EFFECT OF CONCURRENT FEEDBACK AND POSTURAL TASK DIFFICULTY ON POSTURAL CONTROL

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SEDA TAŞCI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF PYHSICAL EDUCATION AND SPORTS

SEPTEMBER 2022

Approval of the thesis:

EFFECT OF CONCURRENT FEEDBACK AND POSTURAL TASK DIFFICULTY ON POSTURAL CONTROL

submitted by **SEDA TAŞCI** in partial fulfilment of the requirements for the degree of **Master of Science in Physical Education and Sports, the Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Yaşar KONDAKÇI
Dean
Graduate School of Social Sciences

Prof. Dr. Sadettin KİRAZCI
Head of Department
Department of Physical Education and Sports

Prof. Dr. Sadettin KİRAZCI
Supervisor
Department of Physical Education and Sports

Assist. Prof. Dr. Hüseyin ÇELİK
Co-Supervisor
Hacettepe University
Department of Exercise and Sport Sciences

Examining Committee Members:

Prof. Dr. Mustafa Levent İNCE (Head of the Examining Committee)
Middle East Technical University
Department of Physical Education and Sports

Prof. Dr. Sadettin KİRAZCI (Supervisor)
Middle East Technical University
Department of Physical Education and Sports

Assist. Prof. Dr. Hüseyin ÇELİK (Co-Supervisor)
Hacettepe University
Department of Exercise and Sport Sciences

Assoc. Prof. Dr. Selçuk AKPINAR
Nevşehir Hacı Bektaş Veli University
Department of Physical Education and Sports

Assoc. Prof. Dr. Pınar ARPINAR AVŞAR
Hacettepe University
Department of Exercise and Sport Sciences

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Seda TAŞCI

Signature:

ABSTRACT

EFFECT OF CONCURRENT FEEDBACK AND POSTURAL TASK DIFFICULTY ON POSTURAL CONTROL

TAŞCI, Seda

M.S., Physical Education and Sports Department

Supervisor: Prof. Dr. Sadettin KİRAZCI

Co-Supervisor: Asst. Prof. Dr. Hüseyin ÇELİK

September 2022, 154 pages

Studies investigating the effect of concurrent feedback reported inconsistent results, especially on motor tasks with different difficulties. There is also lack of studies examining the effects of concurrent feedback on postural tasks with different difficulties. To fill this gap, this study investigated the effect of concurrent visual feedback (CVF) and postural task difficulty (PTD) on postural control in acquisition and retention phases. Participants were 40 university students who were randomly allocated to experimental and control groups based on time of arrival and gender. Participants performed six postural tasks with varying difficulties in one day. Each task was repeated three times for 60 seconds. Instantaneous center of pressure (CoP) location was provided to the experimental group as the source of CVF in acquisition phase, but it was withdrawn in retention phase (24 hours in between). Participants in control group performed same tasks without any feedback in both phases. The assessment parameters were velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) of CoP trajectory. Acquisition phase results showed that feedback had a significant effect on variability in the AP and RD directions, ellipse area, and entropy parameters. Retention phase results showed that CVF did not affected any assessed parameters. PTD has been found to be effective for both acquisition and retention phases. This study indicated that CVF improved variability, ellipse area, and entropy parameters. CVF might increase adaptation to specific contexts and augment sensory integration by preventing cognitive overload and affect postural sway parameters positively. However, limited number of trials and sessions with CVF might be reason for the lack of retention effect.

Keywords: Postural Control, Postural Sway, Concurrent Feedback, Task Difficulty, Postural Task Difficulty

ÖZ

EŞ ZAMANLI GERİBİLDİRİM VE POSTÜRAL GÖREV ZORLUĞUNUN POSTÜR KONTROLÜNE ETKİSİ

TAŞCI, Seda

Yüksek Lisans, Beden Eğitimi ve Spor Bölümü

Tez Yöneticisi: Prof. Dr. Sadettin KİRAZCI

Ortak Tez Yöneticisi: Dr. Öğr. Üyesi Hüseyin Çelik

Eylül 2022, 154 sayfa

Eş zamanlı geribildirimin etkilerini araştıran çalışmalar, özellikle farklı zorluklara sahip görevler için tutarsız sonuçlar göstermiştir. Literatürde, farklı zorluklara sahip postüral görevler sırasında eş zamanlı geribildirimin etkilerini inceleyen çalışmalar sınırlıdır. Bu çalışma, eş zamanlı görsel geribildirim ve postüral görev zorluğunun postür kontrolü üzerindeki etkilerini araştırmayı amaçlamıştır. 40 üniversite öğrencisi deney ve kontrol gruplarına her gruptaki katılımcı sayısı her iki cinsiyet için eşit olacak şekilde rastgele atanmıştır. Katılımcılar, farklı zorluklara sahip altı postüral görevi bir gün seansında gerçekleştirmişlerdir. Her görev 60 saniye boyunca üç kez tekrarlandı. Kazanım seansında, deney grubundaki katılımcılara, altı farklı postüral görevi gerçekleştirirken CoP konumları hakkında eş zamanlı görsel geribildirim verilmiştir. Kontrol grubuna, aynı postüral görevleri gerçekleştirirken CoP konumları hakkında eş zamanlı görsel geribildirim verilmemiştir. Bir gün sonra yapılan kalıcılık testinde her iki gruba da geribildirim verilmemiştir. Çalışma sonucunda, kazanım seansında, eşzamanlı görsel geribildirim CoP zaman serilerinin, AP ve RD yönündeki değişkenliğini, elips alanını ve entropisini etkilediğini göstermiştir. Kalıcılık seansına ise eşzamanlı görsel geribildirim herhangi bir parametreyi etkilememiştir. Postüral görev zorluğunun hem performans hem de kalıcılık testleri sırasında etkili olduğu bulunmuştur. Bu çalışma, eşzamanlı görsel geribildirim varlığında bazı postüral salınım parametrelerinde iyileşmeye işaret etmektedir. Eşzamanlı görsel geribildirim bilişsel aşırı yüklenmeyi önleyerek ve duyusal bilgi entegrasyonunu artırarak vücudun belirli bağlamlara uyumunu arttırmış ve postüral salınım parametrelerini olumlu yönde etkilemiş olabilir. Ancak, bu çalışmada eşzamanlı görsel geribildirim tekrar sayısı ve seans sayısı, kalıcı etki gözlenmesi ne yönelik olarak yeterli gelmemiş olabilir.

Anahtar Kelimeler: Postüral Kontrol, Postüral Salınım, Eş Zamanlı Geribildirim, Görev Zorluğu, Postüral Görev Zorluğu

To a Pandemic-free World

ACKNOWLEDGMENTS

This thesis came up as a result of many individuals' assistance, encouragement, and guidance. I owe a great deal of gratitude to each of them.

Foremost, I would like to express my deep and sincere gratitude to my supervisor Prof. Dr. Sadettin Kirazcı for his continuous support of my graduate study and research. I envy and respect his patience, motivation, vision, and immense knowledge. His guidance was very valuable to me throughout the entire research and writing process. I would also like to thank him for his empathy and deep sense of humor. It was a great privilege and honor to work and study under his guidance.

I would like to express my deep gratitude to my co-advisor Assist. Prof. Dr. Hüseyin Çelik, without whom I would not have been able to complete this thesis. His creative thinking ability, analyzing skills, and extensive knowledge had a great place in this study. The confidence and comfort he gave me, especially in the analysis part of my thesis and during my most stressful times motivated me to continue my thesis.

I thank profusely all the participants for taking place in the experiment and Modeling and Simulation R&D Center employees for facilitating the data collection process. My sincere thanks also go to my friends, colleagues, and all those I care about who helped me through this journey for their moral support and empathy.

I am extremely grateful to my parents for their love, prayers, care, and sacrifices in educating and preparing me for my future. I wouldn't be in this position without their support throughout my life. Also, I express my thanks to my beloved little sister for giving me joy, help, and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATONS

CoP	Center of Pressure
CoM	Center of Mass
CoG	Center of Gravity
AP	Anteroposterior
ML	Mediolateral
RD	Resultant Distance
QS	Quiet Stance
TS	Tandem Stance
SS	Single Stance
PQS	Quiet Stance on Balance Pad
PTS	Tandem Stance on Balance Pad
PSS	Single Stance on Balance Pad
PTD	Postural Task Difficulty
CVF	Concurrent Visual Feedback

CHAPTER I

INTRODUCTION

Since the existence of human life on earth, humans have been able to survive in the ordinary flow of life thanks to their advanced ability of movement. Posture control which is the innate ability of people controlled by sensory and motor processes has evolved over time and it has enabled them to perform complex movements. If we need to take a closer look at this issue, individuals need relevant information as a resource to perform movements and control their posture. Relevant information is at the forefront of these external resources. In this thesis, information and its effects related to individual movements, specifically posture control, is investigated.

This chapter provides a general overview of the feedback and postural control in two parts. The first part presents an introduction to the feedback concept with general terms and features and the second part is related to an introduction to the concept of postural control. These two issues will be handled comprehensively in the Literature Review Chapter.

1.1. Feedback

Feedback is quite a broad term that is mostly used in the field of education, sports, rehabilitation, and engineering. It is the information individuals receive during their execution of movement or after the execution of their movement through their sensory organs (e.g., eyes, ears, nose, tongue, and skin) or external sources (e.g., teachers, therapists, or a device). When learning a new skill or improving a learned skill, feedback plays a significant role in accomplishing desired outcomes.

In motor learning and control settings, there are a lot of factors to be considered, among which feedback may be one of the most crucial one. In addition to having practices, it is also of excellent value for learners to receive feedback while practicing a skill (Winstein, 1991). Schmidt and Lee (2011) define feedback as “Information about performance or errors that the learner can use for making future corrections” (p. 256). Similarly, Magill and Anderson (2017) define feedback as a general term related to the information received while performing or after completion of a skill. Mastering feedback and its features can provide advantages in various motor learning and control settings. In literature, the nature of feedback is generally divided into two main types: intrinsic feedback and extrinsic feedback. When information is provided to individuals intrinsically from their sensory organs, which are always present to them, it is called intrinsic feedback. The other name for intrinsic feedback is known as sensory feedback. It is inherently available for individuals to enable them to reach relevant information during the execution of movement. If information is provided to individuals externally by a teacher, coach, therapist, or specific devices, it is called extrinsic feedback also known as augmented feedback depending on the content of the information.

Sensory feedback is further divided into two categories as proprioceptive feedback and exteroceptive feedback. The sensory information coming from an individual’s own body is called proprioceptive feedback. It is provided by receptors located in muscle spindles, joint receptors, Golgi tendon organs, and vestibular apparatus. On the other hand, exteroceptive feedback contains other senses coming from the external environment like visual, auditory, and tactile senses. To give a general example of sensory feedback; a tennis player feels his/her hips, shoulders, movement of arms, and the contact of the ball and he/she sees the racket and the ball while performing forehand in tennis. The player takes this information directly from sensory organs which are inherent to the task.

The word augmented means increasing, enhancing something. In this context, augmented feedback is an external source that acts as additional support to individuals' senses. In other words, augmented feedback is detailed information that cannot be obtained by a learner, so it can be provided by a display or a trainer (Schmidt & Wrisberg, 2008). There are many ways to provide augmented feedback to learners but generally, practitioners (e.g., teachers, coaches, and therapists), or electronic devices give external information to facilitate the learning process. Augmented feedback can be separated into a knowledge of results (KR) and a knowledge of performance (KP) according to the quality of performance output or a specific movement characteristic (Magill, 1998). Both can be presented in visual, auditory, or tactile forms. For example, in Sharma and her colleagues' (2016) study feedback was provided to participants by giving the longest distance thrown (KR) and by verbal cues and videotape replays of their performance (KP).

Augmented feedback makes the task easier to achieve the goal of the skill and motivates learners to go for it (Van Dijk et al., 2005). In the motor learning setting presenting augmented feedback serves with informational (Schmidt & Lee, 2014), motivational (Wulf & Lewthwaite, 2016), reinforcement (Coker, 2017), and guiding (Adams, 1987) functions which are essential for supporting learners to get the maximum benefit from feedback.

Feedback can be given in a variety of ways with different modalities depending on the motor and other features of tasks (Sigrist et al., 2012). Technical displays are getting increasingly common to provide augmented feedback and they can be used with different modalities such as vision (screens, head-mounted displays), hearing (speakers, headphones), haptics (vibrotactile actuators, robots), and a combination of them (Sigrist et al., 2012). The visual system can be considered one of the most significant systems of the human body during interaction with the outside world. Owing to its importance, methods that appeal to the visual system are widely used in feedback studies. In motor learning studies, visual feedback can be provided by using a variety of methods including observation, videos, and technical displays. Visual feedback is convenient not only for learning purposes but also in the field of rehabilitation (Patton et al., 2013). However, processing too much visual information can result in visual tunneling or paying attention to only specific cues because of high processing needs (Zhu et al., 2020). When the visual system is overloaded by too much information, one can utilize auditory and tactile feedback to provide additional resources to the learner.

Timing is a considerable issue when providing feedback while learning a new skill. Feedback is separated into two categories in terms of when it is provided to individuals. These are concurrent feedback (i.e., during the execution of motor skills) and terminal feedback (i.e., after the completion of a motor skill). Studies investigating concurrent vs. terminal feedback found that participants who received concurrent feedback and terminal feedback at the same time obtained greater positive effects compared to participants who received only terminal feedback (Vander Linden et al.,1993; Winstein et al., 1996; Schmidt & Wulf, 1997). It has also been shown that concurrent feedback has positive effects in the acquisition phase and resulted in better error correction. However, these studies further showed that the opposite results are observed in retention tests without providing feedback.

In terms of skill acquisition, there are distinctions between performance and learning which are temporary fluctuations in behavior and relative permanent behavior change respectively. For controlling learning and performance, feedback, especially KR feedback, is one of the strongest and the most significant variable (Bilodeau & Bilodeau, 1961). In addition, motor learning studies that investigate human learning and performance mostly benefit from the properties of feedback. In the 20th century, Thorndike's studies on learning indicated that the consequences of a behavior determine the occurrence of that behavior in the future, which is called ‘the law of effect’. It states that if responses to action produce satisfying effects, it is more likely to occur again. On the contrary, if responses are unpleasant, then the action is less likely to occur again. According to Thorndike (1898), feedback should also be given to learners as often as possible in this process. As it is clearly understood, the reinforcement property of feedback is highlighted in this behavioral theory.

In terms of achieving permanent behavior change, modifying the frequency of feedback is thought to have diverse effects on learning. To clarify this issue, Bilodeau et al. (1959) found that there is a progressive improvement with the provision of feedback while no improvement or decrement is observed when feedback is not provided. To determine whether learning has taken place, learners execute their performance without being previously informed in retention tests. The results of some tests indicate that the informational property of feedback can be detrimental to motor skill learning when it is provided too much. Salmoni et al. (1984) and Schmith (1991) explain this condition by referring to a guidance hypothesis. It states that receiving feedback frequently during the acquisition phase of skill learning creates a dependency on feedback and as a result performance drops when feedback is not given (Salmoni et al., 1984; Schmidt, 1991).

A considerable amount of literature has been published on the effects of feedback with different conditions (i.e., type, time, frequency, and precision) on various motor skills. The use of different feedback conditions according to the age of learners (Liu et al., 2013), the skill level of learners (Guadagnoli & Lee, 2004), and the properties of the task (Guadagnoli & Lee, 2004) is fundamental for learning/relearning motor tasks. Especially, the effectiveness, pros/cons of concurrent feedback, and the variety of feedback frequencies have been tested with various tasks. In this context, results tend to differ from each other specifically on tasks with different complexities. Some studies in which simple motor tasks were used showed that the results of different feedback frequencies are usually similar (Dunham & Mueller, 1993; Lai & Shea, 1998).

Some other studies indicated that reducing feedback frequency, by varying the relative frequency without changing the number of trials, is more favorable than providing a 100% frequency of feedback (Winstein & Schmidt, 1990; Sparrow & Summers, 1992). Furthermore, the detrimental effects of frequent feedback while learning a skill are supported by some studies (Weeks & Kordus, 1998; Winstein & Schmidt, 1990).

Contrary to the results of the studies, Shea & Wulf (1999) obtained different results in terms of learning complex tasks. They found that providing concurrent feedback is a beneficial method when learning complex postural control tasks. Some of the later works about feedback also indicated that the principles of providing feedback to simple motor skills cannot be generalized to complex motor skills (Wulf & Shea, 2002; Guadagnoli & Lee, 2004). Therefore, it seems that choosing the proper frequency of feedback to enhance motor skill acquisition is controversial and further studies are needed especially in the different difficulties of motor tasks focusing specifically on postural control.

