the components of postural sway. *Neuroscience Letters*, (703), 99-103.

Duarte, M. (2015). Comments on "Ellipse area calculations and their applicability in posturography" (Schubert and Kirchner, vol.39, pages 518-522, 2014). *Gait & Posture*, 41, 44-45.

Dunbar, K. &. (1984). A horse race of a different color: Stroop interference patterns with transformed words. *Journal of Experimental Psychology: Human Perception and Performance,* 10(5), 622–639.

Dux, P. E., & Marois, R. (2009). The attentional blink: A review of data and theory. *Attention, Perception, & Psychophysics*, 71(8), 1683-1700.

Ebersbach, G., Dimitrijevic, M., & Poewe, W. (1995). Influence of concurrent tasks on gait: a dual-task approach. *Perceptual Motor Skills*, 81(1), 107-13.

Estevan, I., Gandia, S., Villarrasa-Sapina, I., Luis Bermejo, J., & Garcia-Masso, X. (2018). Working Memory Task Influence in Postural Stability and Cognitive Function in Adolescents. *Motor Control*, 22(4), 425-435.

Fortier, S., & Basset, F. (2012). The effects of exercise on limb proprioceptive signals. *Journal of Electromyography and Kinesiology*, 22(6), 795–802.

Fraisse, P. (1969). Why is naming larger than reading? *Acta Psychologica*, 30, 90–103.

Friedman, A. P. (1982). Dividing attention within and between hemispheres: testing a multiple resources approach to limited-capacity information processing. *J. Exp. Psychol. Hum. Percept. Perform.*, 8 (5), 625–650.

Gandolfi, M., Vale, N., Filippetti, M., Dimitrova, E., Geroin, C., Picelli, A., & Smania, N. (2018). Postural control in individuals with Parkinson's disease. *In Physiotherapy*, 4(11), 5-18.

Gomes, M., & Barela, J. (2007). Postural Control in Down Syndrome: The Use of Somatosensory and Visual Information to Attenuate Body Sway. *Motor Control*, 11(3), 224-234.

Gurfinkel, V., Cacciatore, T., Cordo, P., Horak F., Nutt, J., & Skoss, R. (2006). Postural muscle tone in the body axis of healthy humans. *J. Neurophysiology*, 96(5), 2678–2687.

Gurfinkel, V., Ivanenko, Y., & Levik, Y. (1994). The contribution of foot deformation to the changes of muscular length and angle in the ankle joint during standing in man. *Physiol. Res.*, 43(6), 371–377.

Gurfinkel, V., Ivanenko, Y., Levik, Y., & Nabakova, I. (1995). Kinesthetic reference for human orthograde posture. *Neuroscience*, 68(1), 229–243.

Hadders-Algra, M. (2005). Development of Postural Control During the First 18 Months of Life. *Neural Plasticity*, 12(2-3), 99–108.

Harvey, N. (1984). The Stroop Effect: Failure to Focus Attention or Failure to Maintain Focusing? *The Quarterly Journal of Experimental Psychology Section A*, 36(1), 89–115.

Holden, M., Ventura, J., & Lackner, J. (1994). Stabilization of posture by precision contact of the index finger. *J Vestib Res*, 4(4), 285–301.

Horak, F. (2006). Postural control and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, 35(2), 117-1111.

Horak, F. (2009). *Postural Control. In: Binder M.D., Hirokawa N., Windhorst U. (eds) Encyclopedia of Neuroscience.* Berlin, Heidelberg: Springer.

Horak, F. B., Henry, S. M., & Shumway-Cook, A. (1997). Postural perturbations: new insights for treatment of balance disorders. *Phys Ther*, 77(5), 517-33.

Horak, F., & Diener, H. (1994). Cerebellar control of postural scaling and central set in stance. *J Neurophysiol*, 72(2, 479–493.

Horak, F., & Frank, J. (1996). Effects of dopamine on postural control in parkinsonian subjects: scaling, set and tone. *J Neurophysiol*, 75(6), 2380–2396.

Horak, F., & Macpherson, J. (1996). *Published for the American Physiology Society by Oxford University Press*, 255-292.

Horak, F., & Macpherson, J. (1996). In: Handbook of Physiology. Exercise: Regulation and Integration of Multiple Systems. F. Horak, & J. Macpherson in *Postural orientation and equilibrium* (s. 255-292). New York: Published for the American Physiology Society by Oxford University Press.

Horak, F., & MacPherson, J. (1996). *Postural equilibrium and orientation.* New York, 255-292: American Physiology Society by Oxford University.

Horak, F., Diener, H., & Nashner, L. (1989). Influence of central set on human postural responses. *Journal of neurophysiology*, 62(4), 841-853.

Hwang, S., Agada, P., Kiemel, T., & Jeka, J. (2016). Identification of the Unstable Human Postural Control System. *Frontiers in Systems Neuroscience*, 10, 22.

Imbrosciano, A., & Berlach, R. G. (2006). The Stroop Test and its Relationship to Academic Performance and General Behaviour of Young Students. *Teacher Development*, 9(1), 131-144.

Ivanenko, Y., & Gurfinkel, V. (2018). Human Postural Control. *Frontiers in Neuroscience*, 12, 171.

James, W. (1890). Attention. *The principles of psychology*, 1, 402-458.

Jeannerod, M. (1988). *The Neural and Behavioral Organization of Goal-directed Movements.* Oxford: Clarendon Press.

Jeka, J. (2006). Light touch contact: not just for surfers. *Neuromorphic Engineer*, (3), 3-6.

Jeka, J. J. (1997). Light Touch Contact as a Balance Aid. *Physical Therapy*, 77(5), 476-87.

Jeka, J., & Lackner, J. (1994). Fingertip contact influences human postural control. *Experimental Brain Research*, 100(3), 495-502.

Jeka, J., & Lackner, J. (1995). The role of haptic cues from rough and slippery surfaces in human postural control. *Experimental Brain Research*, 103(2), 263-276.

Jeka, J., Schoner, G., Dijkstra, T., Ribeiro, P., & Lackner, J. (1997). Coupling of fingertip somatosensory information to head and body sway. *Experimental Brain Research*, 113(3), 478-483.

Jeong, B. (1991). Respiration effect on standing balance. *Archives of physical medicine and rehabilitation*, 72(9), 642-645.

Kahneman, D. (1973). Attention and Effort. *Englewood Cliffs, NJ: Prentice-Hall*, Vol: 1063.

Kanekar, N., & Aruin, A. (2014). Aging and balance control in response to external perturbations: role of anticipatory and compensatory postural mechanisms. *American Aging Association*, 36(3), 9621.

Kanekar, N., Lee, Y.-J., & Aruin, A. (2012). Effect of light finger touch in balance control of individuals with multiple sclerosis. *Gait & Posture*, (38), 643-647.

Kavounoudias, A., Gilhodes, J.-C., Roll, R., & Roll, J.-P. (1999). From balance regulation to body orientation: two goals for muscle proprioceptive information processing. *Experimental Brain Research*, 124(1), 80–88.

Keele, S. (1973). *Attention and human performance.* California: Goodyear; Pacific Palisades.

Keele, S. W. (1972). Attention demands of memory retrieval. *Journal of Experimental Psychology*, 93(2), 245–248.

Kendall, F., & McCreary, E. (1984). “Muscles, Testing and Function” (Third Edition). *Br J Sports Med.,* Mar; 18(1), 25.

Kihlstrom, J. P. (2018). Cognitive psychology: Overview. J. P. Kihlstrom in, *Reference Module in Neuroscience and Biobehavioral Psychology* (s. 1-14). New York: Elsevier.

Lackner JR, R. E. (2000). Fingertip contact suppresses the destabilizing influence of leg muscle vibration. *J Neurophysiol*, 84, 2217–2224.

Lackner, J. (1988). Some proprioceptive influences on the perceptual representation of body shape and orientation. B. *Brain*, 1 (11), 281-297.

Lackner, J., & Dizio, P. (2000). Aspects of body self-calibration. *Trends in Cognitive Sciences*, 4(7), 279–288.

Lackner, J., Rabin, E., & Dizio, P. (2000). Fingertip contact suppresses the destabilizing influence of leg muscle vibration. *J Neurophysiol*, 84, 2217–2224.

Lacour, M., Bernard-Demanze, L., & Dumitrescu, M. (2008). Posture control, aging, and attention resources: Models and posture-analysis methods. *Neurophysiologie Clinique/Clinical Neurophysiology*, 38 (6), 411–421.

Laessoe, U., & Voigt, M. (2018). *Gait & Posture*, (28), 62-68.

Lajoie, Y., Jehu, D., Richer, N., & Chan, A. (2017). Continuous and difficult discrete cognitive tasks promote improved stability in older adults. *Gait & Posture*, 55, 43-48.

Lajoie, Y., Richer, N., Jehu, D. A., & Tran Ylan. (2016). Continuous Cognitive Tasks Improve Postural Control Compared to Discrete Cognitive Tasks. *Journal of Motor Behaviour*, 48(3), 264-269.

Lee, D., & Lishman, J. (1975). Visual proprioceptive control of stance. *Journal of Human Movement Studies*, 1(2), 87–95.

Lee, F., & Taatgen, N. (2002). Multitasking as skill acquisition. *Proceedings of the Fifth International Conference on Cognitive Modeling*, 225-230.

Lee, Y. G. (2018). Effect of a cognitive task and light finger touch on standing balance in healthy adults. *Experimental Brain Research*, 236, 399-407.

Legrand, A., Mazars, K., Lazzareschi, J., Lemoine, C., Olivier, I., Barra, J., & Bucci, M. (2013). Differing effects of prosaccades and ant saccades on postural stability. *Exp. Brain Res.*, (3), 397-405.

Leone, C., Feys, P., Moumdjian, L., D'Amico, E., Zappia, M., & Patti, F. (2017). Cognitive-motor dual-task interference: A systematic review of neural correlates. *Neurosci Biobehav Rev*, 75, 348-360.

Macpherson, J., & Fung, J. (1999). Weight support and balance stance in the chronic spinal cat. *J Neurophysiol*, 82(6), 3066–3081.

Madeleine, P., Nielsen, M., & Arendt-Nielsen, L. (2011). Characterization of postural control deficit in whiplash patients by means of linear and nonlinear analyses – A pilot study. *Journal of Electromyography and Kinesiology,* 21(2), 291–297.

Maki, B., & Mcllroy, W. (2007). Cognitive demands and cortical control of human balance-recovery reactions. *J Neural Transm*, 114(10), 1279-96.

Marcos, D., & Watanabe, R. N. (2021). Notes on Scientific Computing for Biomechanics and Motor Control. Zenodo. March 11.

Marsden, C., Mertton, P., & Morton HB. (1981). Human postural responses. *Brain*, 104(3), 513-534.

Massion, J. (1994). Postural control system. *Current opinion in neurobiology*, 4(6), 877-887.

Massion, J. (1998). Postural control systems in developmental perspective. *Neuroscience and Biobehavioral Reviews*, 22(4), 465–72.

Matthews, P. (1988). Proprioceptors and their contribution to somatosensory mapping: complex messages require complex processing. *Can J Phyiol Phannacol.*, 63(6), 430-438.

McCollum, G., Shupert, C., & Nashner, L. (1996). Organizing sensory information for postural control in altered sensory environments. *J Theor Biol.*, 7;180(3), 257-70.

McLeod, P. (1977). Parallel processing and the psychological refractory period. *Acta Psychol (Amst),* 41, 381—96.

McNevin, N., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Hum Mov Sci*, 21, 187–202.

Mergner, T., Maurer, C., & Peterka, R. (2003). A multisensory posture control model of human upright stance. *Progress in Brain Research Neural Control of Space Coding and Action Production*, 142, 189-201.

Mitra, S. (2003). Postural costs of suprapostural task load. *Hum Mov Sci*, 22, 253—70.

Mohapatra, S. K. (2011). Postural control in response to an external perturbation: effect of altered proprioceptive information. *Experimental Brain Research*, 217(2), 197–208.

Moore, S., Rushmer, D., Windus, S., & Nashner, L. (1988). Human automatic postural responses: responses to horizontal perturbations of stance in multiple directions. *Exp Brain Res.*, 73(3), 648-58.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological review*, 86(3), 214.

Navon, D., & Miller, J. (1987). Role of outcome conflict in dual-task interference. *J Exp Psychol Hum Percept Perform*, 13, 435—438.

Nijboer, M., Borst, J., van Rijn H., & Taatgen, N. (2014). Single-task fMRI overlap predicts concurrent multitasking interference. *NeuroImage*, 100, 60-74.

Panjan, A., & Šarabon, N. (2010). Review of Methods for the Evaluation of Human Body Balance. *Sport Science Review*, XIX, 5-6.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychol. Bull.,* 116 (2), 220–244.

Pellecchia, G. (2003). Postural sway increases with attentional demands of on current cognitive task. *Gait and Posture.*, 18, 29–34.

Pérennou, D., Decavel, P., Manckoundia, P., Penven, Y., Mourey, F., Launay, F., & Pfitzenmeyer, P. (2005). Evaluation of balance in neurologic and geriatric disorders. *Annales De Réadaptation Et De Médecine Physique: Revue Scientifique De La Société Française De Rééducation Fonctionnelle De Réadaptation Et De Médecine Physique*, 48(6), 317-335.

Peterka, R. (2002). Sensorimotor Integration in Human Postural Control. *Journal of Neurophysiology*, 88(3), 1097–1118.

Philips, C. (1986). *Movements of the Hand.* Liverpool, United Kingdom: Liverpool University Press.

Plummer, P., Eskes, G., Wallace, S., Clare, G., Fraas, M., Campbell, G., Skidmore, E. (2013). Cognitive-Motor Interference During Functional Mobility After Stroke: State of the Science and Implications for Future Research. *Arch Phys Med Rehabil.*, 94(12), 2565-2574.

Polskaia, N., & Lajoie, Y. (2016). Reducing postural sway by concurrently performing challenging cognitive tasks. *Human Movement Science*, 46, 177-183.

Rabin, E., Dizio, P., Ventura, J., & Lackner, J. (2008). Influences of Arm Proprioception and Degrees of Freedom on Postural Control with Light Touch Feedback. *Journal of Neurophysiology*, 99(2), 595-604.

Redick, T. S., & Engle, R. W. (2006). Working memory capacity and attention network test performance. *Applied Cognitive Psychology*, 20(5), 713–721.