1.2. Postural Control

Postural control is one of the most crucial determinants for a human being to maintain normal operation of daily living activities. While we are sitting on a chair to have lunch or working on a project and standing on a firm surface or standing on a boat in motion, our postural control mechanisms work for maintaining an upright position and alignment with the environment against gravitational forces to keep our posture controlled. When we think about postural control a little deeper, we can say how important it is for many tasks and situations, not just for daily life activities but also for professional athletes who use their postural control abilities at higher levels and people who have postural control problems according to age, physical and sensory system deficiencies. To illustrate this notion, we can think of a tightrope walker while he/she tries to keep his/her posture under control, some yoga poses that require mastering controlling posture, and a ballet performer who combines the strength of her aesthetic and her posture controlling abilities, a child born with cerebral palsy, a person who lost one of his/her legs due to an accident or just an old person with age-related postural problems. While many examples about the control of posture and its use come to our mind, we need to understand its definition, influencing factors, the mechanism of operation, and measuring methods to clarify the term postural control.

Postural control can be defined as the way that the central nervous system (CNS) regulates sensory information from somatosensory, vestibular, and visual inputs about the position of our body to produce appropriate motor output and controlled upright posture with activation of muscles. Postural orientation and postural equilibrium are two main functional aims of human posture control (Horak, 2006). The active regulation of body segments to align and tone concerning gravity, support surface, visual setting, and internal references is known as postural orientation. The perception of convergent sensory input from the somatosensory, vestibular, and visual systems is used to determine spatial orientation in postural control (Horak, 2006). Postural equilibrium, on the other hand entails the coordination of sensorimotor strategies to stabilize the body's center of mass (CoM) during both self-initiated and externally influenced ailments in postural stability (Horak, 2006). When the posture of an individual is stable, it can be said that the person is in balance. Balance is maintained when the CoM is controlled on the base of support (BoS). The CoM is a hypothetical point that reflects the center of whole-body mass and the BoS is a contact point of the body with the ground (see Figure 1.1). Besides these two variables, two other key concerns are the center of gravity (CoG) and the center of pressure (CoP). Although these two variables are different from each other, they are related to each other, and they are prominent variables for quantifying human posture control and locomotion. The CoG can be described as a point at which total body mass is gathered when there is not any external impact on the body’s inertia functions (Benda et al., 1994). The CoP is a projection of a point on the ground which indicates the center of vertical force distribution on the body (Benda et al., 1994). In the posture and locomotion studies, the specification of CoG requires the knowledge of the position and mass of body parts, for this reason it cannot be directly determined (Benda et al., 1994) and the CoP information can be benefited to determine the location of CoG. Consequently, it is safe to say that the knowledge of the CoP location is mostly used in such studies.

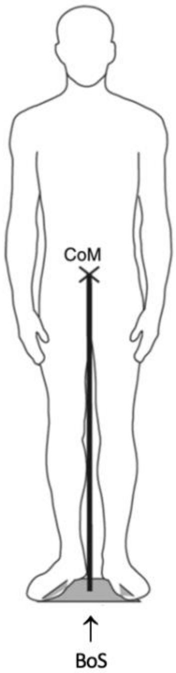


Figure 1.1. Illustration of CoM and BoS in Quiet Stance

Note. Adapted from Balance training. In *Textbook of Neural Repair and Rehabilitation* (2nd ed., Vol. 2, p. 106) by Mak, M., & Horak, F. B., 2014, Cambridge University Press.

Instead of evaluating posture control as a single system, it is necessary to consider it as a system in which more than one sensory and motor systems work together. Postural instability is encountered when any of these systems are not working properly. According to Horak (2006), six resources are needed for control of the posture which are biomechanical constraints, movement and sensory strategies, orientation in space, control of dynamics, and lastly cognitive processing. Biomechanical properties of the body play a significant role in controlling posture and any constraints in the biomechanics of a person results in postural instability but the most important one among these constraints is the feet. They are responsible for the size and the quality of the base of support so any problem, even if it looks trivial, will affect postural control (Horak, 2006).

An individual uses three movement strategies to keep the body in equilibrium: ankle and hip strategies keep the feet in the desired place, on the other hand, stepping and reaching actions change the base of support for controlling stance posture. An appropriate strategy is chosen according to surface properties and amount of oscillation. In addition to movement strategy to keep posture stable, there is also sensory strategy. Information comes from somatosensory, visual, and vestibular systems as sensory information to keep posture stable, and a person can change the dependency ratio of each sense according to environmental changes which is called sensory reweighting (Horak, 2006).

Changing the position of the body parts following external stimuli known as orientation in a postural control context and it is a very crucial resource for controlling upright posture. External stimulants can be counted as the gravity, support surface, visual surroundings, and internal references of the body. A person who has an ordinary nervous system automatically orientates the body according to task and environment by using this system (Horak, 2006). In a quiet stance, a healthy person's center of pressure (CoM) is inside the base of support (BoS), but it is not the same when a person is walking or changing the posture from one to another. These controlling factors of dynamic parameters can change and affect a person's postural control (Winter et al., 1993). Lastly, cognitive processing plays a vital role in postural control. Postural task difficulty and cognitive processing are directly proportional to each other thus, reaction times and other indicators of performance in cognitive tasks decrease with increasing the difficulty of postural tasks (Horak, 2006).

Static balance tasks can be a good determiner for assessing and improving postural control with appropriate training programs (Donath et al., 2016). However, even these tasks e.g., quiet stance, are used for the determination of the postural control, they may not create a major challenge for the human postural control system by themselves (Clifford & Holder-Powell, 2010). Therefore, some modifications should be added to static balance tasks for creating compelling tasks both for training and research purposes. The American College of Sports Medicine recommend some variations of static balance tasks to turn them into more challenging tasks, these are modifying the base of support (double-leg stance, tandem stance, single-leg stance) and manipulating environmental information to change sensory input (standing on firm or foam surface, standing eyes open or closed and changing head position) (Chodzko-Zajko et al., 2009). In general, postural control studies combine postural task difficulty with some other factors such as feedback, attention, or dual-task to see if there is any effect or interaction with task difficulty.

Some modalities of feedback such as visual feedback have been reported to improve postural control (Cawsey et al., 2009; Rougier et al., 2004). However, it is debatable which characteristics of feedback are more effective. The frequency of feedback attracts the attention of researchers as a significant variable in terms of motor learning and control studies specifically posture control. Feedback frequency and other factors such as task difficulty, level of the learner, and environment are closely related to each other. Winstein & Schmidt' (1990) study stated that using frequent feedback on simple motor task is not beneficial for learning motor skill. On the other hand, Shea & Wulf (1999) claimed that providing concurrent feedback is a beneficial method when learning complex postural control tasks. However, studies regarding frequent feedback frequency and postural control task difficulty have been relatively limited. These two factors should be carefully regulated when providing effective feedback to learners.

1.3. Problem Statement

In the literature on feedback, a considerable amount of study investigated the effect of feedback on various conditions such as the age of learners (Liu et al., 2013), the skill level of learners (Guadagnoli & Lee, 2004), and the properties of the task (Guadagnoli & Lee, 2004). Especially, positive, and detrimental effects of concurrent feedback still attract the attention of researchers in the feedback related, motor learning and motor control studies.

Although there are some studies investigating the effects of concurrent augmented feedback on different tasks, results differ from each other specifically when the main concern is task difficulty. Studies using simple motor tasks (e.g., tapping tasks, line drawing) showed that the effect of different feedback frequencies tend to be similar (Dunham & Mueller, 1993; Lai & Shea, 1998). Other studies indicated that reducing the frequency of feedback resulted in more effective results than providing concurrent feedback (Winstein & Schmidt, 1990; Sparrow & Summers, 1992). Additionally, some other studies point out the detrimental effect of frequent feedback on motor skill learning (Weeks & Kordus, 1998; Winstein & Schmidt, 1990). However, Shea & Wulf (1999) is worth a closer look since the authors have focused on learning a complex motor task. The result of the study indicated that providing concurrent feedback is a useful method when learning a complex postural control task (i.e., balance task on the stabilometer). Later studies revealed that the principles of providing feedback during simple motor skills cannot be generalized to complex motor skills (Wulf & Shea, 2002; Guadagnoli & Lee, 2004).

Studies which investigated complex tasks such as a three-dimensional rowing-type movement (Sigrist, 2011) and applying mobilization forces to the cervical spine (Snodgrass et al., 2010) showed the favorable effects of concurrent feedback but, there is a limited body of literature concerning the postural control studies in relation to task difficulty. Balance control may not be considered a novel motor skill, because it is learned in childhood, but the same principles of learning that applying to acquire novel motor skills can be used to constantly enhance postural control throughout one's life, or to re-learn postural control after neurological damage (Shumway-Cook & Woollacott, 1995). In line with the aforementioned information and by considering different effects of concurrent feedback, this study aims to investigate the effects of concurrent visual feedback on different difficulties of postural control tasks to gain further understanding of the postural control mechanisms.

1.4. Research Questions

This study was designed to explore the effects of concurrent visual feedback and postural task difficulty on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy).
The research questions are;

- Is there an interaction between concurrent visual feedback and postural task difficulty on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in acquisition and retention phases?
- Does concurrent visual feedback affect postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) measured in acquisition and retention phases?
- Does postural task difficulty affect postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) measured in acquisition and retention phases?

1.5. Hypotheses

The hypotheses of this study are:

- There would be an interaction between concurrent visual feedback and postural task difficulty on postural sway velocity (AP-ML-RD), variability (AP-

ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) measured in acquisition and retention phases.

- Concurrent visual feedback would affect postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) measured in acquisition and retention phases.
- Postural task difficulty would affect postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area, and regularity (i.e., approximate entropy) measured in acquisition and retention phases.

1.6. Significance of the Study

The importance of this study is to understand the impact of concurrent visual feedback on postural control tasks with various difficulties. When we look at the literature, there are different findings about the effect of concurrent visual feedback. Some studies showed that contrary to widespread belief concurrent feedback can foster both acquisition and retention outcomes, especially when performing complex tasks. However, there is a relatively limited body of literature that is concerned with the effect of concurrent feedback on difficult tasks specifically postural control tasks with several difficulties. Thus, to our best knowledge, this study is one of the early studies that aims to reveal the effects of concurrent visual feedback and different postural task difficulties on postural control both in acquisition and retention phases.

1.7. Limitations

The following were some of the limitations that might influence the study:

- Although professional athletes were not included in the study, participants' physical activities at various levels might affect their postural control.
- Physiological factors such as the foot arch structure and weights of the participants were not considered to cause any effects on postural control parameters.

1.8. Operational Definitions

Feedback: "Feedback is movement-related information that is "fed back" to the learner before, during (concurrent), and after (terminal) an attempt to perform a task to enable modifications for the next action'' (Moinuddin et al., 2021, p. 1).

Augmented Feedback: Augmented feedback is a kind of feedback for defining information about performance or errors that is supplemental to or it augments sensory feedback which is provided by external sources (Schmidt & Lee, 2011).

Concurrent Feedback: Providing augmented feedback during the ongoing movement (Schmidt & Lee, 2011).

Posture: Winter (1995) describes posture as **'**the orientation of any segment of the body relative to the gravitational vector. It is an angular measure from the vertical ground.

Postural Control: Postural control is accepted as a complex motor skill that is regulated by the interaction of sensory and motor processes (Horak & Macpherson, 1996) for producing appropriate motor output to keep the body in balance. It has two main functional goals: postural orientation and postural equilibrium.

Postural Sway: Postural sway is a reflection of interaction between external forces trying to destabilize the body and the postural control system trying to stabilize the body by preventing loss of balance (Pavol, 2005).

Center of Mass (CoM): Center of mass is a passive variable that can be defined as a point reflecting total body mass in the global reference system (Winter, 1995).

Center of Gravity (CoG): Center of gravity is directly connected to the center of mass, and it is a vertically projected point of a center of mass on the ground (Winter, 1995).

Center of Pressure (CoP): Center of pressure is independent of the center of mass, and it is the average of the forces applied to surfaces in contact with the ground (Winter, 1995).

Approximate Entropy (ApEn): Approximate entropy is defined as a complexity index that measures the irregularity of a sequence of numbers or time series and simply, it increases when the irregularity of time series increases (Ramdani et al., 2009).

CHAPTER II

LITERATURE REVIEW

Feedback is an essential variable for the performance of tasks and the learning of new motor skills. It takes place with both natural and external processes, and it is benefited mostly in motor learning and control studies. What is more, feedback is beneficial not only for learning a new skill but also for re-learning skills or refining postural control for rehabilitative purposes. Understanding feedback types and their procedures are quite important and it can lead researchers and instructors to progress in acquisition and retention settings.

The literature review chapter will be handled in two main subjects. The first one will introduce feedback literature with types, sources, functions, and frequencies of it and the second one will handle the postural control concept itself.

2.1. Feedback

Feedback is essential for humans to maintain and develop normal operational activities of daily living. Generally, it is benefited by teachers or coaches in motor learning settings and physical therapists in rehabilitation facilities. It has benefited not only by living organisms but also the functioning of mechanical structures in the field of engineering. Feedback is simply information, but with different properties, the definition and purpose of feedback change. When we look at the literature, feedback is defined in more than one way. Schmidt & Lee (2011) defined feedback as information that learners obtain about their performance and errors to use for making future corrections. According to Magill & Anderson (2017), feedback is a general term that describes information individuals receive about their performance during or after the execution of a motor skill. Therefore, the perception of feedback changes according to the studies carried out in different fields.

In the field of motor learning and control, feedback studies take a large place. Because even though motor skill learning is affected by many critical variables, especially practice itself, feedback has an important place among them (Schmidt & Lee, 2011; Magill & Anderson, 2017). Individuals can receive feedback during or after the completion of the performance and they can use this information for error correction to improve performance outcomes and better learning results. Although feedback seems to be a general term, it is divided into different types, according to the situations such as how it is obtained by people and which information it provides. Figure 2.1. illustrates the different types of feedback. In general, feedback is handled under two main headings; sensory (intrinsic) feedback and augmented (extrinsic) feedback. Sensory feedback is further divided into visual, auditory, proprioceptive, and tactile feedback which indicates sources to get information. Augmented feedback is divided into two knowledge of results (KR) and knowledge of performance (KP) which reflect the type of information given. They will be covered in detail later in this chapter, especially augmented feedback and its' sources, functions, and different frequencies.

2.1.1. Types of Feedback

Feedback is divided into two main categories according to how individuals obtain information. They are called intrinsic (sensory) feedback and extrinsic (augmented) feedback. Individuals naturally receive information through their sensory systems via vision, audition, proprioception, touch, force, and smell. This sensory information is called intrinsic/sensory feedback. While executing a movement, information can be perceived by exteroceptors including visual, auditory, and tactile senses from the external environment or it can be perceived by proprioceptors including individuals' body senses. These proprioceptive receptors are in tissues around joints, skin, muscles, tendons, fascia, joint capsules, and ligaments (Grigg, 1994). Intrinsic feedback is very crucial for human motor learning and motor control. In the study of Cole and Sedgwick, a case history of a man with a complete large fiber sensory neuropathy for 16 years has been investigated to show the vital role of intrinsic feedback (Cole & Sedgwick, 1992). He had the sensations of pain, heat, cold and muscular fatigue but he didn't have the sensations of light touch and proprioception. At the beginning of the rehabilitation, he didn't even initiate the basic movement patterns. After several years of training, he was able to execute basic everyday tasks such as eating and writing. As it is clearly seen, the results showed the importance of intrinsic feedback on human motor learning and motor control processes.

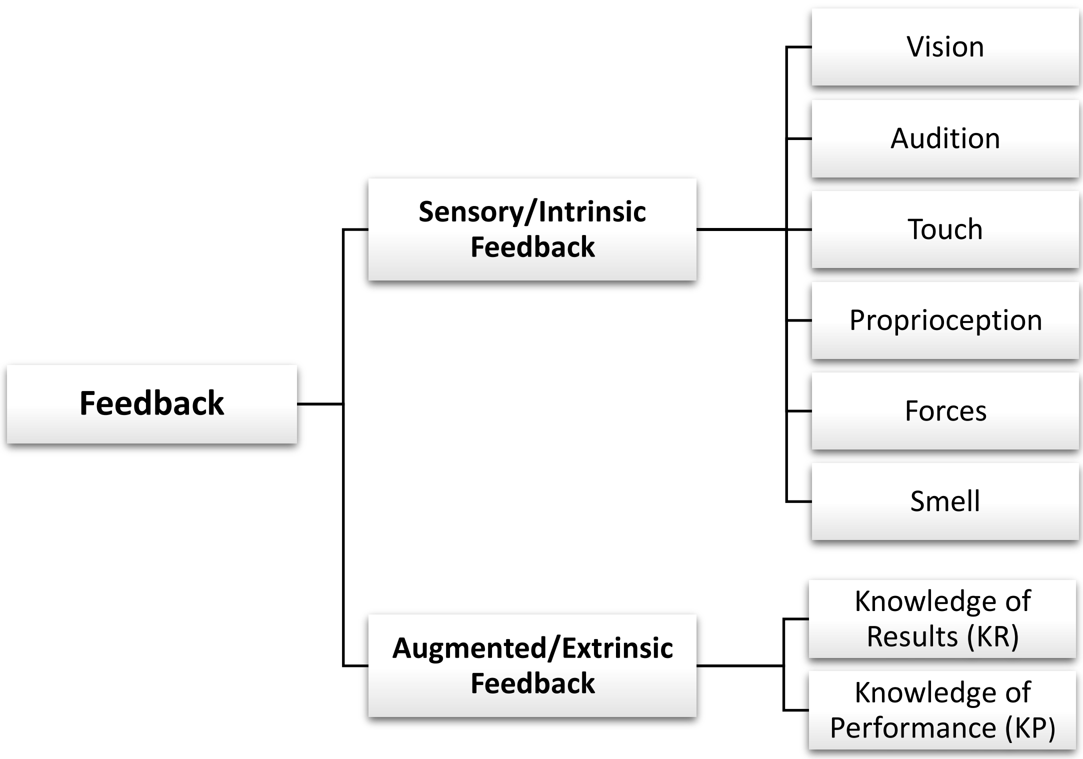


Figure 2.1. Types of Feedback

Note. Adapted from *Motor Learning and Control: Concepts and Applications* (11th ed., p.345) by Magill, R., & Anderson, D., 2017, McGraw Hill.