Révész, A., Michel, M., & Gilabert, R. (2016). Measuring cognitive task demands using dual-task methodology, subjective self-ratings, and expert judgements. *Studies in Second Language Acquisition*, 38, 703–737.

Riccio, G., & Stoffregen, T. (1988). Affordances as constraints on the control of stance. *Hum Mov Sci*, 7, 265—300.

Roerdink, M., De Haart, M., Daffertshofer, A., Donker, S., Geurts, A., & Beek, P. (2006). Dynamical structure of center-of-pressure trajectories in patients recovering from stroke. *Exp Brain Res.*, 174(2), 256-69.

Rougier, P. R., & Bonnet, C. T. (2016). How providing more or less time to solve a cognitive task interferes with upright stance control; a posturographic analysis on healthy young adults. *Human Movement Science*, (47), 106–115.

Saffer, M., Kiemel, T., & Jeka, J. (2008). Coherence analysis of muscle activity during quiet stance. *Exp Brain Res.*, 185(2), 215–226.

Schmidt, R. A., Lee, T. D., Winstein, C. J., Wulf, G., & Zelaznik, H. N. (1999). *Motor Control and Learning: A behavioral emphasis.* Champaign: IL: Human Kinetics.

Schmitz, C., Martin, N., & Assaiante, C. (2002). Building anticipatory postural adjustment during childhood: A kinematic and electromyographic analysis of unloading in children from 4 to 8 years of age. *Experimantal Brain Research*, 142(3), 354–364.

Sherrington, C. (1947). *The integrative action of the nervous system,* New Haven: 2nd edn.: Yale University Press, 1947.

Shumway-Cook, A., & Woollacott, M. (2000). Attentional demands and postural control: the effect of sensory context. *J Gerontol A Biol Sci Med Sci*, Jan;55(1), M10-6.

Singer, R., Hausenblas, H., & Janelle, C. (2001). Handbook of research on sport psychology. B. Abernethy in, *Attention* (s. 2nd ed., pp. 53–85). New York: Wiley.

Srinivasan, M., Whitehpuse, J., & LaMotte, R. (1990). Tactile detection of slip: surface microgeometry and peripheral neural codes. *Journal of Neurophysiology*, 63(6), 1323-1332.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643–662.

Swan, L., Otani, H., & Loubert, P. V. (2007). Reducing postural sway by manipulating the difficulty levels of a cognitive task and a balance task. *Gait & Posture*, 26(3), 470-4.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285.

Tinetti, M., Speechley, M., & Ginter, S. (1988). Risk factors for falls among elderly persons living in the community. *N Engl J Med*, 319(26), 1701-7.

Tombu, M., & Jolicoeur, P. (2003). A central capacity sharing model of dual-task performance. *J Exp Psychol-Hum Percept Perform*, 29, 3-18.

Towey, G., Fabio, R., & Capri, T. (2019). Measurement of attention. In T. F. In Caprì, *Psychology Research Progress* (pp. 42-83). New York: Nova Science Publisher.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology*, 12, 242–248.

Treisman, A. M. (1964). The Effect of Irrelevant Material on the Efficiency of Selective Listening. *The American Journal of Psychology.*, 77(4), 533–546.

Treisman, A., & Riley, J. (1969). Is selective attention selective perception or selective response? A further test. *Journal of Experimental Psychology*, 79(1), 27–34.

Van der Fits, I. B.-A. (1998). The development of postural response patterns during reaching in healthy infants. *Neuoroscience and Biobehavioral Reviews*, 22(4), 521–6.

Watson, M., & Black, F. (2008). *The human balance system: A complex coordination of central and peripheral systems.* Portland: OR: Vestibular Disorder.

Wickens, C. (1980). *The structure of attentional resources. Attention and performance.* VIII 8.

Wickens, C. (2008). Multiple Resources and Mental Workload. *The Journal of the Human Factors and Ergonomics Society*, 50(3), 449-55.

Wickens, C. D. (1976). The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance*, 2(1), 1–13.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, 3(2), 159-177.

Winter, D. (1995). Human balance and posture control during standing and walking, GaitPosture. *Gait & Posture*, 3:193–214.

Winter, D., Patla, A., Ishac, M., & Gage, W. (2003). Motor mechanisms of balance during quiet standing. *J. Electromyogr. Kinesiol*, 13(1), 49-56.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of the posture and gait: a review of an emerging area of research. *Gait & Posture*, 16(1), 1-14.

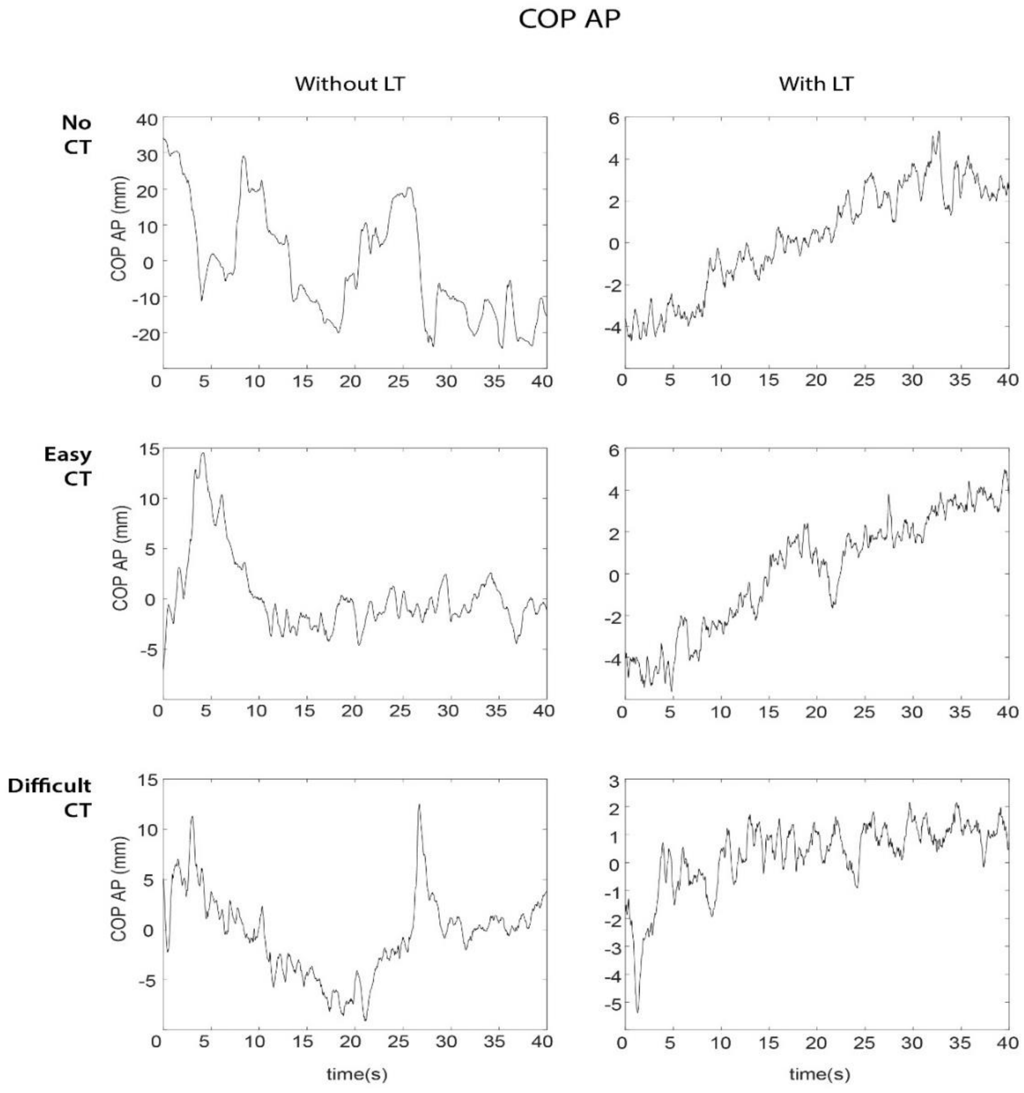
Wulf, G. (2007). Attentional focus and motor learning: a review of 10 years of research. *E-journal Bewegung Train*, 1, 1–11.

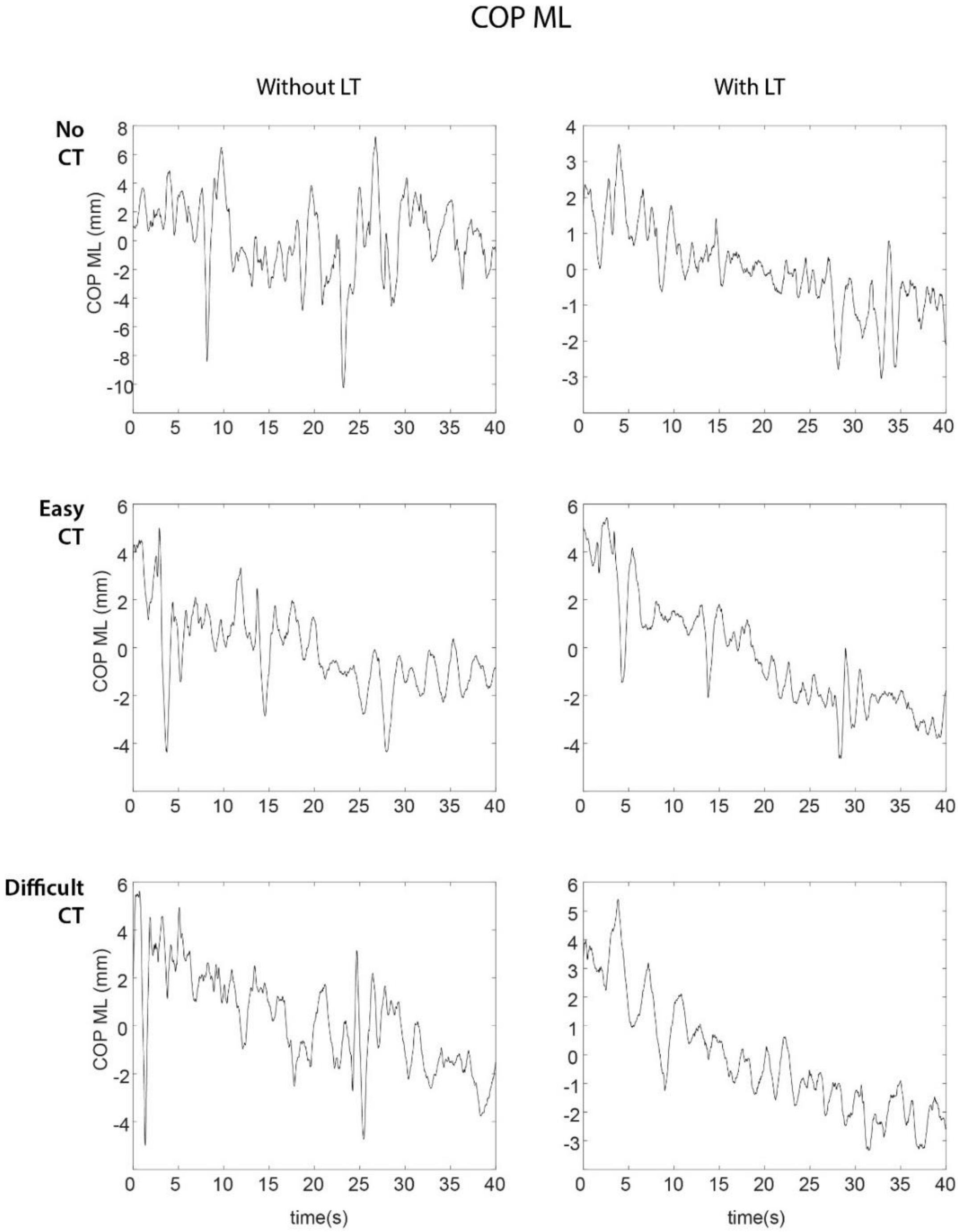
Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 54(4), 1143-1154.