In terms of controlling posture, individuals utilize three main sensory systems for obtaining appropriate information (Winter, 1995). Visual cues are benefited to plan locomotion and avoid obstacles during movement, the vestibular system works as a 'gyro' to sense and provides information on linear and angular acceleration of the body and the somatosensory system works to perceive the position and speed of the body parts, their interaction with external objects and orientation of ground reaction forces (Winter, 1995).

Augmented means adding or increasing something in this case it works as additional information to enhance individuals' sensory information which is normally available (intrinsic feedback). Augmented feedback is also called extrinsic feedback. It is provided to individuals/learners by some external sources such as comments of a coach, instructor, therapist, digital displays, and videotape replays (Schmidt & Wrisberg, 2004). Augmented feedback is further divided into the knowledge of results (KR) and knowledge of performance (KP). Knowledge of results feedback is giving information about the outcome of performance. For example, telling learners how far they were off the target or informing them about the scores they made. In many everyday situations and tasks, KR feedback is not further beneficial for motor learning because, it is unnecessarily provided to information obtained from intrinsic feedback via visual, auditory, and kinesthetic channels (Zhu et al., 2020). The study found that information on KR is not helpful to enhance learning since, the task had already included natural information about the movement (Platz et al., 2001).

Knowledge of performance feedback gives information on the nature and characteristics of movement patterns. For example, giving information about the limb position of learners during the gymnastic routine. As information about movement patterns is more difficult to obtain by learners intrinsically, KP is most applied during real training settings (Winstein, 1991). The results of the recent study showed that using KP feedback on skilled motor activity (throwing a soft spongy ball) resulted in better performance and learning outcomes compared to KR feedback. Furthermore, researchers claim that using more complex tasks can result in more definitive and larger differences in favor of KP feedback (Sharma et al., 2016). Even if their pros and cons vary, both KR and KP are utilized for motor learning. To summarize, although KR is effective in learning performance and training, KP is more effective in skill retention compared to KR (Zhu et al., 2020).

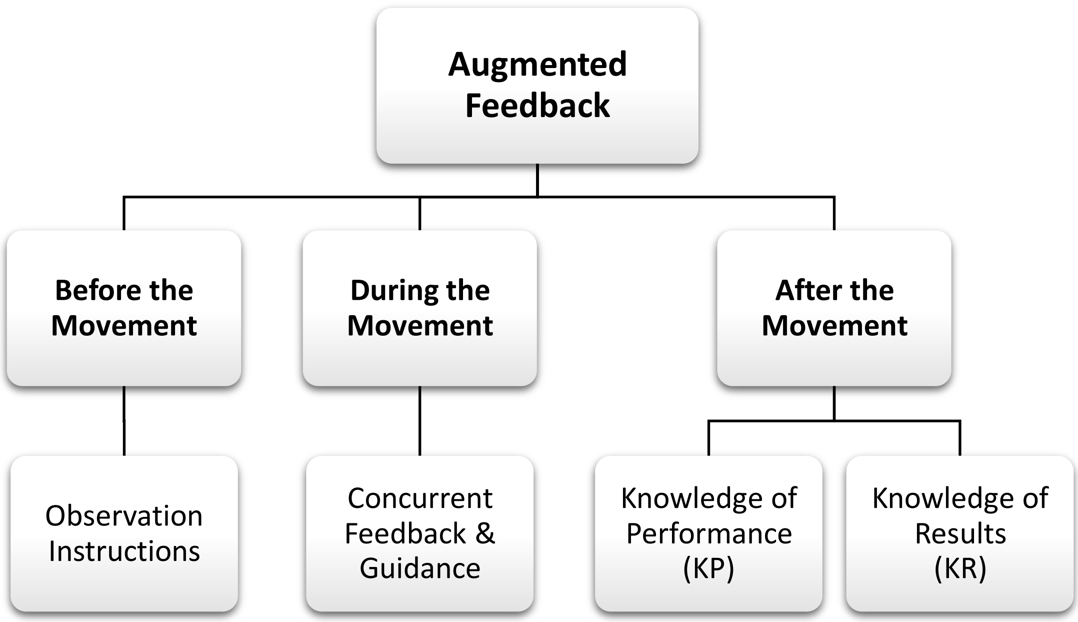


Figure 2.2. Augmented Feedback Scheme

Note. Adapted from *Motor learning and performance: From principles to application* (5th ed., p.257*)* by Schmidt, R. A., & Lee, T. D., 2014*,* Human Kinetics.

Augmented feedback can be provided to individuals in several ways (see Figure 2.2). Before providing feedback, design should be systematically evaluated, and environmental/individual conditions should be considered to get maximal results from feedback. Visual, auditory, and tactile modalities mostly benefited to supply augmented feedback. All three have advantages and disadvantages that vary depending on circumstances.

Visual augmented feedback is considered a foundation of augmented feedback types due to its significance of vision as a sensory resource. Visual feedback is mainly used for providing spatial information or situations that other sensory systems cannot be reached due to environmental or individual problems (Zhu & Kaber, 2012). The advantage of visual feedback is for learners to get an idea of the location of an object quickly and accurately or a limb. In addition, for rehabilitation purposes, visual feedback conveys spatial error information or deviations of limbs from the target with robotic-assisted systems (Brewer et al., 2008). However, if visual feedback presents too much information, visual overload and visual tunneling may appear due to high processing demands (Zhu & Kaber, 2012).

When the visual system is overloaded, auditory or tactile feedback modalities can be included to overcome too much information from visual channels. Studies using auditory feedback found benefits in task learning and performance through providing error and performance information. For example, a study found that both KR and KP auditory feedback is effective for re-learning reaching tasks in stroke patients (Chen et al., 2015). Moreover, haptic feedback modalities have benefited surgery operations with computer-based force production tasks, or it has been used in the form of vibrotactile for improving standing balance in healthy young adults (Morris et al., 2007; Ballardini et al., 2020). Consequently, augmented feedback can be presented in the form of almost all sensory modalities, and generally they are successful in enhancing human learning, re-learning, and performance processes.

2.1.2. Functions of Feedback

It has been shown that feedback plays a critical role in learning and control of motor skills. Another curiosity arises from this statement; which functions of feedback are critical in the acquisition of motor skills? In the feedback literature, four important functions have been identified in terms of learning motor skills (Adams, 1987; Salmoni et al., 1984). These are informational, motivational, reinforcement, and guidance functions of feedback. When learning a new skill, individuals often need interpretable additional information related to their actions. Because, they may not have enough experience to interpret information from their sensory systems, the informational properties of feedback lead them to make necessary corrections for skill refinement. In this way, their next performance will be purified by the same errors, and it will be closer to desired performance.

The motivation of learners is another important function in motor learning and control context. The motivational role of feedback keeps individuals alert, maintains their interest, boosts their energy, and encourages them to reach higher performance goals (Schmidt & Lee, 2011). The motivational function of feedback is considered as a performance variable rather than a learning variable because it works for increased efforts and continuous participation of learners/individuals, instead of correcting specific errors to directly affect the learning process. On the other hand, later discussions indicated that motivation is a strong indirect learning variable (McMorris, 2004; Schmidt & Lee, 2011). The reason behind this view is that motivated learners will be able to practice more intensively, longer and in a planned manner, thereby they can produce better learning outcomes as well.

Another significant function of augmented feedback is reinforcement. It is reflected in performance as a continuing desired behavior and diminishing/ eliminating of undesired behavior. In 1927, Thorndike indicated this notion with 'the law of effect' which stated that if an action elicited by stimulation followed by pleasant or rewarding results, it tends to be repeated when the stimulus occurs again but if results are unpleasant or punishing it tends not to be repeated and diminishes.

Lastly, augmented feedback guides learners to correct their actions and stay within the correct boundaries of performance. Guidance can be very strong for reducing errors, besides sometimes it may prevent them to make errors completely. The guidance function of feedback seems to be beneficial if guidance is present during the acquisition. However, learners can create dependency on feedback and when it is removed, performance remarkably deteriorates on retention tests which is called the 'guidance hypothesis' (Salmoni et al., 1984). The rationale behind this hypothesis is using only external information without developing a capability to move independently by using own inherent feedback. The guidance hypothesis has been mostly tested in experiments using knowledge of results (KR) (Anderson et al., 2005). In a typical study, participants practice the task with augmented feedback during the period known as the acquisition phase (Schmidt & Lee, 2011). This part is thought to be an indicator of a combination of learning effects and temporary guidance effects coming from augmented feedback (Fujii et al., 2016). To test the skill whether is learned or not, the performance is evaluated in retention tests without providing augmented feedback. Acquisition and retention data are analyzed separately to eliminate the temporary guidance effect of feedback. Retention tests are thought to reflect clearer results to understand to what extent the skill is learned and retained (Park et al., 2000; Vander Linden et al., 1993).

According to the results of studies that have been carried out, researchers indicate three possible assumptions for the negative effect of too much guidance on learning (Schmidt, 1991). The first one indicates that when augmented feedback is provided too frequently, learners become to rely on augmented feedback, and they cannot utilize it from their sensory feedback. As a result of this reliance on augmented feedback, performance deteriorates during retention tests when there is no provided augmented information. In connection with this, the second one indicates the reduced frequency of augmented feedback facilitates learning because, it encourages learners to use their sensory feedback during retention trials without feedback (Salmoni et al., 1984; Schmidt et al., 1989). Lastly, frequent augmented feedback is taught to increase performing more variable movement patterns (Salmoni et al., 1984; Schmidt et al., 1989). Movement variability increases because frequent augmented feedback encourages learners to over-correction which is called '*maladaptive short-term corrections*' (Schmidt, 1991). Learners can show this correction pattern even if their performance is close to target, but it withholds learners to recognize and produce stable movement patterns in retention.

2.1.3. Frequency of Feedback

In the literature on feedback, more than one idea has emerged to find the appropriate guidelines for providing effective feedback in relation to skill learning. Some concerns have arisen for formulating useful methods such as adjusting precision, timing, and frequency of feedback. Studies that investigated the precision of feedback benefited mostly from KR verbal feedback due to its advantages of being easily regulated (Edwards, 2011). In terms of precision of feedback, information can contain only the direction of an error, or it can also contain the magnitude of an error which are called qualitative and quantitative feedback respectively. Feedback should be precise enough for learners to interpret meaningfully, for this reason using quantitative feedback is preferable than using qualitative feedback. Studies support this notion by showing that individuals receiving more precise information during acquisition tend to be more precise in retention trials (Magill & Wood, 1986; Reeve et al., 1990). Concerning the aforementioned information, the result of a study from Magill & Wood (1986), showed that the precision of KR feedback can be classified as a learning variable.

In motor learning and feedback studies, learning and performance effects should be separated to interpret them properly. Varying practice conditions can lead to two distinct outcomes: a relatively permanent change in performance, which reflects the learning effect, or a temporary outcome which reflects the performance effect (Schmidt, 1991). Performance effects are temporary while learning effects persist even after a day or more. To understand whether learning has taken place, individuals are asked to perform the task without receiving feedback, this procedure is called a retention test. The questions of when and how frequently feedback should be provided are essential for understanding the learning and performance effects.

Individuals can receive augmented feedback during the execution of the task (i.e., concurrent feedback) or immediately after the completion of the task (i.e., terminal feedback). In addition, there are some other feedback techniques obtained by modifying the frequency (Winstein & Schmidt, 1990) such as summary (Schmidt et al., 1989), faded, bandwidth (Lee & Carnahan, 1990), and learner-regulated feedback (Janelle et al., 1997).

It was thought that feedback should be provided frequently to get greater learning gains (Thorndike, 1931). However, receiving feedback concurrently can result in negative learning effects (Magill & Anderson, 2017). This negative learning effect has been indicated in different tasks such as continuous bimanual coordination tasks (Verschueren et al., 1997), isometric elbow-extension force production tasks (Vander Linden et al., 1993), a partial weight-bearing task in a clinical setting (Winstein et al., 1996). The reason for this negative learning effect of concurrent feedback is thought to be originated from the dependency-producing property of feedback and it's labeled the guidance hypothesis (Salmoni et al., 1984; Winstein & Schmidt, 1990). On the other hand, the guidance effect of concurrent feedback can be utilized to facilitate performance and enhance skill learning if it is provided in an appropriate manner (Magill & Anderson, 2017). In the study of Buchanan & Wang (2012), participants were required to learn a complex pattern of coordination between two hands with the provision of visual augmented feedback in the form of a Lissajous template. One group was trained with the cursor superimposed (side group) while the other group was trained with the cursor presented in a separate window (behind the group). They exhibited 5 min of performance and 15 minutes later they took the retention test without feedback. A dramatic reduction was observed in the performance of the behind group when the feedback was drawn off, whereas the side group was able to sustain their performance in the lack of visual feedback. The result of the study indicated that guidance depends on the format of the display which provides visual feedback, not on the frequency (Buchanan & Wang, 2012).

In 2007 a meta-analysis of Marschall et al. stated that providing concurrent as well as very frequent feedback was found to be detrimental to learning simple tasks, but this notion may not be accurate for learning complex, sport-related tasks. Moreover, individuals can be more benefited from concurrent feedback as the difficulty of the task increases (Sigrist et al., 2012). Some possible explanations are suggested for this outcome of concurrent feedback. Firstly, concurrent feedback can attract an external focus of attention (Shea & Wulf, 1999) and it can enhance automatic behavior. Concurrent feedback can prevent cognitive overload (Wulf & Shea, 2002) and allow individuals to reach specific information to learn complex tasks. Lastly, the guiding function of feedback can assist learners to understand components of complex motor tasks (Huegel & O'Malley, 2010).

2.2. Postural Control

In ordinary conditions, posture control is one of the first tasks that individuals learn, master, and use until death. To be able to carry out activities of daily living, individuals must master balance and posture control because almost all the tasks that individuals perform require controlling body position with the environment. Pollock et al. (2000) defined postural control as "the act of maintaining, achieving or restoring a state of balance during any kind of posture or activity." (p. 404). Besides this definition, to understand how postural control systems operated, we will look at some conceptual theories and then how different systems work together. Different biomechanical and neurophysiological approaches have benefited to understand how postural control mechanisms work (Horak & Macpherson, 1995). According to the biomechanical approach, posture control is seen as a multilink inverted pendulum, in which the position of the center of mass (CoM) is the main parameter that needs to be controlled within the limits of the base of support (BoS) (Maurer & Peterka, 2005).

The term center of mass (CoM) was first introduced by the ancient Greek physicist, mathematician, and engineer Archimedes of Syracuse in the form of center of gravity

(CoG). He showed that the force exerted by all weights at different points on a lever will be the same force applied when the weights are moved to a single point called the center of mass (CoM). In the light of this information, the term balance or equilibrium, as used in mechanics, is defined as ''the state of an object when the resultant load actions (forces or moments) acting upon it are zero'' (Newton's First Law). For the human body, the position, and the motion of the body's center of mass (CoM) are controlled by the nervous system according to the body's movements and rotations to keep the body in balance. The center of mass in the human body is an imaginary point that indicates the average location of the total mass of the body, moreover, it is not strictly determined and varies according to body orientation. For example, when we are in a quiet stance our center of mass is in the abdomen area and the projection of it is approximately 20 mm in front of the second lumbar vertebra (Kandel et al., 2013).

Two other key concerns related to CoM are the center of gravity (CoG) and the center of pressure (CoP) for assessing human postural control and locomotion. The center of gravity is a hypothetical point in which the body's center of mass gathers in stable conditions without changing the body's translational properties. The center of pressure is also a point, but it shows on the ground, and it is a projection of vertical force distribution on the body the information about CoP can be obtained directly from the force plate while assessing posture (Benda et al., 1994). These terms have been defined by many researchers in the literature, but almost all give the same meaning. In 2013, Kandel et al., the defined center of gravity as a hypothetical point on the body that gravitational reaction forces act on. The gravitational reaction forces, which push upward against each foot, counteract gravity and gravitational reaction forces gather in one point, the net ground force, which occurs on a hypothetical point on the ground named the center of pressure. The last term is a base of support (BoS), which underlies human balance and postural control definition. According to the general expression, to be able to say that a person is balanced, he/she needs to keep the body's center of mass within the base of support which is an area beneath a person’s every point of contact making with supporting surfaces. These contact points do not have to be on the body all the time, sometimes a leg of the chair a person sits in, or a crutch is included in it.