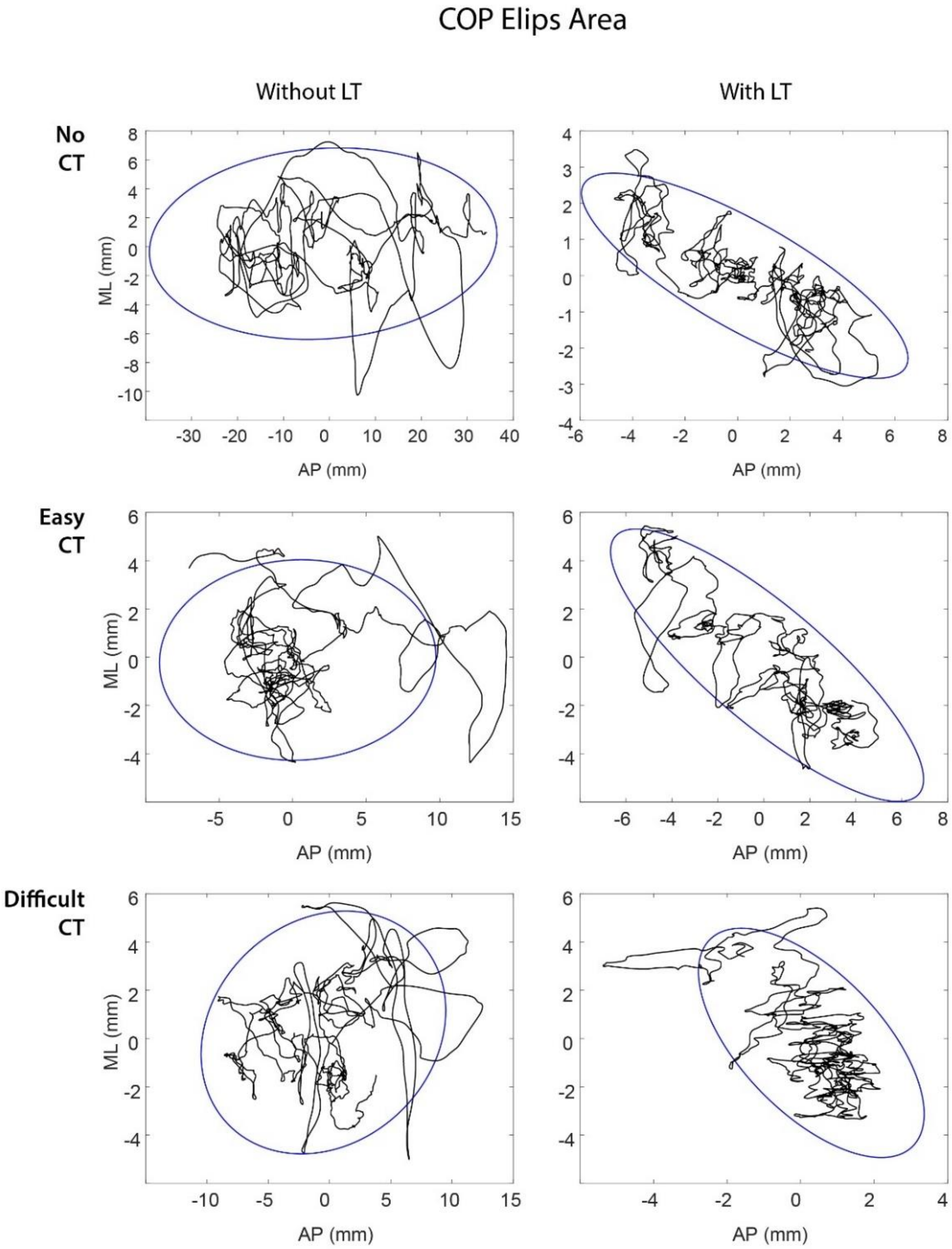
APPENDICES

A: SAMPLE COP GRAPHS

Below are graphs that illustrate COP graphs of a participant in light Touch and no light touch conditions in combination with cognitive tasks (none/easy/difficult).




COP ML
Without LT
With LT
No CT
Easy CT
Difficult CT
COP ML (mm)
time(s)


COP Elips Area
Without LT
With LT
No CT
Easy CT
Difficult CT
ML (mm)
AP (mm)

B: APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

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14 NİSAN 2020

Konu : Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi : İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Doç. Dr. Sadettin KİRAZCI

Danışmanlığını yaptığınız Tuğba ÇELİK'in "Bilişsel görev zorluğu ve hafif dokunuşun postür kontrolü üzerine kombine etkisi" başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **116-ODTU-2020** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Dr. Öğretim Üyesi Şerife SEVİNÇ
İAEK Başkan Vekili

C: TURKISH SUMMARY / TÜRKÇE ÖZET

HAFİF DOKUNMA VE BİLİŞSEL GÖREV ZORLUĞUNUN POSTÜR KONTROLÜNE KOMBİNE ETKİSİ

GİRİŞ

Hayatımızın sürdürülmesi için, özellikle günlük görevler için belirli bir düzeyde postüral kontrol gereklidir. Gün içinde bilinçli veya bilinçsiz olarak gerçekleştirdiğimiz birçok postüral eylem vardır.

İnsan postüral kontrolü antik Yunan'dan beri bir araştırma konusudur ve yerçekimsel bir ortamda denge ve yönelimi koruyabilme yeteneği olarak tanımlanmaktadır. Horak & (Ivanenko & gurfinkel, 2018; Horak & Macpherson, 1996) Macpherson'a (1996) göre, postüral kontrolün iki davranışsal amacı vardır: postüral oryantasyon ve postüral denge. Postüral oryantasyon, vücut segmentlerinin birbirine ve çevreye göre konumlandırılması olarak tanımlanabilir; postürel denge ise vücut üzerinde hareket eden tüm iç ve dış kuvvetlerin istenen pozisyonu korumak için dengede olduğu bir durumdur. İnsan iki ayaklı duruşu stabil değildir, sakin bir duruş pozisyonunda bile, postüral kontrol sistemi dik duruşu sürdürebilmek için aktif kalır. Bu karmaşık sensorimotor görev, omurilik, beyin sapı, beyincik ve korteksi içeren çeşitli nörolojik yapıların çalışmasını gerektirir. İnsan dik duruşunun sağlanması, sadece CNS'den gelen komutlara değil, aynı zamanda görsel, somatosensöri ve vestibüler girdilerin entegrasyonuna ve bu sistemlerin çevresel değişikliklere göre adaptasyonuna da bağlıdır (Rougier & Bonnet, 2016; Shumway-Cook & Woollacott, 2000).

Postüral kontrol, insanların günlük yaşamları boyunca yürütmeleri gereken izole bir görev değildir. Günlük görevlerimizin çoğu, sabit veya dinamik bir ortamda vücut pozisyonunu korumak gibi çeşitli zorluk seviyelerine sahip bilişsel bir görev ve postüral bir görevin kombinasyonunu içerir. Çoklu görev biçimi olarak, çift görev aynı anda birden fazla görevin yerine getirilmesidir (Lee & Taatgen, 2002) ve günlük yaşamlarımız boyunca yaygın olarak kullanılır (Wickens, 2008; Lee & Taatgen, 2002). Bir insanın dikkat kapasitesinin aynı anda iki veya daha fazla görevi yerine getirmekle sınırlı olduğu iyi bilinmektedir. Bu sınırlama şu soruları beraberinde getirir (Abernethy, 1988): İnsan postüral kontrolü için belirli bir dikkat gerekir mi veya belirli bir dikkat olmadan sadece otomatik süreçlerle mi kontrol edilir?

Postüral kontrolün minimum bilgi işleme gerektiren otomatik süreçler yoluyla sürdürüldüğü düşünülse de bazı araştırmalar postüral kontrolün önemli ölçüde bilgi işleme gerektirdiğini göstermektedir. Dikkat görevler arasında (Woollacott & Shumway-Cook, 2002) toplam kapasiteyi aşılacak şekilde bölündüğünde, bir veya daha fazla görevde artan hatalar veya gecikmeli yanıtlar oluşur. Bu durumda, ikili görev paradigması ortaya çıkar. (Singer, Hausenblas, & Janelle, 2001)

İkili görev paradigması, iki görevin (birincil görev ve ikincil görev) eşzamanlı performansının varlığındaki performansı değerlendirmek için kullanılan bir metodolojidir. Birçok araştırmacı, ikili görevin sınırlı dikkat kapasitesi nedeniyle postüral kontrolü bozduğunu iddia ederken, (Donker, 2007; Polskaia &Lajoie,2016; Murillo ve ark.,2012), bazıları ise ikili görevin postüral kontrolün otomatizasyonunu sağlayarak postürü geliştirdiğini belirtir (Bergamin, vd., 2014; Pellecchia, 2003; Swan, Otani, & Loubert, 2007; Stevens, Barbour, Meredith, & Timothy, 2016).

Postüral kontrolü etkileyen bir diğer faktör de somatosensör sistemin bilinçli dokunma ve basınç algısı ile işlediği mekanik bir uyaran olan "hafif dokunma"dır. Genellikle, vücudun çok küçük bir kısmı (örneğin, işaret parmağı) sabit bir yüzeyle temas halindedir ve bu temas mekanik bir destek sağlamaksızın postür salınımını azaltır (Lackner & Dizio, 2000; Jeka, 2006). Hafif dokunuş, işaret parmağın 1N'den daha az bir kuvvetle sabit bir yüzeye dokunması olarak tanımlanır ve ek duyusal bilgi sağladığı varsayılır (Holden, Ventura, & Lackner, 1994).

Hafif dokunuşunun postür kontrolü üzerindeki olumlu etkileri çeşitli popülasyonlarda görülmüştür. Örneğin multipl skleroz, down sendromu, otizm, (Kanekar, Lee, & aruin, 2012) gelişimsel koordinasyon bozukluğu (Chen & Tsai, 2016) ve periferik nöropati tanısı alan kişilerde hafif dokunma ve (Gomes & Barela, 2007) postür arasındaki ilişkiler araştırılmış ve hafif dokunmanın postür kontrolü üzerindeki olumlu etkileri raporlanmıştır (Chen & Tsai, 2015; Dickstein, Shupert, & Horak, 2001).

Üç görevi aynı anda gerçekleştirmenin sonuçları – 1) Postüral Görev, 2) Bilişsel Görev, 3) Hafif Dokunuş postür kontrolü üzerindeki etkisi bilişsel görevin postür üzerine etkisi iyi belgelenemediğinden iyi bilinmemektedir (Chen, Chen, Tu, & Tsai, 2015; Baldan A., Alouche, Aroujo, & Freitas, 2014).

Lee ve ark., (2018) sağlıklı yetişkinlerle bir çalışma yaptı ve hafif dokunuş ve eşzamanlı bilişsel görevin postüral kontrol üzerindeki etkisini araştırdı. Sonuçlar, sakin duruş sırasında vücut salınımının bu ikili görevin performansından önemli ölçüde etkilenmediğini gösterdi. Hafif dokunuşun vücut salınımı üzerindeki olumlu etkisinin, bilişsel görevin vücut salınımı üzerindeki olumsuz etkisi nedeniyle azalabileceği öne sürülmüştür.

Literatürün bulguları göz önüne alındığında, bu çalışma bilişsel görev zorluğu seviyesini değiştirerek hafif dokunuşun ve bilişsel görevin postur kontrolü üzerindeki kombine etkilerini araştırmayı amaçlamaktadır. Dikkati iki farklı zorluk seviyesinde bilişsel görevlere yönlendirmenin postur kontrolünü farklı şekilde etkileyebileceği ve bu nedenle hafif dokunuşla birlikte gerçekleştirildiğinde postur kontrolü üzerinde de farklı etkileri olabileceği öne sürülmüştür.

LİTERATÜR TARAMASI

Postür Kontrolü

Postür kontrolü, merkezi sinir sistemimizin (MSS) kontrollü, dik bir duruşun sürdürülmesi için diğer kaynaklardan gelen duyusal bilgileri nasıl düzenlediğini açıklayan bir terimdir. Somatosensöri, görsel ve vestibüler sistemler, postür kontrolü ve dengeyi sağlayan üç ana bileşendir (Ivanenko & Gurfinkel, 2018; Alcock, O'Brien, & Vanicek, 2018). Bu üç bileşenin herhangi birinde bir sorun oluşursa, diğer ikisi bu sorunu telafi edebilir (Horak F., 2006).

Posturel Kontrol Mekanizmaları

Posturel Kontrolün Biyomekanik ve Kas-İskelet Özellikleri

Bir davranış olarak postüral kontrolün üç ana görevi vardır: 1) vücut segmentlerinin hizalanması, 2) postüral denge, 3) postüral oryantasyon. Dik duruş öncelikle postüral tonun varlığı ve vücut segmentlerinin hizalanması ile sağlanır. Bu hizalamanın elde edilmesiyle, vücudun ağırlık merkezi destek tabanı içinde tutulmalıdır. Bu, postüral görevin ikinci kısmını oluşturur; postürel denge. Postürel denge, vücut üzerinde hareket eden tüm iç ve dış kuvvetlerin istenen pozisyonu korumak için dengede olduğu bir durum olarak tanımlanır. Son olarak, postüral görev çevre ile ilgili olarak bedensel yönelimi korumayı içerir. Bu görevler tamamlandıktan sonra duruş, farklı segmentler arasındaki etkileşimi düzenleyerek ve hareket sırasında eklem sertliğini ayarlayarak eylemler için mekanik destek sağlar. (Bronstein, Brandt, Woollacott, & Nutt, 1996; Horak & MacPherson, 1996).

Duyusal Sistem ve Postürel Kontrol

Duyusal sistem, görsel, vestibüler, somatosensör ve proprioseptif sistemler dahil olmak üzere duyu sistemlerinin entegrasyonu ile CNS'ye bilgi göndererek postürel kontrolde önemli rol oynayan bir bileşendir (Massion, 1994). Göreve ve çevresel bağlam gereksinimlerine göre görsel, vestibüler ve somatosensör sistemlerin katkısı değişebilir.

Görsel sistem, çevresel ipuçlarına göre vücut konumunun ve yönünün belirlenmesinde rol oynar (Watson & Siyah, 2008). Görsel bilgilerin yokluğunun veya eksikliğinin postüral kontrolde bozulmaya yol açtığı da bilinmektedir. (Watson & Siyah, 2008)

Vestibüler sistem duyusal sistemin önemli bir parçasıdır ve hareket, denge ve mekansal yönelim dahil olmak üzere bilgi sağlar ve böylece postürel dengenin korunmasına yardımcı olur. Kısacası, vestibüler sistem yerçekimi ve atalet kuvvetleri hakkındaki bilgileri motor sistemine iletir.

Somatosensör sistemin ana rolü dokunma, basınç, konum, sıcaklık, titreşim ve hareketi algılamaktır. Somatosensör sistem, temas yüzeyinin kuvvetleri ve özellikleri ve vücut segmentlerinin göreli konfigürasyonu hakkında bilgi sağlamaktan sorumludur (Brodal, 1969; Horak & MacPherson, 1996).

Somatosensöri Sistem ve Hafif Dokunuş

Hafif dokunuş, işaret parmağı ile 1N'den fazla olmayan bir kuvvetle sabit bir yüzeye hafifçe dokunmak olarak tanımlanır. Holden ve diğerleri. (1994), sabit bir yüzeydeki parmak ucu temasının postürel kontrolü geliştirebileceğini göstermiştir, ancak temas kuvvetleri mekanik destek sağlayacak kadar büyük değildir. Somatosensör ipuçları, postüral kontrolün organizasyonu için çok önemli bir yönelim referansıdır.

Merkezi Sinir Sistemi (MSS) ve Postüral Kontrol

Sakin duruş, basit bir statik durum olmaktan ziyade sensorimotor süreçlerin yoğun etkileşimi ve bu süreçlerin sonucu olarak tanımlanır (Horak & Macpherson, 1996). MSS, hem dış (çevresel değişimler) hem de iç (görsel, vestibüler ve proprioseptif sistemler) kaynaklardan farklı türde bilgiler alır. Bu bilgileri kullanarak, MSS duyusal bilgilerin düzenlenmesinde ve gerekli reaksiyonların yürütülmesinin planlanmasında rol oynar (Lee & Lishman, 1975; McCollum, Shupert, & Nashner, 1996)

Sakin duruş bozulunca, MSS dengeyi yeniden sağlamak için reaksiyonları düzenler. Reaksiyon stratejisinin türü (ayak bileği stratejisi, kalça stratejisi ve adım alma stratejisi) perturbansın yönüne ve büyüklüğüne göre seçilir (Moore, Rushmer, Windus, & Nashner, 1988).

Dikkat

Dikkat Teorisi

Çeşitli dikkat teorilerinde dikkat, algı ve hafıza arasındaki bağlantı olarak kabul edilir. İlk dikkat teorileri, dikkatin seçici olduğunu ve işlem kapasitesinin sınırlı olduğunu varsayarken (Kahneman, 1973), sonraki teoriler dikkatin birden fazla kaynağı olduğu ve sınırlı olmadığını iddia etmiştir (Wickens C., 1980).