The neurophysiological approach to the human postural control system deals with neural circuits by biomechanical considerations. Ivanenko and Gurfinkel (2018) indicated that human postural control needs specialized neural cycles, and they added that simple biomechanical approaches cannot explain postural control mechanisms entirely. For this reason, to clarify human postural control, an understanding of different theories about human motor control is important. In the next part, various theories of motor control will be discussed.

2.2.1. Human Motor Control Theories

The study of motor control handles the nature of movement and how it is controlled by many systems. Movement is essential for human beings to survive. To give the simplest example, individuals must move to eat, work, and communicate with each other. Individual, task, environmental factors, and their interaction with each other formed movement so, individuals execute the movement to perform the task properly in a particular environment (Shumway-Cook & Woollacott, 2017). Figure 2.3. shows the concept of movement.

Many theories have discussed human motor control from different perspectives. To illustrate, some theories highlight extrinsic (i.e., environmental) influences, others highlight intrinsic (i.e., individual) influences for controlling human movement. To give brief information about motor control theories the reflex theory, the hierarchical theory, the motor programming theories, the systems theory, and the ecological theory will be tackled respectively.

The reflex theory of human motor control with foundations was determined by Sherrington in 1906. According to his research, reflexes are the building blocks that make a connection with each other to form complex behavior. A central nervous system is organized in hierarchical levels and from this point of view, the brain has control over the higher, middle, and lower levels which are higher association areas, the motor cortex, and the spinal levels of motor function respectively (Foerster, 1936).

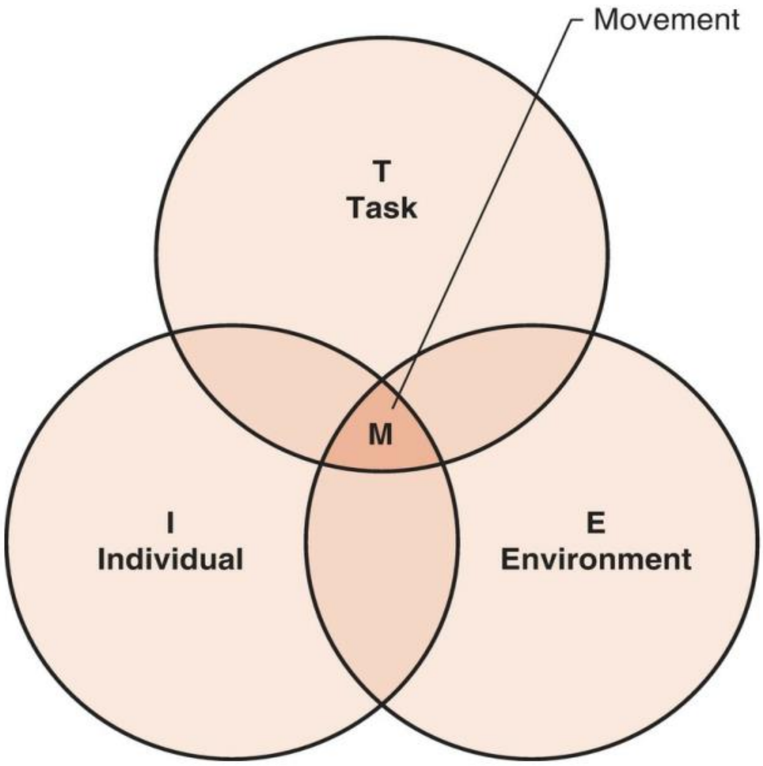


Figure 2.3. Individual, Task, Environmental Factor and Their Interaction to Form Movement

Note. Reprinted from *Motor control: Translating research into clinical practice* (5th ed., p.38) by Shumway-Cook, A., & Woollacott, M. H., 2017, Philadelphia: Wolters Kluwer.

The reflex/hierarchical theory is referred to as both reflex and hierarchical theory in clinical literature on motor control (Shumway-Cook & Woollacott, 2017). According to this theory, postural control is a simple task, and it is controlled only by the neurophysiological system (Horak, 2006). The system is formed by afferent pathways, the central nervous system (CNS), and efferent pathways. Sensory neurons in afferent pathways carry the information from visual, vestibular, and somatosensory systems to the CNS which consists of the cerebral cortex, cerebellum basal ganglia, brainstem, and spinal cord. The role of the CNS is to process and integrate the information from sensory cues. Sensory cues are primarily processed at the spinal cord level then, reflex, and voluntary control of posture happen through motor neurons in afferent pathways (Shumway-Cook & Woollacott, 2017). With processed sensory cues, feedback is provided with efferent pathways to different muscles that are responsible for postural control and allow those muscles to contract appropriately (Guskiewicz, 2011).

The concept of hierarchical and reflex control has changed lately. According to the present concept of hierarchical control, each level of the nervous system can have control over higher or lower levels based on the task and reflexes cannot be treated as the only determinant of motor control, but they are an important factor for the formation and control of movement (Shumway-Cook & Woollacott, 2017).

The motor programming theories of motor control helped researchers to understand CNS from a different point of view. They started to change their idea that the CNS is mostly a reactive system and the direction of their research consider the physiology of actions rather than the physiology of reactions (Shumway-Cook & Woollacott, 2017). According to this theory, when there is no afferent stimulus or impulse, a particular motor response may be appearing from a sensory stimulus or a central process, so it is more appropriate to refer to a central motor pattern (Shumway-Cook & Woollacott, 2017). The opinion which stated that with the absence of reflexive action, the movement is still possible has supported by Grillner in 1981. He examined the locomotion of cats and found that without sensory inputs or descending patterns from the brain, spinal neural networks still can produce locomotion (Grillner, 1981).

The systems theory states that neural systems and their control over the movement cannot be comprehended without an understanding of other influential systems on movement (Bernstein, 1967). It explains that movement is not controlled by only central or peripheral systems but also it is affected by interaction among multiple systems (Bernstein, 1967). The theory gives importance to initial conditions and their effects on movements. There are some critical features of systems theory which are degrees of freedom, synergies, self-organization, nonlinear behavior, and variability (Shumway-Cook & Woollacott, 2017).

The ecological theory slowly started to form in 1966 by Gibson. He focused on how our motor system interacts with the environment to execute goal-oriented movements. In his research, the main idea was to get knowledge of how people define the beneficial information in the environment and how they use this information to control movements. This idea was broadened by Lee & Young (1986) and turned into an ecological approach.

2.2.2. The Systems Approach of Postural Control

Postural control is not controlled by a single system or a set of reflexes, it is considered a complex motor skill formed by the interaction of multiple sensory and motor processes. From this point of view, the systems approach explains postural control as a complex skill and requires constant interaction between musculoskeletal and neural systems (Horak, 2006). According to Horak (2006), the two main goals of postural control are postural stability and postural orientation. Postural stability is an ability to stabilize CoM within BoS, postural orientation, on the other hand, is an ability to keep body segments aligned with gravity, support surface, visual environment, and internal references. The systems approach comes from a need for evaluation and rehabilitation of individuals whose ability is limited to perform movements and control posture, moreover, it also detects context-specific problems to understand in which contexts people are at risk of falling (Horak, 2006).

The systems framework analyzes postural control within six different systems, these systems are; movement strategies, control of dynamics, sensory strategies, cognitive influences, orientation in space, and biomechanical constraints (Horak, 2006). Figure 2.4 illustrates these systems. Each of these different systems has its neural circle and each of them is responsible for aspects of postural control (Horak et al., 2009). Since these systems work together, a problem in one of them can affect performing many tasks (Horak et al., 2009). Broglio et al. (2015) showed that vestibular injury of athletes due to a concussion may affect their running abilities in a straight line with their head turned or it may affect their ability to track flying objects.

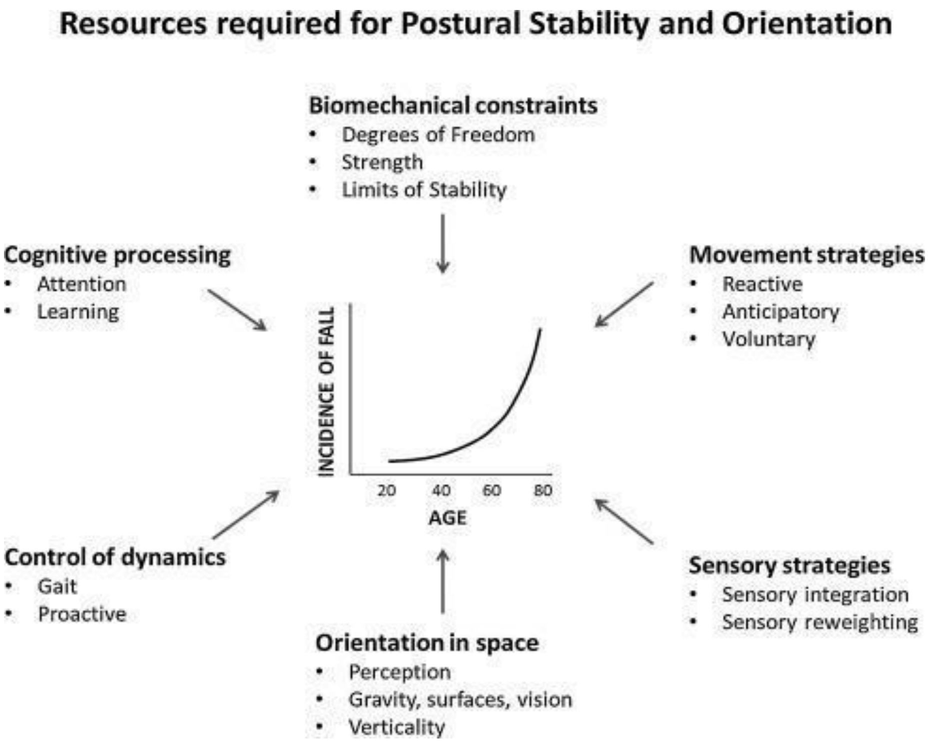


Figure 2.4. Resources Required for Postural Stability and Orientation

Note. Reprinted from ''Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls?'', by Horak, F. B., 2006, *Age and Ageing,* 35(suppl_2), ii7–ii11, p. ii8.

Movement Strategies: The equilibrium of vertical posture is achieved when the CoM is positioned over the BoS and it is aligned with the CoP (Santos et al., 2010). Any perturbation from inside such as fast body movements or outside such as sudden movement of support surface may result in loss of body equilibrium. The CNS uses two postural adjustments to restore balance. These are anticipatory and compensatory postural mechanisms. To maintain stability without initiating a movement, the CNS first activates trunk and leg muscles as an anticipatory postural response (Santos et al., 2010). Moreover, the anticipatory postural strategy maintains stability by compensating for instability caused by moving a limb before voluntary movement (Horak, 2006). After postural instability occurs, compensatory postural responses control and change BoS with individual reaching and stepping actions (Horak, 1987; Santos et al., 2010). When there is an external perturbation, a healthy individual sways, takes a step, or reaches respectively to restore balance (Shumway-Cook & Woollacott, 2017).

Individuals may use different postural strategies to keep body equilibrium depending on the task, the nature, the velocity of perturbation, direction, prior experience, and initial position (Horak, 2006). These strategies can be the ankle strategy, the hip strategy, or the stepping strategy (see Figure 2.5). During the ankle strategy the body moves around the ankles like an inverted pendulum, it is a convenient strategy to keep the body in balance when standing on a firm and even surface with a small number of sways (Horak, 2006). The hip strategy is simply exerting torque from the hips, it is more appropriate when the CoM should move quickly, standing on soft surfaces and conditions that are hard to produce ankle torque (Horak, 2006). When keeping feet in the same position is not important such as during gait and perturbation is too large to compensate by the ankle and hip rotations, the stepping strategy is commonly used. The rates of using these strategies may vary with age. The study indicated that to maintain postural stability, elderly people with a high risk of falling tend to use more stepping, reaching, and hip strategies compared to people with a low risk of falling who uses ankle strategy (Maki et al., 2000).

Control of Dynamics: During gait or movements requiring a change of posture, controlling body CoM requires more complex control than controlling body CoM during a quiet stance because, different than a quiet stance healthy individuals' body CoM during these kinds of activities is not inside of the BoS (Horak, 2006). Individuals use different control dynamics according to the direction of stability. To illustrate, during walking forward postural stability is controlled by placing a moving limb under the falling CoM (Horak, 2006). On the other hand, lateral postural stability is controlled by the lateral trunk and lateral placement of feet (Bauby & Kuo, 2000). As individuals age, their body compositions and control dynamics may change. The review article showed that elderly people who are inclined to fall have more lateral deviated body CoM and irregular foot placement compared to normal people (Prince et al., 1997).

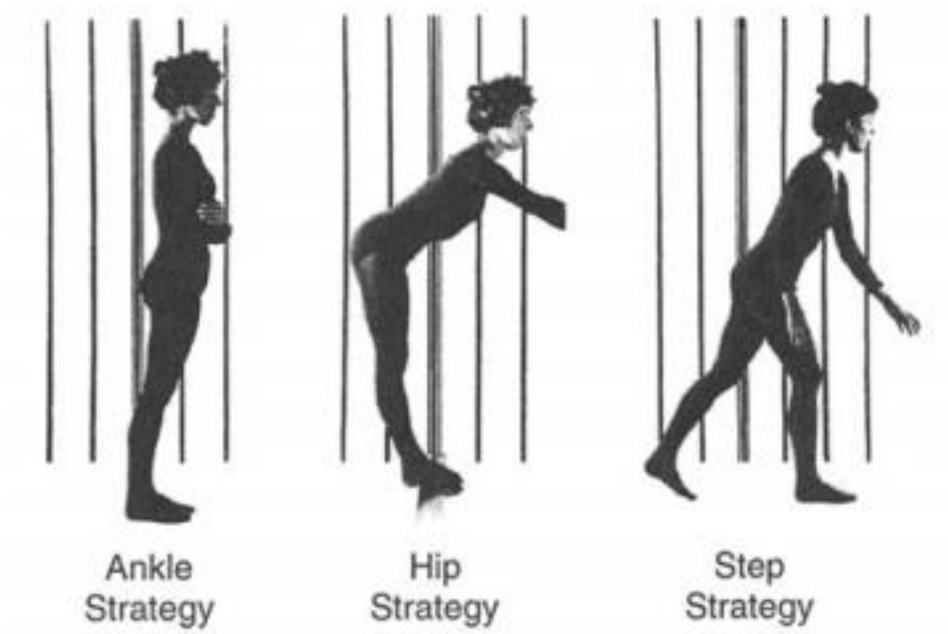


Figure 2.5. Strategies for Postural Correction

Note. Reprinted from ''Postural Adaptation for Altered Environments, Tasks, and Intentions'', Horak, F., & Kuo, A., 2000, Biomechanics and Neural Control of Posture and Movement, 267–281, p.269.

Sensory Strategies: As people live in an environment with full of different senses, somatosensory, visual, and vestibular systems are quite important for them to integrate sensory information in the related brain areas and interpret complex sensory environments to generate movement or stability-related activities (Horak, 2006). Individuals obtain information about the location and relation of the body with the surrounding environment through the visual system. Information about the position and movement of the head in the space is provided by the vestibular labyrinth which is in the inner ear (Shumway-Cook & Woollacott, 2017). Lastly, the somatosensory system consists of mechanoreceptors located in skin, muscles, joints, and ligaments and it provides information about the position of the body in space (Shumway-Cook & Woollacott, 2017).

The change in the sensory environment results in the brain reweighting its' relative dependence on each of the senses (Horak, 2006). To illustrate, while healthy individuals standing in a well-lit environment and standing on a firm surface, they benefited most from the somatosensory system than the visual and vestibular system (Peterka, 2002). On the other hand, while standing on an unstable surface, the sensory weighting increases to visual and vestibular information because dependence on surface inputs decreases for postural control (Peterka, 2002). Since individuals live in a constantly changing environment, a reweighting ability between these senses, which varies according to the sensory context, is very important to ensure stability (Horak, 2006). A deficit in CNS like Parkinson disease (Park et al., 2015) or Alzheimer's disease (Horak, 2006) and a problem in peripheral sensory mechanisms can change the sensory reweighting abilities of individuals and affects their postural stability (Horak, 2006).

Cognitive Processing: Many cognitive resources need to be processed and interpreted to achieve posture control (Horak, 2006). Cognitive processing increases with the difficulty of the postural task, as evidenced by the longer reaction time in a standing person than in a person sitting with support (Horak, 2006). Research showed that secondary cognitive tasks impact the performance of postural tasks and a possible explanation for this is the sharing of cognitive resources by postural control mechanisms and by other cognitive processes (Camicioli et al., 1997; Rosso et al., 2017). According to Horak (2006), individuals who are occupied with secondary cognitive tasks may experience falling because the cognitive process is divided into two tasks and so not sufficient control of posture.

Orientation in Space: Postural orientation is one of the two important aims of postural control. It requires an ability of body parts concerning gravitational forces, support surface, internal references, and visual environment (Horak, 2006). For a healthy individual it is an automatic process that is controlled by the nervous system according to context and task to orient the body in space (Horak, 2006). This process is illustrated by Horak (2006) with surface tilts; when the support surface is straight an individual can orient his/her body vertically to the surface and if there is a tilt on the surface then the posture is oriented to gravity. Studies have shown that human perception of verticality and upright posture may have been represented by more than one neural process (Karnath et al., 2000). In research by Bisdorff et al. (1996) it has been shown that the perception of visual verticality or aligned straight line in the dark is independent of postural verticality; to illustrate the ability to keep aligned the body without vision. Pathologies of the body in different areas may affect related verticality regions. For example, individuals with unilateral vestibular loss have a problem with visual verticality, whereas individuals with hemineglect due to stroke have a problem with postural verticality (Karnath et al., 1998).

Biomechanical Constraints: Multiple biomechanical elements play an important role to control posture such as quality and size of the base of support (the feet), range of motion of lower extremities, CoM alignment, trunk, and lower extremity strength (Horak, 2006). Controlling body CoM within the BoS is important for controlling posture. In the stance position, limits of stability are explained as an area for individuals to move their CoM to maintain equilibrium without changing BoS and its' shape resembles a cone (McCollum & Leen, 1989). For this reason, equilibrium is not a specific position, but an area determined by various factors such as the size of the feet, muscle strength, and limitations on joints (Horak,2006). In addition, functional limits of stability are affected by the representation of limits in the CNS (Horak, 2006). In research from Duncan et al. (1990), it has been shown that individuals with a tendency to fall also have small stability limits. The central nervous system needs to interpret correctly for the stability limits of the body otherwise, postural instability may occur (Horak, 2006).

2.2.3. Assessment of Postural Control

Measurement of postural control is crucial, especially for sports settings and clinical considerations. In clinical settings, postural control assessment methods can be benefited to quantify balance deficits of individuals on the other hand, in sports settings training improvements can be observed with these methods. Assessment methods should consider the goals and implementation of postural control depending on environmental conditions, specific tasks, and the purpose of individuals (Massion, 1994). Different assessment methods use various methodologies, and technologies and they differ in the level of assessment therefore, coaches, therapists and clinicians should consider their differences and choose the appropriate method according to specific needs (Panjan & Sarabon, 2010). To objectify postural control various quantitative and qualitative variables were measured (Paillard & Noé, 2015). The quantitative analyses show the substitution of the CoM, the CoP, body segments, measurement of electromyographic activities, and evaluation of different sensory information acting on postural control (Paillard & Noé, 2015). On the other hand, the qualitative analysis assesses postural control by highlighting mechanical and neurophysiological aspects (Paillard & Noé, 2015). When measuring postural control, some tests require special instruments, while others do not. In the following two sections, detailed information and the pros and cons of these different methods for the assessment of postural control will be given.

Non-instrumented Postural Control Tests: Basic tests without using instruments were designed to measure older individuals' postural abilities and their inclination to fall but just a few of them consider individuals with pathologies (Paillard & Noé, 2015). These procedures follow standardized test protocols but are still affected by individual factors because, observation of the examiner is also an important criterion (Panjan & Sarabon, 2010). The more difficult tests such as the Flamingo Test (Sundstrup et al., 2010) and The Sharpened Romberg Test (Fitzgerald, 1996) are used especially in sports settings while the others such as Timed Up-and-Go Test (Podsiadlo & Richardson, 1991), the Berg Balance Scale (Berg, 1989), Tinetti Test (Tinetti et al., 1994), Mini Balance Evaluation Systems Test (Franchignoni et al., 2010), Short Physical Performance Battery (Guralnik et al., 1994) and the Postural Assessment Scale for Stroke Patients (Benaim et al., 1999) are used for the adult population and for detecting their risk of falling. Besides these assessment choices, walking speed and monopodial stance time can be a predictor of the risk of falling for the elderly. For example, a study showed that elderly people who cannot maintain standing on one leg for 5 seconds have a high risk of falling (Vellas et al., 1997). The study which used 4-meter distance walking speed tests indicated that walking speed is a predictor of weak functional abilities and a risk of falling for elderly people (Abellan Van Kan et al., 2009). Although these measurement methods are useful and usable, other more instrumented methods may be required for more precise measurements where objective results are desired.

Instrumented Postural Control Tests: Even if non-instrumented tests are beneficial for therapists and coaches, they are classified as a gross indicator of functional and postural abilities. Detailed analyzes need tests with technological devices and with these devices, it is possible to carry out kinetic, kinematic, and electrophysiological analyses (Paillard & Noé, 2015).

Kinetic Assessment: The most widely utilized kinetic devices for measuring postural function are wobble boards and force platforms (Paillard & Noé, 2015). Wobble boards are mostly made of wood or plastic boards with hemispherical or hemicylindrical seesaws that can create unstable surfaces (Cimadoro et al., 2013). According to the working system of wobble boards, it requires individuals' CoM projected over the board's point of contact with the ground and this system increases postural sway and make pressure on the postural control system when compared to standing on stable surfaces (Cimadoro et. al., 2013). Even though wobble boards are affordable and useful in a sport setting and balance rehabilitation, they provide only superficial postural sway parameters without directional information which is required for full-fledged postural function assessment (Paillard & Noé, 2015).

Force platforms are made of plates that are stable in all directions and have load sensors positioned under them. Force platforms can be divided into two categories according to load cells. The first one equipped with mono-axial load sensors can measure the only vertical component of the ground reaction force, on the other hand the other one equipped with load sensors can measure three components of the ground reaction force and the moment of force acting on the plates (Duarte & Freitas, 2010). Force platforms can calculate the medial-lateral (ML) and anterior-posterior (AP) time series of the CoP during postural tests regardless of the number of axes their plates have (Paillard & Noé, 2015). In summary, the force platform can calculate various variables of the CoP parameter, which is widely used to evaluate postural function (Duarte & Freitas, 2010), and this feature makes force platforms the gold standard among kinetic devices (Huurnink et al., 2013).

Kinematic Assessment: Some kinematic devices for assessing postural function are 3D body-worn accelerometers (Mancini et al., 2012), Electro-goniometers (Oullier et al., 2002), Laser-displacement sensors (Sasagawa et al., 2009). To assess postural function, both qualitative and quantitative information can be accessed through basic video recording systems but, only 3D motion capture systems can record very small motions emerging from an unperturbed quiet stance with a high level of reliability and accuracy (Günther et. al., 2009).

Electromyography Assessment: Another method used in postural control assessment is electromyography (EMG) recording. With EMG recordings amplitude, frequency, and temporal parameters can be analyzed and differentiated (Merletti & Parker, 2004). These parameters show different postural responses of an individual. For example, amplitude analysis shows the effectiveness of muscle activity for executing a specific postural task, frequency analysis showed that the amplitude spectrum of muscle activity increases with increasing platform oscillations (Fujiwara et al., 2006). Lastly, temporal analysis shows postural responses against movement of platform or anticipatory postural adjustments (Saito et al., 2014).

Postural control can be measured with appropriate technological tools and tests for the target population, the purpose of postural movement, and environmental conditions. However, these postural analysis methods are not fully sufficient to experimentally verify all theoretical considerations related to postural function (Paillard & Noé, 2015).

2.2.4. Factors Affecting Postural Control

Good postural control decreases the risk of falls in the elderly and reduces the risk of sports injuries in athletes. It is necessary to consider individual, environmental, and other conditions to improve, assess posture control, and in some cases choose the appropriate treatment methods. In this context, there are some factors to consider e.g., age, sex, body factors, experience, and postural task characteristics are some of them.

Age-related changes are quite effective in postural control systems of the elderly as one-third of the population aged 65 years and older report falls each year (MacRae et al., 1992). On the other hand, gender differences haven't been reported as an effective factor during quiet standing activities (Maki et al., 1990). In 1995, a study compared age (20 to 35 and 60 to 75) and their gender differences based on force platform measures and functional reach to measure postural control (Hageman et al., 1995). The result showed that postural sway increases with age, but no gender differences were found in outcome measures of postural sway (Hageman et al., 1995). Another research stated that gender affects postural control of the elderly but not any effect on young subjects which states that females were more stable than males and they attributed this result to height differences between participants. (Nakamura et al., 2001). On the contrary, another new study found no gender differences affect postural stability even though there were height differences between males and females in the young and elderly groups (Palazzo et al., 2021). The result of this study also showed larger body sways in the elderly compared to younger subjects (Palazzo et al., 2021). The reason for these results can be explained by the decline in somatosensory functions of individuals over 60 years of age (Collins et al., 1995).

When considering anthropometric factors affecting postural stability, it is suggested that weight is a major determinant of postural stability compared to height (Hue et al., 2007). According to research, there is a strong correlation between body weight and postural stability which states increase in body weight causes a decrease in postural stability (Hue et al., 2007). Additionally, balance and postural control are important for almost all sports branches, but these are more important for being successful in some sports. Being an expert in these kinds of sports such as gymnastics and dance requires good posture control and balance (Asseman et al., 2008; Bruyneel et al., 2010). Even if it is not a professional sport, some physical activities have been shown to increase posture control and reduce falls for selected populations and the elderly (Gregg et al., 2000; Gardner, 2000). These studies showed that athletes or people doing exercises are better at postural control than novice or sedentary people. In some cases, the type and characteristics of the sport may also affect postural control. The research showed that athletes who were involved in playing soccer were found to show better postural control competence compared with athletes who were involved in playing baseball (Liang et al., 2019). These results emphasized that all factors should be considered as much as possible to assess postural control and obtain valid and reliable results.

In the previous parts of this chapter, we mentioned movement and how it is affected and formed by various factors. One of these factors is a task and different properties of tasks have differently affected human postural control and other movements. The difficulty of postural and other movement-related tasks may not be specifically defined because they are influenced by many related factors such as individual and environmental features. The intended task can evolve to be more difficult by changing individual and environmental factors concerning the own specific properties of the task. In general, tasks get more difficult as their complexity levels increases. For example, a task can be accepted as difficult if it has more than one degree of freedom or cannot be learned and mastered in a single practice session (Wulf & Shea, 2002). Degrees of freedom is first mentioned by Bernstein in 1967 and it is a movement problem but also a solution to the nervous system's countless choices of movement by freezing these choices at the beginning of learning a motor skill also, it is beneficial for defining stages in learning of physical activities. Individuals in the first stage of learning a new task, typically 'freeze the degrees of freedom' by locking some of their joints, and as time goes by their movements become more coordinated and they learn how to unfreeze their locked joints.

Since static balance tasks such as quiet stance cannot create enough challenges on the postural control system by itself, desirable challenges on postural tasks can be created by changing some individual and environmental factors. In performing static balance tasks, the movement of the joints and limbs be kept as stable as possible for this reason, they are not as effective as the senses to stabilize the posture. As in all other movements, some external information should be received to maintain postural control. In the context of posture control, this information can be obtained from somatosensory, vestibular, and visual systems as sensory information. Restricting and changing this information will result in difficulties in producing necessary motor output to control posture and will transform the task into a more difficult one.

In the context of postural control tasks, external information can be received from more than one source. Two of this sensory information are feet as a proprioceptive or eyes as visual information. Manipulating these senses and the BoS automatically affects the postural control system. To illustrate, manipulating sensory input by standing on a firm vs. foam ground, standing with eyes open vs. closed, or changing BoS by manipulating support surface size by bi-pedal stance, tandem stance, and mono-pedal stance have a great effect on postural sway measures assessed with young healthy adults (Muehlbauer et al., 2012). According to the research by Cohen et al. (1996) standing with eyes closed or standing on a foam ground are more challenging than bi-pedal standing on firm ground with eyes opened for young participants. Another study showed that postural sway is greater while standing on two legs with eyes closed compared to standing with eyes opened condition assessed with young adults (16-30 years) (Hytönen et al., 1993).

Postural sway also increased when performing postural tasks on a foam surface compared to performing them on a firm surface (Muehlbauer et al., 2012) and reducing the BoS starting from a quiet stance, Romberg-sharpened stance, and one-leg stance (Amiridis et al., 2003). In research by Shafizadeh et al. (2020), it is shown that there was a significant positive linear trend by increasing postural task difficulty (two-leg standing, one-leg standing on the dominant leg, and two-leg standing on an inflatable balance cushion with and without dual-task) on postural sway measures. According to The American College of Sports Medicine challenging postural tasks are formed by gradually decreasing BoS or changing sensory input separately (Chodzko-

Zajko et al., 2009) but according to the study by Muehlbauer et al. (2012), stance and sensory manipulations can be combined to create challenging postural control tasks.

2.3. Feedback & Postural Control

There are a lot of postural control studies searching for the effect of providing feedback concurrently and with different frequencies. These studies generally include the demonstration of an individual's center of gravity (CoG) or center of pressure (CoP) as feedback to learn or improve static and dynamic balance skills. The study which modified the frequency of feedback to 100% and 67% frequencies found that a feedback frequency of 67% is recommended for the static balance tasks (bipedal standing on a seesaw) in which the surface support generates instability (Marco-Ahulló et al., 2018). In addition, D'Anna et al. (2015) indicated that both concurrent presentation and discretized presentation of concurrent feedback are superior to no feedback condition on quiet stance assessed with force plate but, discretized feedback promotes more natural postural behavior (D'Anna et al., 2015).

On the other hand, despite these recent findings about the role of concurrent feedback, in the study of Shea & Wulf (1999), 32 students were tested with a balance task on the stabilometer. A total of four groups executed the balance task with (1) only internal focus instructions, (2) only external focus instructions, (3) internal focus instructions with feedback, and (4) external focus instructions with feedback. After 7 practice trials every two days, participants took a retention test without any feedback or instructions. Results showed that feedback enhanced performance during acquisition, also there wasn't observed any performance decrement when feedback was withdrawn (Shea & Wulf, 1999). As a result, the effects of concurrent feedback on various motor tasks are different from each other, especially in retention tests. These results suggest that more studies are needed to understand the effects of concurrent feedback, especially on postural tasks of varying difficulty.

CHAPTER III

METHOD

This chapter will present the research methodology conducted in this thesis to investigate the effect of concurrent visual feedback and postural task difficulty on postural sway parameters. The purpose of this chapter is to give brief information about the characteristics of the subjects, data collection apparatus and procedures, experimental protocols, and data analyses.

3.1. Subjects

40 voluntary participants were included in the study, and they were divided into a control group and an experimental group. They were randomly allocated to groups by considering gender to have equal distribution in each group. The age limit was set between 18-30 to avoid the effect of age on the postural sway parameters. All the participants were university students and had normal or corrected to normal vision and did not have any neurological or musculoskeletal disorders which can affect postural control. Participants were considered to have healthy postural systems since they did not have any diseases which could affect postural control. The sample size was determined on the estimated effect size of 0.30. Calculations using G*Power software v3.1 revealed that an estimated sample size of at least 28 participants was recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.80. Ethical approval was obtained from the Research and Ethics Committee of Middle East Technical University. Subjects gave written consent, and they filled demographic information form before participation (see Appendix A).

Data was collected in the Motion Capture Laboratory at Middle East Technical University Modeling and Simulation R&D Center.

3.2. Data Collection Procedures and Apparatus

While participants performed postural tasks with six different difficulties as quiet stance on firm ground (QS), tandem stance on firm ground (TS), single-leg stance on firm ground (SS), quiet stance on the balance pad (PQS) (Balance-pad, Alcan Airex AG, Switzerland), tandem stance on the balance pad (PTS) and single-leg stance on the balance pad (PSS), they received concurrent feedback (experimental group), or they did not receive concurrent feedback (control group).

The foam surface is formed by a balance pad (see Figure 3.1) placed on the force plate.

Figure 3.1. Illustration of Airex Balance Pad

Raw data is collected at a sampling rate of 1000Hz for each trial and exported through Bertec Digital Acquire 4.1.20 software of the force plate (Bertec Corporation, Columbus, OH, USA). Raw data included force (F) and moment (M) on x, y, and z axes and CoP displacement in the anteroposterior (AP) and mediolateral (ML) directions. Experimental processes include monitoring and recording force plate data and presentation of concurrent feedback related to CoP on the computer screen. The screen resolution was set at 800x600 pixel throughout the data collection. The size of the feedback screen was 12cm-by-12cm and it was an extension of the original data collection software. Stored data were used for processing by scripts written in MATLAB R2021b (The Mathworks, Inc., Natick, MA, USA). The measurement methods and analyzed sway parameters were explained in detail below.

3.2.1. Measurement of Ground Reaction Forces

Ground reaction forces in 3 orthogonal axes (Fx, Fy, Fz), moments (Mx, My, Mz), and CoP displacement in AP-ML directions were measured via a 120x120 cm force plate (Bertec Corporation, Columbus, OH, USA) (see Figure 3.2). Data were acquired via USB which was connected to a computer. Bertec Digital Acquire 4.1.20 software and MATLAB were used for data collection algorithms and post-processing the data respectively. Original extension of the Bertec Digital Acquire 4.1.20 software was used to acquire force plate signals and provide feedback on COP position.

Figure 3.2. Illustration of the Force Plate

3.2.2. Analysis of Sway Parameters

The 60s-long CoP signals were collected and processed for the analysis. The sampling frequency was fixed to 1000 Hz imposed by the Bertec data acquisition interface. The mean value was subtracted from each time series and the second order zero lag low pass Butterworth filter with a cut-off frequency of 10 Hz (Schmidt et al., 2002) was used for filtering the COP data.