Stroop Etkisi ve Dikkat

Stroop testi hem uyumlu (örneğin, kırmızı renk mürekkeple yazılmış "kırmızı" kelimesi) hem de uyumsuz modda (örneğin, "sarı" renkli mürekkeple yazılmış "kırmızı" kelimesi) renkli kelimeleri içerir. Katılımcılardan kelimenin yazıldığı mürekkep rengini adlandırmaları istenir.

Dikkat ve Postüral Kontrol

Geleneksel görüşe göre, postüral kontrol bilgi işleme için minimum bilinç gerektirir ve refleksif olarak kontrol edilir (Kerr, 1985; Pellecchia, 2003). Bununla birlikte, dikkat kaynaklarının postüral kontrolün organizasyonunda rol oynadığını öne süren karşıt görüşler vardır.

Pellecchia (2003), eşzamanlı bilişsel görevlerin zorluğu açısından postüral kontrolü inceledi. Sakin duruş sırasında deneklere 3 saniye boyunca geriye doğru sayılan rakamları tersine çevirme ve basamak sınıflandırması görevleri verildi. Sonuçlar, bilişsel görevlerin dikkat taleplerindeki artışın postüral duruş sırasında salınımda artışa neden olduğunu göstermiştir. Bu sonuç, artan dikkat talep düzeyiyle görev entegrasyonunun daha zor hale geldiğini gösterebilir. Ancak, çocuklarla yapılan benzer bir çalışmada Blanchard ve ark. (2005) farklı sonuçlar gözlemlendi. 19 çocuk güç platformunda üç farklı görev gerçekleştirdi: sessiz duruş, geriye doğru sayma ve ikinci sınıf düzeyinde cümleler okuma. Sonuçlar, çocukların artan dikkat talepleri ile salınımları azaltarak postürel duruşlarını ayarlayabildiklerini ortaya koydu. Bunun nedeni, yazarın açıkladığı gibi çocuklar tarafından benimsenen farklı stratejiler olabilir.

Öte yandan, Shumway-Cook ve Woollacott'un (2000) bulguları, postüral kontrolün sadece duyusal bilgilere refleksif bir yanıt olmadığını göstermektedir. 18 genç yetişkin ve 36 yaşlı (18'i düşme veya denge bozukluğu öyküsü olan ve 18'i düşme öyküsü olmayan) çalışmaya katıldı ve işitsel bilişsel görevi yerine getirdi. İşitsel görev altı farklı duyusal koşulda yerine getirildi. Bu koşullar, postüral kontrol için gerekli olan doğru görsel ve somatosensör ipuçlarının kullanılabilirliğini değiştirdi. Sonuçlar, işitsel görevin performansının duyusal bağlamın hiçbirinde genç yetişkinlerde postürel dengeyi etkilemediğini göstermiştir. Ancak yaşlı yetişkinlerde durum farklıydı. Duyusal bilgiler azaldıkça postüral kontrolün dikkat talebi arttı. Ek olarak, bu artış denge bozukluğu olan yaşlılar için tüm duyusal bağlamlarda mevcutken, sağlıklı yaşlılar için hem görsel hem de somatosensör ipuçları kaldırıldığında mevcuttu.

İkili Görev Metodolojisi ve Postüral Kontrol

Literatürde, ikili görev paradigması altında bulunan mekanizma henüz net değildir. Bir motor ve bilişsel görev aynı anda gerçekleştirildiğinde, bu performanslar bu eşzamanlı yürütmeden etkilenebilir. Aynı anda iki farklı görev gerçekleştirildiğinde, bir veya her iki görevin performansı bozulabilir. Buna "ikili görev enterferansı" denir (Shumway-Cook & Woollacott, 2000; Leone, vd., 2017; Friedman, 1982

YÖNTEM

Çalışmaya yaşları 18-40 arasında değişen sağlıklı 18 birey gönüllü olarak katılmıştır

Protokol 1: Motor Görev (Yalnızca Sakin Duruş)

Sakin duruş görevi üç tekrar ile gerçekleştirdi. Katılımcılardan kuvvet platformunun üzerinde ayaklar omuz genişliğinde açık ve kollar yanda salınırken rahat bir pozisyonda beklenmeleri istendi.

Protokol 2: İkili Görev (Sakin Duruş ve Bilişsel Görev Denemeleri)

Bilişsel görev denemeleri, hafif dokunuşla ve hafif dokunuş olmadan farklı zorluk seviyeleri için tekrar edildi. Bilişsel görevler rastgele bir sıra ile katılımcılara sunuldu. Her bir tekrar 40 sn sürdü ve üç başarılı tekrardan sonra bir deneme tamamlandı.

Protokol 3: Hafif Dokunuş Denemeleri (Bilişsel Görev ile /Bilişsel Görev olmadan Sakin Duruş)

Hafif dokunuş denemelerinde katılımcılar sakin duruş sırasında tercih ettikleri elleriyle metal sensöre işaret parmakları ile hafifçe dokundular. Bu sırada dirsek 90° ve diğer parmaklar bükülü idi. Katılımcılar 1N'u geçen bir kuvvet uyguladığı zaman test uygulayıcısı bunu takip edip denemeyi sonlandırabilir durumdaydı. Hafif dokunuş denemeleri bilişsel görevlerle birlikte ve bilişsel görev olmadan tekrar edildi. Her bir tekrar 40 sn sürdü ve üç başarılı tekrardan sonra bir deneme tamamlandı.

İstatistiksel Analiz

Bağımlı değişkenler olarak belirlenen altı COP parametresi; COP ortalama hız ($COP_{VEL)}$, COP elips alanı (COP_{EA}), COParalığı (COParalığı AP ve COParalığı ML), rms COP değerleri AP (rms_{AP}) ve ML (rms_{ML}). Her deneme için tüm COP değerleri hesaplandı. Bilişsel görevin zorluk seviyeleri (3 seviye; hiçbiri, kolay, zor) ve hafif dokunuşun varlığı (iki seviye; evet, hayır) faktörler olarak dahil edildi. Her giriş, konu içi deneme değişkenliğinin etkisini ortadan kaldırmak için ortalama üç özdeş denemeye karşılık gelir. Alfa anlamlılık düzeyi $p<0,05$ olarak belirlendi. Tüm denekler aynı faktörler için birden çok kez ölçüldüğünden, her bir COP parametresi için ayrı ayrı (iki yönlü tekrarlanan ölçümler ANOVA) yapılmıştır.

SONUÇLAR

Ana Bulgular

Bilişsel Görev x Hafif Dokunuş Etkileşimi

COP ortalama hızı haricinde bütün COP parametrelerinde bilişsel görev ve hafif dokunuş arasında etkileşim bulunmuştur.