Postural sway mean velocity, range, variability (RMS), area, and regularity were investigated by calculating CoP Velocity (CoP_{VEL}), Range and RMS values in anteroposterior direction (AP), mediolateral direction (ML) and resultant distance (RD), CoP Ellipse Area (CoP_{EA}) and COP approximate entropy (CoP_{ApEn}) respectively. Overview and the notations (Prieto et al., 1996; Quijoux et al., 2021) of these parameters are summarized below;

- N: number of data points in the CoP trajectories.
- X: AP axis.

$$X_n = ML_n - \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} ML_i$$

- Y: ML axis.

$$Y_n = AP_n - \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} AP_i$$

- R (Resultant Distance, RD): Euclidean distance of the CoP to the origin.

$$R_n = \sqrt{X_n^2 + Y_n^2}$$

COV: Covariance between the AP and the ML variations of CoP.

$$\mathrm{COV} = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} X_n Y_n$$

- **COP mean velocity (mean speed):** sway-path normalized to signal duration.

$$\text{SWAY LENGTH ML} \quad \sum_{n=1}^{\mathrm{N}-1} |X_{n+1} - X_n| \qquad \text{MEAN SPD ML} \quad \frac{\text{SWAY LENGTH ML}}{\mathrm{T}}$$

$$\text{SWAY LENGTH AP} \quad \sum_{n=1}^{\mathrm{N}-1} |Y_{n+1} - Y_n| \qquad \text{MEAN SPD AP} \quad \frac{\text{SWAY LENGTH AP}}{\mathrm{T}}$$

$$\text{SWAY LENGTH} \quad \sum_{n=1}^{\mathrm{N}-1} \sqrt{(X_{n+1} - X_n)^2 + (Y_{n+1} - Y_n)^2} \qquad \text{MEAN SPD} \quad \frac{\text{SWAY LENGTH}}{\mathrm{T}}$$

- **COP range:** maximal deviation of COP.

$$\text{RANGE ML} \qquad \max_{1 \le n \le m \le \text{N}} |X_n - X_m|$$

$$\text{RANGE AP} \qquad \max_{1 \le n \le m \le \text{N}} |Y_n - Y_m|$$

$$\text{RANGE AP - ML} \qquad \max_{1 \le n \le m \le \text{N}} \sqrt{(X_n - X_m)^2 + (Y_n - Y_m)^2}$$

- **RMS COP:** root mean square COP displacement relative to the mean COP location which is equal to standard deviation.

$$\text{RMS ML} \qquad \sqrt{\frac{1}{\text{N}} \sum_{n=1}^{\text{N}} X_n^2}$$

$$\text{RMS AP} \qquad \sqrt{\frac{1}{\text{N}} \sum_{n=1}^{\text{N}} Y_n^2}$$

$$\text{RMS RADIUS} \qquad \sqrt{\frac{1}{\text{N}} \sum_{n=1}^{\text{N}} R_n^2}$$

- **COP Prediction Ellipse area:** the area of ellipses containing 95% of the data.

$$\text{PEA} = \pi a_P b_P = \pi \frac{2(n+1)(n-1)}{n(n-2)} F_{(1-\alpha),2,n-2} \cdot \sqrt{\lambda_1 \lambda_2}$$
$$\approx \pi \chi_2^2 \cdot \sqrt{\lambda_1 \lambda_2} = \pi \chi_2^2 \sqrt{\det(\text{S})}.$$

(For detailed information see; Schubert & Kirchner, 2014; Chew, 1966)

- **CoP Approximate Entropy:** a regularity measure of time series.

$$C_i^m(r) = \{\text{number of } x(j) \text{ such that } d[x(i), x(j)] \le r\}/(N - m + 1)$$

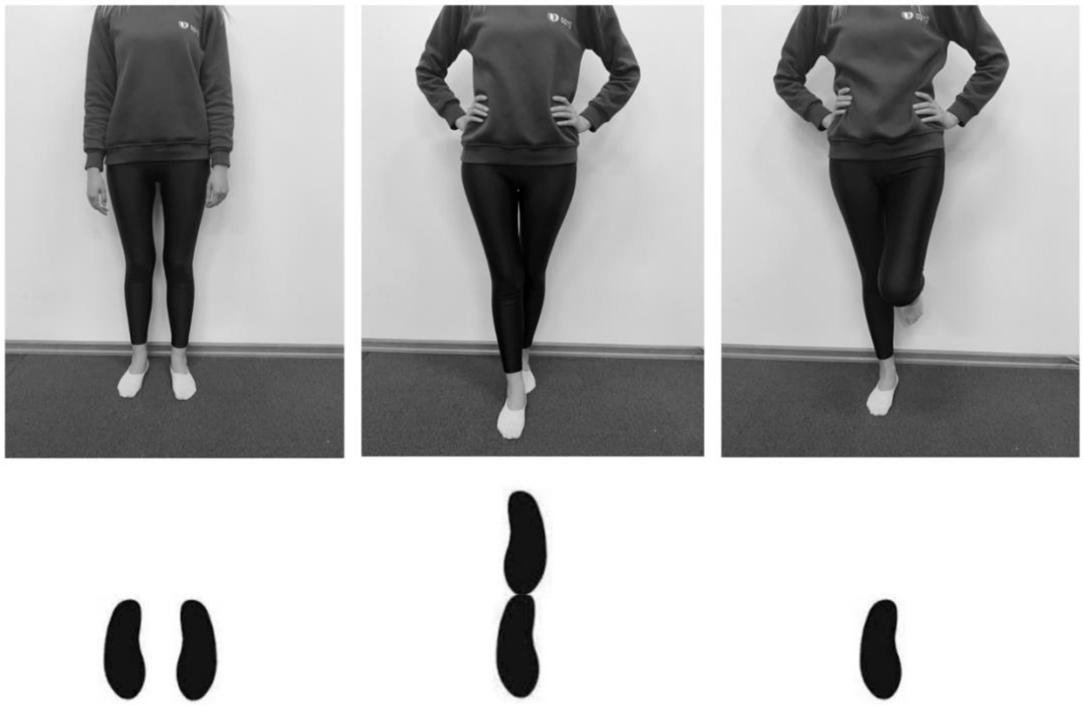
$$\Phi^m(r) = (N - m + 1)^{-1} \sum_{i=1}^{N-m+1} \ln C_i^m(r)$$

$$\text{ApEn}(m,r,N) = \Phi^m(r) - \Phi^{m+1}(r).$$

(Pincus, 1991; Pincus, 1995)

3.2.3. Postural Tasks

Postural tasks with varying difficulties were chosen as motor tasks (see Appendix B). The difficulty level of tasks was formed by modifying the base of support (BoS area) (quiet stance, tandem stance, single-leg stance) (see Figure 3.3) and manipulating sensory input (firm surface, foam surface) (Muehlbauer et al., 2012). The dominant leg was determined by verbally asking about their preferred leg in daily work and physical activities, and which foot they use to hit the ball. The order of the six postural tasks was randomized for each subject by a random sequence generator both for acquisition and retention phases. (https://www.random.org/sequences/).



Quiet Stance Tandem Stance Single-Leg Stance

Figure 3.3. Illustration of Postural Tasks

3.2.4. Feedback Configurations

Participants in the experimental group received feedback concurrently. To provide feedback about their CoP information, the display monitor was placed at eye level and 1 m away, the cursor represents instantaneous changes in the location of their CoP while performing postural tasks for the 60s. On the other hand, the control group did not receive any feedback about their instantaneous CoP location while performing the same postural tasks.

3.2.5. Experimental Procedure: Feedback and Postural Tasks

Subjects were randomly allocated to either experimental or control group. Participants in the experimental group received concurrent feedback on their CoP and participants in the control group did not receive any feedback on their CoP while performing three different postural control tasks on firm and on foam surfaces totaling six different difficulties. Each participant was asked to perform three trials for each difficulty for 60 seconds (see Table 3.1). The next day participants in both groups performed the same postural tasks in three trials without receiving any feedback in the retention test.

<u>Postural Tasks and Difficulties:</u>

- QS: Quiet stance on firm ground
- TS: Tandem stance on firm ground
- SS: Single-leg stance on firm ground
- PQS: Quiet stance on balance pad
- PTS: Tandem stance on balance pad
- PSS: Single-leg stance on balance pad

Table 3.1. Description of the Experimental Procedure.

Feedback Conditions	Postural Control Tasks	
	Firm Surface	Foam Surface
With Concurrent Visual Feedback (Experimental Group)	Quiet Stance Tandem Stance Single-Leg Stance	Quiet Stance Tandem Stance Single-Leg Stance
Without Concurrent Visual Feedback (Control Group)	Quiet Stance Tandem Stance Single-Leg Stance	Quiet Stance Tandem Stance Single-Leg Stance

3.3. Experimental Protocols

In this study, postural tasks which have different difficulties were included as follows: QS, TS, SS, PQS, PTS, and PSS. These tasks were performed separately with or without receiving concurrent feedback on CoP location depending on whether participants were in an experimental or in a control group. The order of six different tasks was performed in a randomized order for each subject both for acquisition and retention phases separated by 24 hours. Each task was repeated three times successfully before moving on to the next task. If the participants disrupted their assigned task positions, for example, in the one-leg stance touching the ground with the other feet or pulling the hands from the waist they were asked to repeat the task. Participants performed all tasks under the guidance of the same researcher, and they performed all tasks without shoes but wearing socks.

All tasks were performed with eyes open until the subject completed three trials successfully for each task (Ruhe et al., 2010). Participants performed each task for the 60s and the mean of three trials was utilized for further analyses. Rest periods of the 60s were provided between three trials during which subjects were allowed to sit down (Pinsault & Vuillerme, 2009). While participants performing the tasks, the instruction was ‘stand as still as possible’ which is ‘mümkün olduğunca hareketsiz dur’ in the Turkish language (Ruhe et al., 2010). According to the information obtained at the end of the data collection process, the total repetition rate was 4.31% based on all tasks on the acquisition and retention phases.

3.3.1. Protocol 1: The Experimental Group

Participants in the experimental group performed three trials of six postural tasks (QS, TS, SS, PQS, PTS, PSS) on the force plate for the 60s while they received concurrent feedback on their CoP location. The foam ground was made by placing the Airex balance pad on the force plate. A detailed description of postural task conditions is below.

- QS - Quiet stance on firm ground: Participants stand on the force plate with their feet shoulder-width apart and arms relaxed at their sides.
- TS - Tandem stance on firm ground: Participants stand on the force plate with their feet in a tandem position and place their arms akimbo.
- SS - Single-leg stance on firm ground: Participants stand on the force plate with a dominant leg on the ground and the other knee of the leg flexed between 45 ° and 90 ° and placing the arms akimbo.
- PQS – Quiet stance on foam ground: Participants stand on the balance pad placed on the force plate with their feet shoulder-width apart and arms relaxed at their sides.
- PTS - Tandem stance on foam ground: Participants stand on the balance pad placed on the force plate with their feet in tandem position and placing their arms akimbo.
- PSS - Single-leg stance on foam ground: Participants stand on the balance pad placed on the force plate with only one foot on the ground and the other knee of the leg flexed between 45° and 90° and placing the arms akimbo.

Concurrent feedback was provided by the display monitor placed at eye level height and 1 meter away from the participants. The cursor on the screen represented instantaneous changes in the location of their CoP. Participants were instructed to keep the cursor in the center of the monitor during the tasks.

3.3.2. Protocol 2: The Control Group

The protocol and the tasks were the same for the participants in the control group. However, they did not receive any feedback on the CoP location. They asked to look at the fixed point located on the black screen monitor placed at eye level height and 1 m away from them (see Figure 3.4).

Figure 3.4. Experimental Set-up (illustration of PTS)

3.3.3. Protocol 3: Retention Test

Participants both in the experimental and the control group took the retention test 24 hours later they performed postural tasks without receiving any feedback on their CoP locations. They asked to look at the fixed point located on the black screen monitor placed at eye level height and 1 m away while performing each postural task three times and in the randomized order.

3.4. Statistical Analysis

Related to the research questions, several analyses were performed to indicate the effects of concurrent feedback on CoP velocity on anteroposterior direction (AP), mediolateral direction (ML), and resultant-distance (RD) (CoP_{VEL-AP}, CoP_{VEL-ML}, CoP_{VEL-RD}), CoP variability on AP-ML-RD directions (CoP_{RMS-AP}, $CoP_{RMS-ML,}$ CoP_{RMS-RD}), CoP range on AP-ML-RD directions ($CoP_{RANGE-AP}$, $CoP_{RANGE-ML}$, $CoP_{RANGE-RD}$), CoP ellipse area (CoP_{EA}) and CoP regularity (i.e., approximate entropy) (CoP_{ApEn}) at different postural task difficulties measured in acquisition and retention phases. The dependent variables of this study were CoP velocity (AP-ML-RD directions), CoP variability (AP-ML-RD directions), CoP range (AP-ML-RD directions), CoP ellipse area, and CoP regularity (i.e., approximate entropy). Table 3.2 shows the statistical design of the study. All variables were measured for each identical 3 trials and an average of these trials was utilized for analyses to eliminate the effect of within-subject inter-trial variability.

The independent variables of this study were groups with two levels (control group: without concurrent feedback and experimental group: with concurrent feedback) and postural task difficulties as a repeated factor with six levels (QS, TS, SS, PQS, PTS and PSS). Two-way mixed-design (within-between) analysis of variance models (two-way split-plot ANOVA) was separately computed for postural sway (CoP) measures in addition, acquisition and retention tests data were analyzed separately as well. If there were significant main effects of postural task difficulty, Bonferroni-corrected paired t-tests were used as post hoc comparisons.

Table 3.2. Statistical Design of the Study

CoP Sway Parameters	Groups	Postural Task Difficulty
VEL-AP, VEL-ML, VEL-RD, RANGE-AP, RANGE-ML, RANGE-RD, RMS-AP, RMS-ML, RMS-RD, Ellipse Area, Approximate Entropy	Control Group	Quiet Stance Tandem Stance Single Stance Quiet Stance on Pad Tandem Stance on Pad Single Stance on Pad
	Experimental Group	Quiet Stance Tandem Stance Single Stance Quiet Stance on Pad Tandem Stance on Pad Single Stance on Pad

The main assumptions underlying two-way mixed model ANOVA are: 1) continuous level of measurement (all CoP variables measured at continuous level); 2) random sample (the groups represent the random sample from the population); 3) independent observations (there is no dependency between the participant's scores); 4) normal distribution; 5) homogeneity of variance; 6) sphericity. The validity of the normality assumption was checked by the Kolmogorov-Smirnov D test, Shapiro-Wilk's W test, Histogram, Q-Q- plot, and skewness kurtosis. Homogeneity of variance assumption was evaluated by using Levene's test. Lastly, to check the sphericity assumption, Mauchly's test was checked and if this assumption was violated Huynh-Feldt or Greenhouse- Geisser correction was utilized. The statistical significance level was set to $p<0.05$. Analyses were conducted with Statistical Package for Social Sciences (SPSS, Version 28.0, IBM, USA).

CHAPTER IV

RESULTS

This study aimed to investigate the effects of concurrent visual feedback and postural task difficulty on postural sway parameters. The results will be presented in two parts. In the first part, descriptive statistics of acquisition and retention test results with means and standard deviations will be expressed separately and in the second part, postural sway findings (interaction between concurrent visual feedback and postural task difficulty, main effects of concurrent visual feedback and main effects of postural task difficulty) in acquisition and retention test results will be presented separately in connection with the hypotheses.

4.1. Descriptive Statistics in Acquisition and Retention Phases

In the study, 40 voluntary participants (7 female, 13 males in each group) aged between 18-30 years were included. They divided into control group (n=20; age:23 ± 3.04 years; height:174 ± 0.10 cm; weight:73.35 ± 17.23 kg) and experimental group (n=20; age:22.35 ± 1.63 years; height:176 ± 0.10 cm; weight:75.69 ± 21.51 kg) (see Table 4.1). The body mass index of the participants was calculated and presented in Appendix C.

Table 4.1. Descriptive Statistics of Participants

Participants	Control Group Age (Years)	Control Group Height (cm)	Control Group Weight (kg)	Experimental Group Age (Years)	Experimental Group Height (cm)	Experimental Group Weight (kg)
1	24	200	103.5	23	193	122.0
2	25	170	67.20	24	182	80.00
3	25	169	53.00	22	179	120.0
4	21	186	81.60	24	190	95.70
5	25	190	102.0	26	178	71.50
6	19	178	59.90	23	171	58.20
7	23	165	59.30	24	174	69.80
8	21	176	75.00	21	172	58.80
9	20	167	66.10	22	176	70.20
10	30	167	101.0	23	192	113.2
11	23	177	97.40	24	174	67.00
12	23	185	89.20	21	159	45.00
13	22	165	56.00	23	185	74.00
14	27	170	78.90	21	170	62.10
15	24	172	56.20	22	181	59.10
16	28	174	56.00	20	169	63.40
17	20	160	60.50	20	171	75.10
18	20	172	74.60	20	155	84.60
19	21	170	72.50	21	170	69.10
20	19	165	57.00	23	172	55.00
Mean	23	174	73.35	22.35	176	75.69
SD	3.04	0.10	17.23	1.63	0.10	21.51

Participants performed 6 different postural control tasks consecutively in a randomized order both in acquisition and retention phases. During acquisition phase, the experimental group provided concurrent visual feedback of their CoP location, and the control group did not receive any feedback. During retention phase, both groups did not receive feedback. Each task consisted of three trials and the average of the three trials was utilized for statistical analysis. The means and standard deviations of six postural tasks are presented separately for acquisition (see Table 4.2 & Table 4.3) and retention (see Table 4.4 & Table 4.5) phases.

Table 4.2. Means and Standard Deviations for the Variables in Acquisition Phase

CoP Parameters		QS		TS		SS	
		M	*SD* (±)	*M*	*SD* (±)	*M*	*SD* (±)
Control Group	VEL-AP	6.10	1.49	15.30	5.37	20.13	6.36
	VEL-ML	4.60	1.82	13.36	3.25	20.45	4.98
	VEL-RD	8.52	2.49	22.56	6.45	31.82	8.54
	RANGE-AP	23.08	7.21	33.15	11.57	43.11	8.57
	RANGE-ML	13.99	4.36	29.47	6.08	27.62	4.23
	RANGE-RD	13.80	4.42	21.16	5.89	24.77	5.17
	RMS-AP	4.42	1.41	6.04	1.99	7.87	1.76
	RMS-ML	2.49	0.70	5.00	0.89	4.75	0.86
	RMS-RD	5.14	1.45	7.95	1.97	9.27	1.71
	EA	200.60	105.19	572.95	264.17	697.20	227.67
	ApEn	0.06	0.02	0.11	0.2	0.12	0.03
Experimental Group	VEL-AP	7.04	1.64	16.60	3.57	21.97	3.32
	VEL-ML	4.78	1.30	13.22	2.50	19.70	2.93
	VEL-RD	9.43	2.10	23.51	4.41	32.69	4.16
	RANGE-AP	20.56	5.83	26.49	7.94	40.53	8.96
	RANGE-ML	11.78	4.24	28.53	6.16	27.49	3.51
	RANGE-RD	11.79	3.39	18.60	4.83	24.07	6.00
	RMS-AP	3.58	1.03	3.91	1.08	6.44	1.16
	RMS-ML	1.79	0.62	4.81	1.05	4.79	0.69
	RMS-RD	4.05	1.13	6.24	1.38	8.06	1.30
	EA	123.80	85.13	361.85	169.40	584.15	181.40
	ApEn	0.09	0.02	0.13	0.02	0.15	0.02

Note. N=40 (Control Group: n=20, Experimental Group: n=20). QS: quiet stance, TS: tandem stance, SS: single stance

Several mixed model ANOVAs were run to determine the effect of concurrent visual feedback (CVF) and postural task difficulty (PTD) on eleven postural sway measures assessed with CoP (VEL-AP, VEL-ML, VEL-RD, RANGE-AP, RANGE-ML, RANGE-RD, RMS-AP, RMS-ML, RMS-RD, EA, ApEn) separately in acquisition and retention phases.

Table 4.3. Means and Standard Deviations for the Variables in Acquisition Phase

CoP Parameters		**PQS**		**PTS**		**PSS**	
		M	*SD* (±)	*M*	*SD* (±)	*M*	*SD* (±)
Control Group	VEL-AP	10.63	1.84	19.52	7.51	23.69	5.73
	VEL-ML	7.28	1.77	18.49	5.74	24.70	6.77
	VEL-RD	14.22	2.67	29.80	10.11	37.88	9.44
	RANGE-AP	40.78	7.61	54.01	17.95	54.14	10.17
	RANGE-ML	23.01	4.19	33.51	6.78	31.73	4.94
	RANGE-RD	23.58	4.28	31.67	10.86	30.73	6.06
	RMS-AP	7.42	1.59	9.83	3.65	9.18	1.88
	RMS-ML	3.98	0.79	5.58	1.18	5.58	1.03
	RMS-RD	8.48	1.59	11.42	3.59	10.79	1.98
	EA	548.20	193.73	1043.35	525.13	971.55	325.66
	ApEn	0.06	0.02	0.09	0.02	0.12	0.03
Experimental Group	VEL-AP	12.29	2.27	20.33	6.18	24.93	4.16
	VEL-ML	9.10	2.11	16.85	3.79	23.02	4.11
	VEL-RD	16.89	3.24	29.22	7.79	37.60	5.61
	RANGE-AP	35.54	5.94	46.21	14.41	50.42	9.78
	RANGE-ML	23.08	5.95	34.16	5.84	36.41	25.76
	RANGE-RD	20.65	3.48	28.99	9.88	34.06	26.26
	RMS-AP	6.13	1.03	6.83	1.56	8.00	1.37
	RMS-ML	3.98	1.04	5.59	1.11	5.54	1.08
	RMS-RD	7.36	1.34	8.88	1.85	9.77	1.62
	EA	461.90	174.64	733.00	303.03	851.95	273.09
	ApEn	0.08	0.02	0.11	0.03	0.14	0.02

Note. PQS: quiet stance on balance pad, PTS: quiet stance on balance pad PSS: quiet stance on balance pad

The main assumptions underlying two-way mixed model ANOVA are: 1) continuous level of measurement (all CoP variables measured at continuous level); 2) random sample (the groups represent the random sample from the population); 3) independent observations (there is no dependency between the participant's scores); 4) normal distribution was checked by Kolmogorov-Smirnov D test, Shapiro-Wilk's W test, Histogram, Q-Q- plot and skewness kurtosis (most of the dependent variables are normally distributed in the population for the levels of the within-subject factor but a few of them did not normally distributed.

Table 4.4. Means and Standard Deviations for the Variables in Retention Phase

CoP Parameters		**QS**		**TS**		**SS**	
		M	*SD* (±)	*M*	*SD* (±)	*M*	*SD* (±)
Control Group	VEL-AP	6.53	1.70	16.87	7.38	18.56	5.84
	VEL-ML	4.22	1.39	13.76	3.79	19.52	4.53
	VEL-RD	8.60	2.36	24.20	8.44	29.82	7.80
	RANGE-AP	24.76	8.18	37.42	19.59	44.19	11.70
	RANGE-ML	13.74	5.77	28.25	6.33	27.76	5.66
	RANGE-RD	14.53	4.60	23.87	12.21	25.21	6.68
	RMS-AP	4.90	2.02	6.47	3.32	7.93	2.23
	RMS-ML	2.52	1.24	4.85	1.01	4.70	0.92
	RMS-RD	5.61	2.21	8.22	3.20	9.26	2.31
	EA	228.55	176.31	601.40	424.71	723.05	323.60
	ApEn	0.06	0.02	0.11	0.03	0.11	0.02
Experimental Group	VEL-AP	6.83	1.77	18.18	6.10	20.42	4.86
	VEL-ML	4.62	2.11	13.67	3.00	19.94	5.11
	VEL-RD	9.17	2.87	25.17	6.82	31.60	7.49
	RANGE-AP	26.63	10.18	35.27	11.98	43.12	7.52
	RANGE-ML	13.00	7.17	27.55	5.92	26.91	4.83
	RANGE-RD	16.00	7.29	22.22	6.10	24.94	4.98
	RMS-AP	4.87	1.63	6.35	2.68	7.57	1.27
	RMS-ML	2.25	1.21	4.74	0.94	4.70	0.85
	RMS-RD	5.44	1.92	8.10	2.48	8.95	1.44
	EA	219.50	218.94	562.55	263.22	669.55	222.65
	ApEn	0.06	0.02	0.12	0.03	0.13	0.02

Note. QS: quiet stance, TS: tandem stance, SS: single stance

Keppel & Wickens (2004) stated that F-test is very robust against the violation of normality assumption, especially with a large sample and an equal number of subjects in each group. In this study we had a large sample size and equal subjects in each group, for this reason we assume that the assumption of normality is not violated); 5) homogeneity of variance was checked by using Levene's test (variability of scores for each of the groups is similar except few of them but relying on large sample size and an equal number of subjects in each group, the assumption of homogeneity of variance did not violated.) 6) sphericity assumption was evaluated with Mauchly's test and if this assumption was violated Huynh-Feldt or Greenhouse-Geisser correction was utilized. The statistical significance level was set to $p<0.05$.

Analyses were conducted with Statistical Package for Social Sciences (SPSS, v28.0, IBM, USA).

Table 4.5. Means and Standard Deviations for the Variables in Retention Phase

CoP Parameters		PQS		PTS		PSS	
		M	*SD* (±)	*M*	*SD* (±)	*M*	*SD* (±)
Control Group	VEL-AP	10.55	2.41	20.36	7.99	24.46	6.72
	VEL-ML	7.39	1.91	19.38	5.21	25.69	7.72
	VEL-RD	14.24	3.27	31.20	9.99	39.17	11.09
	RANGE-AP	38.41	8.03	53.54	16.35	56.03	13.44
	RANGE-ML	23.49	5.96	33.75	6.89	30.95	5.57
	RANGE-RD	22.11	5.02	32.26	10.38	32.83	8.73
	RMS-AP	7.03	1.46	9.40	2.65	9.07	1.62
	RMS-ML	4.13	1.03	5.57	1.23	5.33	0.98
	RMS-RD	8.25	1.61	11.03	2.77	10.55	1.82
	EA	539.80	208.23	1007.90	465.82	919.70	315.70
	ApEn	0.06	0.02	0.10	0.02	0.13	0.03
Experimental Group	VEL-AP	10.87	2.20	20.54	7.04	24.76	6.65
	VEL-ML	7.50	2.12	18.73	5.41	24.77	7.52
	VEL-RD	14.54	3.18	30.80	9.66	38.73	10.88
	RANGE-AP	39.96	8.73	56.05	14.44	51.68	11.48
	RANGE-ML	23.37	5.76	33.08	6.12	31.92	6.19
	RANGE-RD	22.86	5.23	33.69	8.51	29.46	6.18
	RMS-AP	7.08	1.73	10.27	3.55	8.92	1.98
	RMS-ML	4.33	1.04	5.54	1.03	5.45	1.03
	RMS-RD	8.36	1.92	11.76	3.54	10.50	2.12
	EA	579.45	271.75	1081.50	512.90	934.25	365.80
	ApEn	0.06	0.02	0.09	0.02	0.13	0.02

Note. PQS: quiet stance on balance pad, PTS: quiet stance on balance pad PSS: quiet stance on balance pad.

4.2. Postural Sway Findings in Acquisition Phase

A 2 x 6 (group x postural task difficulty) mixed-model ANOVAs was run separately to test if the postural sway CoP measures (VEL-AP, VEL-ML, VEL-RD, RANGE-AP, RANGE-ML, RANGE-RD, RMS-AP, RMS-ML, RMS-RD, EA, ApEn) differed between groups (+ feedback & no feedback) within six postural task difficulties (QS, TS, SS, PQS, PTS, PSS) on acquisition. All the assumptions (normality, homogeneity of variances, & sphericity) were checked. The assumption of normality and homogeneity were accepted as normal and when the assumption sphericity was not met, appropriate corrections were applied. The interaction between concurrent visual feedback and postural task difficulty was found in CoP_{RMS-AP}. The main effect of concurrent visual feedback was found in CoP_{RMS-AP}, CoP_{RMS-RD}, CoP_{EA}, CoP_{ApEn} and the main effect of postural task difficulty was found in all CoP parameters. The findings of interaction and main effects are presented in the tables below (see Table 4.6, Table 4.7, & Table 4.8).

CoP Velocity - AP direction (CoP_{VEL-AP}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=76.32$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on CoP_{VEL-AP}, $F(3.127,118.832)=.15$, $p>.05$ and there was no main effect for groups, $F(1,38)=1.42$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{VEL-AP} values between control group ($M=15.89$, $SD=4.05$) and experimental group ($M=17.19$, $SD=2.74$). However, there was a significant main effect of PTD, $F(3.127, 118.832)=161.36$, $p<.05$, partial $\eta^2=.81$ (see figure 4.1), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{VEL-AP}. Partial η^2 indicates a large effect and that 81% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that each pair of PTD were significantly different from each other ($p<.003$) except SS ($M=21.05$, $SD=5.09$) and PTS ($M=19.93$, $SD=6.80$), $t(39)=1.27$, $p>.003$.

Table 4.6. Mixed Design ANOVA for CVF x PTD Interaction in Acquisition Phase

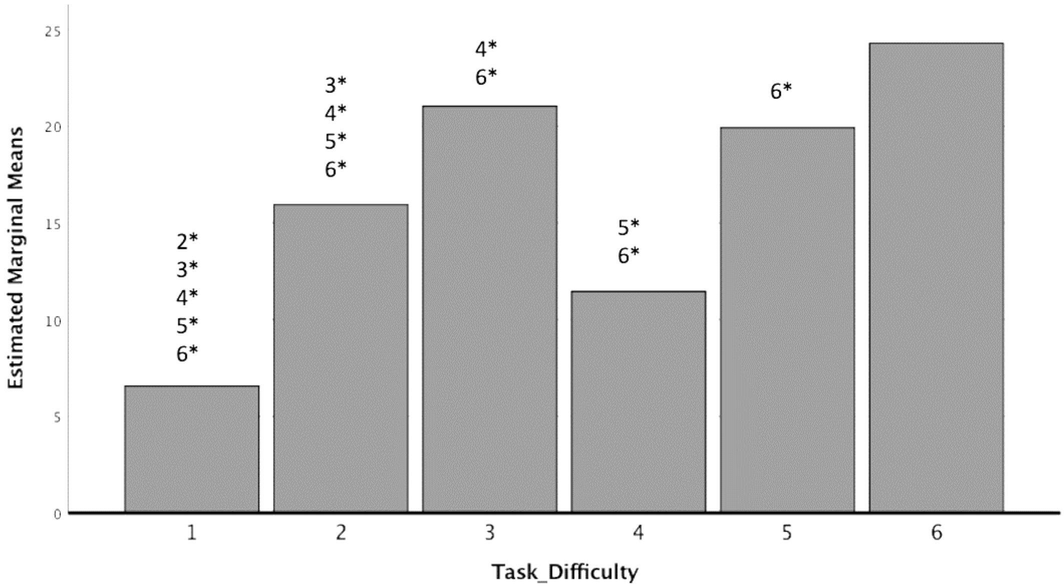
CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	7.92	3.13	2.53	.15	.937	.004
VEL-ML	86.18	2.61	32.97	2.36	.085	.058
VEL-RD	66.08	2.81	23.49	.74	.522	.019
RANGE-AP	238.73	3.17	75.36	.90	.447	.023
RANGE-ML	274.04	1.39	196.85	.87	.389	.022
RANGE-RD	283.55	1.63	173.80	.78	.438	.020
RMS-AP	*30.86*	*2.83*	*10.92*	*3.77*	*.014**	*.090*
RMS-ML	*3.91*	*4.54*	*.86*	*2.00*	*.089*	*.050*
RMS-RD	*17.41*	*2.82*	*6.18*	*2.37*	*.079*	*.059*
EA	*411014.18*	*2.53*	*162263.15*	*2.69*	*.060*	*.066*
ApEn	*.00*	*3.68*	*.00*	*.59*	*.658*	*.015*

Table 4.7. Mixed Design ANOVA for Group (CVF) Main Effect in Acquisition Phase

CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	101.41	1	101.41	1.42	.242	.036
VEL-ML	8.18	1	8.18	.164	.688	.004
VEL-RD	34.19	1	34.19	.24	.627	.006
RANGE-AP	1355.46	1	1355.46	3.72	.061	.089
RANGE-ML	7.41	1	7.41	.04	.834	.001
RANGE-RD	95.09	1	95.09	.48	.494	.012
RMS-AP	*162.48*	*1*	*162.48*	*15.50*	*<.001**	*.290*
RMS-ML	*1.23*	*1*	*1.23*	*.37*	*.548*	*.010*
RMS-RD	*125.88*	*1*	*125.88*	*9.58*	*.004**	*.201*
EA	*9730912.85*	*1*	*1402093.07*	*5.48*	*.025**	*.126*
ApEn	*.03*	*1*	*.03*	*16.70*	*<.001**	*.305*

Table 4.8. Mixed Design ANOVA for PTD Main Effect in Acquisition Phase

CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	8705.12	3.13	2783.72	161.36	<.001*	.809
VEL-ML	10646.73	2.61	4073.47	291.10	<.001*	.885
VEL-RD	23350.48	2.81	8298.37	261.84	<.001*	.873
RANGE-AP	27519.63	3.17	8687.32	103.95	<.001*	.732
RANGE-ML	12616.86	1.39	9062.75	40.08	<.001*	.513
RANGE-RD	10243.91	1.63	6279.03	28.23	<.001*	.426
RMS-AP	*667.81*	*2.83*	*236.28*	*81.61*	*<.001**	*.682*
RMS-ML	*335.18*	*4.54*	*73.87*	*170.98*	*<.001**	*.818*
RMS-RD	*904.21*	*2.82*	*321.21*	*122.99*	*<.001**	*.764*
EA	*16002094.3*	*2.53*	*6317422.57*	*104.71*	*<.001**	*.734*
ApEn	*.15*	*3.68*	*.04*	*100.46*	*<.001**	*.726*



Note. 1: QS, 2: TS, 3: SS, 4: PQS, 5: PTS, 6: PSS

Figure 4.1. Main Effect of PTD on $CoP_{VEL\text{-}AP}$ in Acquisition Phase

CoP Velocity - ML direction ($CoP_{VEL\text{-}ML}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.12$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on $CoP_{VEL\text{-}ML}$, $F(2.614, 99.320)=2.36$, $p>.05$ and there was no main effect for groups, $F(1,38)=.16$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{VEL\text{-}ML}$ values between control group (M=14.82, SD=3.42) and experimental group (M=14.45, SD=2.21). However, there was a significant main effect of PTD, $F(2.614, 99.320)=291.10$, $p<.05$, partial $\eta^2=.89$ (see figure 4.2), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{VEL\text{-}ML}$. Partial η^2 indicates a large effect and that 89% of the variance of change in CoP values was explained by the main effect of PTD. Paired samples t-test indicated that each of the fifteen pairs are significantly different from each other ($p<.003$).