Tablo 1. CT x LT Etkileşimi için Varyans Analizi

Basınç Merkezi Parametreleri		Bilişsel Görev Yok		Kolay Bilişsel Görev		Zor Bilişsel Görev	
		Ort.	SD (±)	Ort.	SD (±)	Ort.	SD (±)
HD	COPEA	10.70	.72	16.15	.803	17.03	.71
	COPVEL	4.92	1.21	5.08	1.34	5.31	1.22
	COPrange AP	11.24	3.80	10.16	3.38	9.74	2.36
	COPrange ML	7.6	1.77	6.61	1.76	6.96	2.60
	RMSAP	2.32	.83	2.00	.63	1.81	.40
	RMSML	1.59	.42	1.36	.42	1.46	.62
HD yok	COPEA	22.54	1.50	17.45	1.0	16.60	.61
	COPVEL	6.81	1.66	6.50	1.29	6.71	1.30
	COPrange AP	22.54	6.37	17.46	4.23	16.60	2.58
	COPrange ML	10.48	3.53	8.38	2.57	8.91	3.60
	RMSAP	4.89	1.57	3.50	.81	3.24	.55
	RMSML	2.12	.77	1.67	.59	1.66	.65

Bilişsel Görevin Ana Etkileri

Hafif dokunuş yok iken bilişsel görevin varlığı anlamlı bir değişim yarattı ancak kolay ve zor bilişsel görevler arasında postür salınımını etkileme açısından anlamlı bir fark yoktu.

Hafif Dokunuşun Ana Etkileri

Hafif dokunuş, postür salınımını tüm koşullarda anlamlı bir şekilde etkiledi.

TARTIŞMA

Bu çalışma, hafif dokunma ve bilişsel görev zorluğunun postüral kontrol üzerindeki kombine etkilerini anlamak için yapılmıştır. Postüral görevin hafif dokunmanın varlığından ve bilişsel görevin(hiçbiri/kolay/zor) varlığından nasıl etkileneceğini araştırdık. Literatür, hafif dokunmanın postüral kontrol üzerindeki olumlu etkisi hakkında uyumlu sonuçlar sunmuştur, ancak bilişsel görevin postüral kontrol üzerindeki etkisi üzerinde bir fikir birliği yoktur. Öte yandan, bilişsel görev ve hafif dokunmanın kombine etkisi ile ilgili sınırlı çalışma vardır.

Bilişsel Görevin Bireysel Etkileri

İlk hipotez, bilişsel görev zorluğu seviyesinin artmasının postüral kontrol üzerinde olumlu bir etkisi olacağıydı. Beklendiği gibi, bilişsel görev zorluğu, sakin duruş sırasında COP ortalama hızı dışında tüm COP parametrelerinde anlamlı farklılıklara neden oldu. Bu sonuçlar literatürde yapılan birçok çalışma ile uyumludur. Uyumlu olmadığı durumlar da söz konusudur ve olası açıklamaları mevcuttur.

Öncelikle çalışmada seçilen motor görev günlük hayatta alışkın olunan ve dolayısıyla dikkat kapasitesini fazla işgal etmeyen bir görevdir (Bronstein, Brandt, Woollacott, & Nutt, 1996). Ancak, motor görevin zorluk seviyesini artırmak ikili görev sırasında bir interferansa sebep olabilirdi (Bustillo-Casero, Villarrasa-Sapiña, & García-Massó, 2017). İkinci olarak bilişsel görevin türü ve zorluk seviyesinin dikkat taleplerini objektif olarak değerlendirmek mümkün değildir. Ayrıca bilişsel görev türünün farklı derecelerde bilişsel-motor interferansa sebep olabileceği bilinmektedir (Ebersbach, Dimitrijeviç, & 1995). Literatürde bilişsel görev türünün bilişsel-motor interferansı nasıl etkilediği tespit edilmemiştir, ancak farklı bilişsel görevlerin bilişsel talebini karşılaştıran çalışmalar vardır. Örneğin, Stroop testinin basit reaksiyon süre testinden daha fazla bilişsel karmaşıklığa sahip olduğu öne sürülmüştür (Dalecki, Bock, & hoffmann, 2013).

Bu çalışmanın bulguları Riley, Baker, & Schmit, (2003)'in bulgularıyla uyumludur. Her iki çalışmanın sonuçları da ortak teori zemininde açıklanabilir. İlk olarak dikkati postüral kontrolden uzaklaştırmak otomatik kontrol süreçlerini aktive etmiştir. İkincil olarak da çoklu kaynak teorisi bu durumu açıklayabilir. Buna göre, iki ayrı görev ortak sınırlı kaynakların kullanımını gerektirmezse, çatışmaya sebep olmazlar (Navon & Gopher, 1979; Wickens, 1980). Son olarak, sonuçlar Navon & Miller'ın (1987) görüşüne göre yorumlanabilir. İki görev benzer etki alanları veya işlemcileri kullanıyorsa, daha az dikkat kaynakları kullanılması nedeniyle işleme verimliliğinin kolaylaşarak ikili görev performansının artabilir.

Hafif Dokunuşun Bireysel Etkisi

İkinci hipotez, postüral kontrol görevine hafif dokunma eklemenin postüral kontrol üzerine olumlu bir etkisi olacağıydı. Tahmin edildiği gibi, hafif dokunma tüm basınç merkezi parametrelerini anlamlı bir düşüşe sebep olarak postüral kontrolü artırdı. Bu sonuçlar literatürde daha önce yapılan çalışmaların bulguları ile uyumludur (Jeka & Lackner, 1994; Jeka J. J., 1997; Tremblay, Mireault, Dessureault, Manning H, & Sveistrup, 2004).

Bu çalışmanın katkısı hafif dokunmanın postür üzerinde farklı zorluktaki bilişsel görevlerle kombine etkisini anlamaktı. Artan bilişsel görev zorluğu hafif dokunma ile birleşince postüral salınım daha da azaldı. Bu çalışmada, hafif dokunmanın postüral kontrol üzerindeki olumlu etkisi kütanöz mekanoreseptörler ve kinestetik mekanoreseptörler tarafından elde edilen ek somatosensöri bilgilerin varlığı ile açıklanmaktadır (Baldan, Alouche, Araujo, & Freitas, 2014; Diener, Dichgans, Guschlbauer, & Mau, 1984). Postüral kontrolün geliştirilmesinde hafif dokunmanın etkinliği için bir başka olası açıklama postüral kasları tetiklemesidir (Jeka J. J., 1997). Ancak, bu çalışmada, kas aktivitesi ile ilgili hiçbir veri toplanmadığından, bu açıklamayı destekleyen bir kanıt yoktur.

Bilişsel Görev ve Hafif Dokunma Etkileşimi

Üçüncü hipotez, bilişsel görev zorluğu ve hafif dokunmanın postüral kontrol üzerinde bir etkileşime sahip olup olmayacağıydı. Sonuç olarak bir basınç merkezi ortalama hızı dışında bütün COP parametrelerinde bir etkileşim mevcuttu ve bu etkileşim bilişsel görev zorluğundan kaynaklandı.

Sonuç

Bilişsel görev ile hafif dokunuş arasında COP ortalama hızı dışında tüm COP parametrelerinde bir etkileşim olduğu ve bu etkileşimin bilişsel görevin zorluğundan kaynaklandığı bulunmuştur. Bilişsel görevin istatistiksel olarak anlamlı etkisi, yalnızca hafif dokunuş olduğunda geçerlidir. Ayrıca, zor bilişsel görev, postür salınımını azaltmada kolay bilişsel görevden daha etkilidir. Hafif dokunuş, postür kontrolü üzerinde istatistiksel olarak anlamlı bir etkiye sahiptir.

D: THESIS PERMISSION FORM / TEZ İZİN FORMU

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TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): The combined effects of cognitive task difficulty and light touch on postural control

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