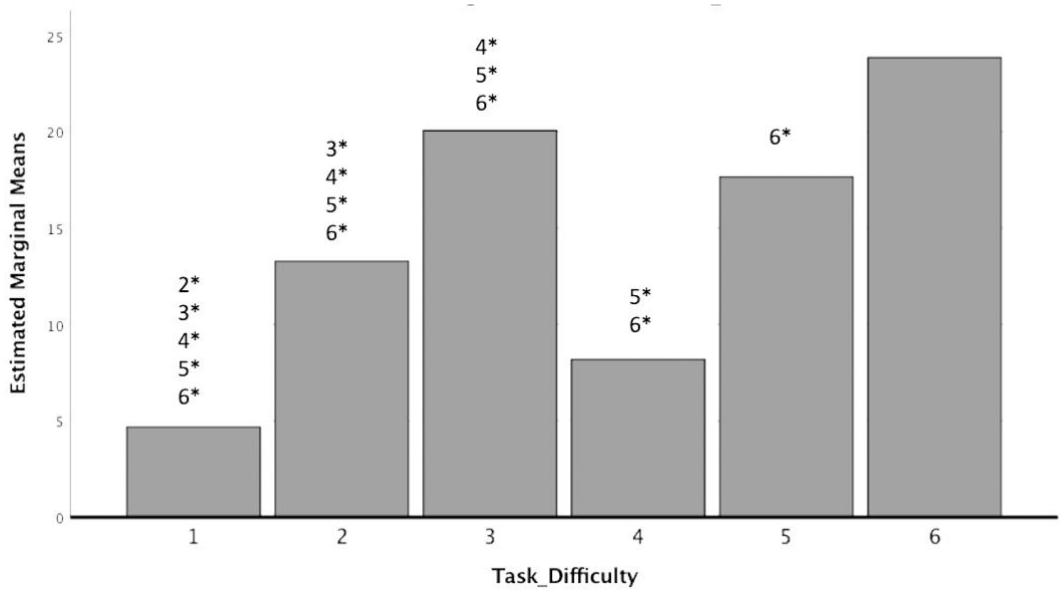


Figure 4.2. Main Effect of PTD on CoP_{VEL-ML} in Acquisition Phase

CoP Velocity - RD direction (CoP_{VEL-RD}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.13$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on CoP_{VEL-RD}, $F(2.814, 106.927)=.74$, $p>.05$ and there was no main effect for groups, $F(1,38)=.24$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{VEL-RD} values between control group (M=24.14, SD=5.78) and experimental group (M=24.89, SD=3.74). However, there was a significant main effect of PTD, $F(2.814, 106.927)=261.84$, $p<.05$, partial $\eta^2=.87$ (see figure 4.3), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{VEL-RD}. Partial η^2 indicates a large effect and that 87% of the variance of change in CoP values was explained by the main effect of PTD. The result of paired samples t-test showed that each pair of PTD were significantly different from each other ($p<.003$) except SS (M=32.26, SD=6.64) and PTS (M=29.51, SD=8.91), $t(39)=2.42$, $p>.003$.

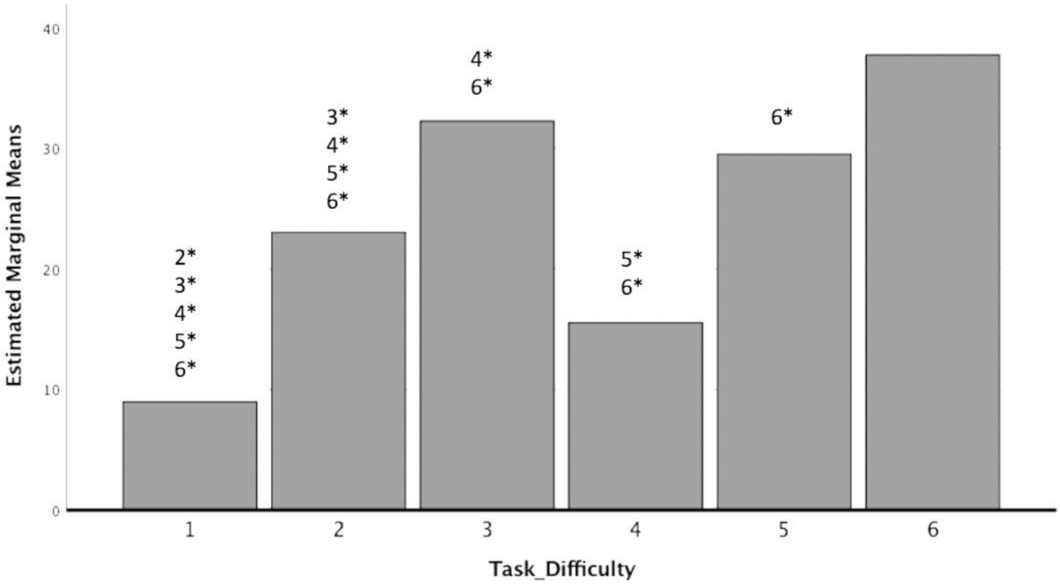


Figure 4.3. Main Effect of PTD on CoP_{VEL-RD} in Acquisition Phase

CoP Range – AP direction ($CoP_{RANGE-AP}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.29$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on $CoP_{RANGE-AP}$, $F(3.168, 120.376)=.90$, $p>.05$ and there was no main effect for groups, $F(1,38)=3.72$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{RANGE-AP}$ values between control group (M=41.38, SD=8.60) and experimental group (M=36.62, SD=6.90). However, there was a significant main effect of PTD, $F(3.168, 120.376)=103.95$, $p<.05$, partial η^2=.73 (see figure 4.4), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoPVEL-AP. Partial η^2 indicates a large effect and that 73% of the variance of change in CoP values was explained by the main effect of PTD. The result of paired samples t-test showed that the difference between SS (M=41.82, SD=8.75) and PQS (M=38.16, SD=7.24) $t(39)=2.90$, $p>.003$ and the difference between PTS (M=50.11, SD=16.55) and PSS (M=52.28, SD=10.03) $t(39)=-1.22$, $p>.003$ was not statistically significant but other than these, other thirteen pairs of PTD are significantly different from each other.

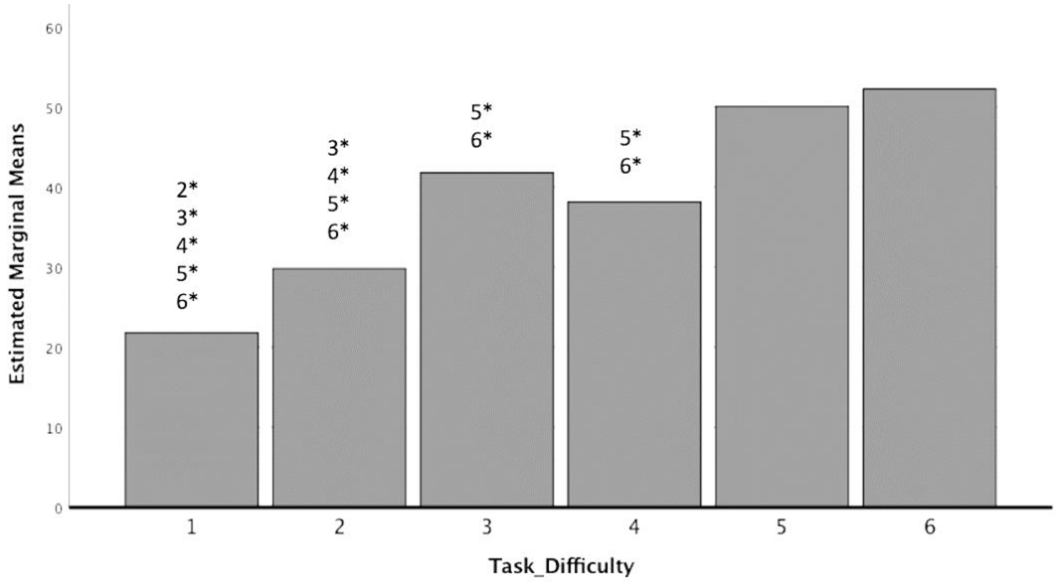


Figure 4.4. Main Effect of PTD on $CoP_{RANGE\text{-}AP}$ in Acquisition Phase

CoP Range – ML direction ($CoP_{RANGE\text{-}ML}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.00$, $p<.05$, it was corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on $CoP_{RANGE\text{-}ML}$, $F(1.392, 52.902)=.87$, $p>.05$ and there was no main effect for groups, $F(1,38)=0.4$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoPRANGE-ML values between control group (M=26.55, SD=4.20) and experimental group (M=26.91, SD=6.16). However, there was a significant main effect of PTD, $F(1.392, 52.902)=40.08$, $p<.05$, partial $\eta^2=.51$ (see figure 4.5), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{RANGE\text{-}ML}$ Partial η^2 indicates a large effect and that 51% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that the difference between eleven pairs were statistically significant $p<.003$. However, the difference between TS (M =29.00 , SD =6.06) and SS (M=27.56, SD=3.84) $t(39)=2.01$ p>.003, the difference between TS (M=29.00, SD=6.06) and PSS (M=34.07, SD=18.46) $t(39)=-1.89$, $p>.003$, the difference between SS (M=27.56, *SD*=3.84) and PSS (*M*=34.07, *SD*=18.46) *t*(39)=-2.26, *p*>.003, the difference between PTS (*M*=33.83, *SD*=6.26) and PSS (*M*=34.07, *SD*=18.46) *t*(39)=-0.83, *p*>.003 was not statistically significant.

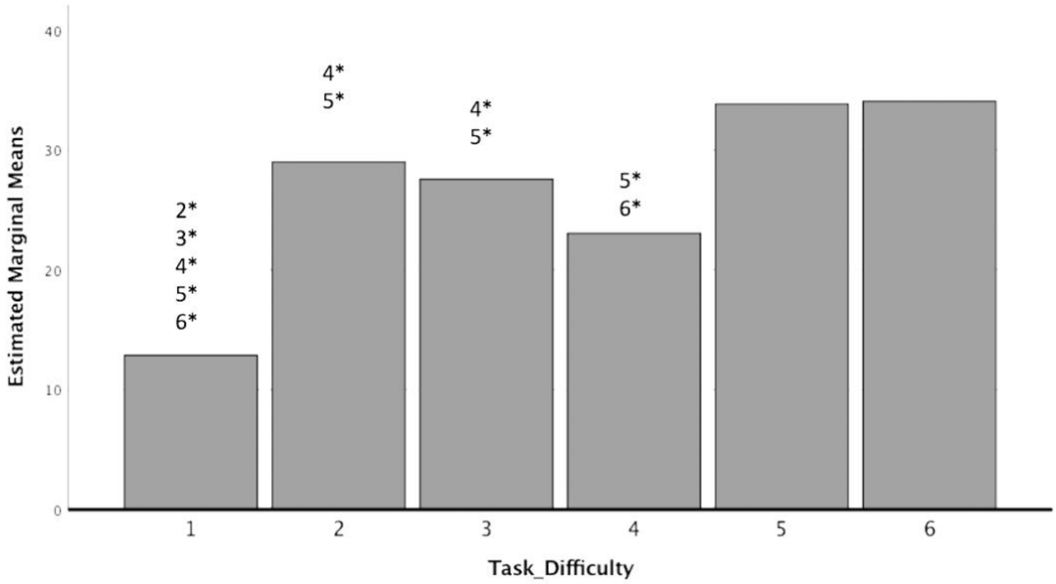


Figure 4.5. Main Effect of PTD on $CoP_{RANGE\text{-}ML}$ in Acquisition Phase

CoP Range – RD direction ($CoP_{RANGE\text{-}RD}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.00$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on $CoP_{RANGE\text{-}RD}$, $F(1.631, 61.995)=.78$, $p>.05$ and there was no main effect for groups, $F(1,38)=.48$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{RANGE\text{-}RD}$ values between control group (*M*=24.28, *SD*=5.03) and experimental group (*M*=23.03, *SD*=6.41). However, there was a significant main effect of PTD, $F(1.631, 61.995)=28.23$, $p<.05$, partial $\eta^2=.43$ (see figure 4.6), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{RANGE\text{-}RD}$ Partial η^2 indicates a large effect and that 43% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that the difference between twelve pairs were statistically significant

p<.003. However, the difference between SS (M=24.42, SD=5.54) and PQS (M=22.11, SD=4.13), t(39)=2.78, p>.003, the difference between SS (M=24.42, SD=5.54) and PSS (M=32.40, SD=18.89) t(39)=-2.60, p>.003, the difference between PTS (M=30.33, SD=10.34) and PSS (M=32.40, SD=18.89), t(39)=-.70, p>.003 was not statistically significant.

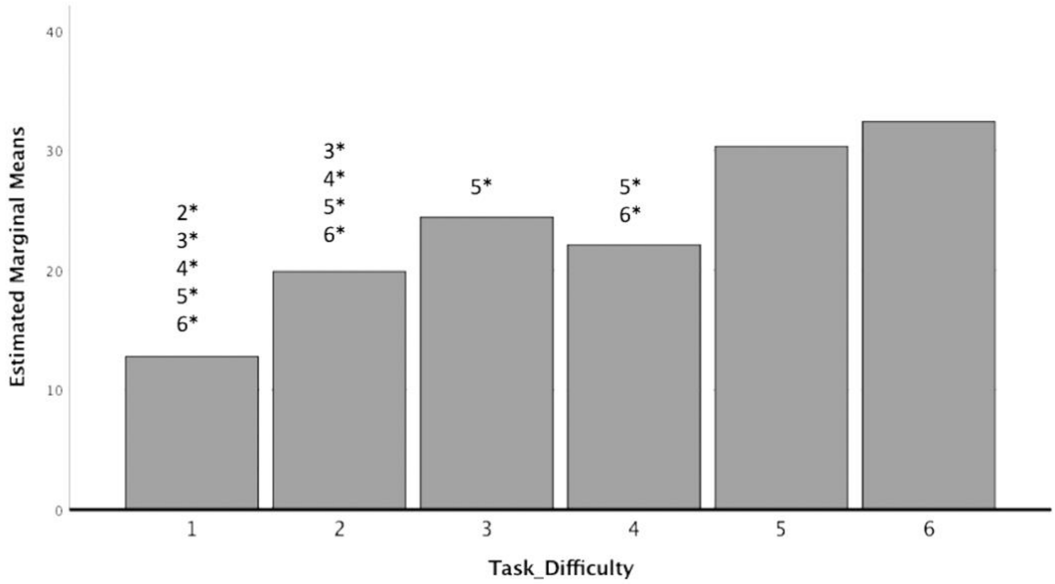


Figure 4.6. Main Effect of PTD on $CoP_{RANGE-RD}$ in Acquisition Phase

CoP Variability - AP direction (CoP_{RMS-AP}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)$=.23, p<.05, it is corrected by the Greenhouse-Geisser estimation. The result of the analysis showed that there was a statistically significant interaction between group and postural task difficulty on $Co_{PRMS-AP}$, F(2.826, 107.400)=3.77, p<.05, partial η^2=.09 (see figure 4.7). It means that the CoP_{RMS-AP} values significantly vary between control group and concurrent visual feedback group within six different postural control tasks. The result of independent t-tests showed that there was a significant difference between groups on QS, t(38)=2.17, p=.04; TS, t(38)=4.20, p<.001; SS, t(38)=3.05, p=.00; PQS, t(38)=3.04, p=.00; PTS, t(38)=3.38, p=.00; PSS, t(38)=2.28, p=.03. The result of paired samples t-tests demonstrated that there was no significant difference between control group scores variability on TS (M=6.04, SD=1.99) and PQS (M=7.42, SD=1.59), SS (M=7.87, SD=1.76) and PQS, SS and PTS (M=9.83, SD=3.65), PQS and PTS, PTS and PSS (M=46.79, SD=13.86) (p>.003). In addition, there were no significant difference between experimental group scores variability on QS (M=3.58, SD=1.03) and TS (M=3.91, SD=1.08), SS (M=6.44, SD=1.16) and PQS (M=6.13, SD=1.03), SS and PTS (M=6.83, SD=1.56), PQS and PTS (p>.003).

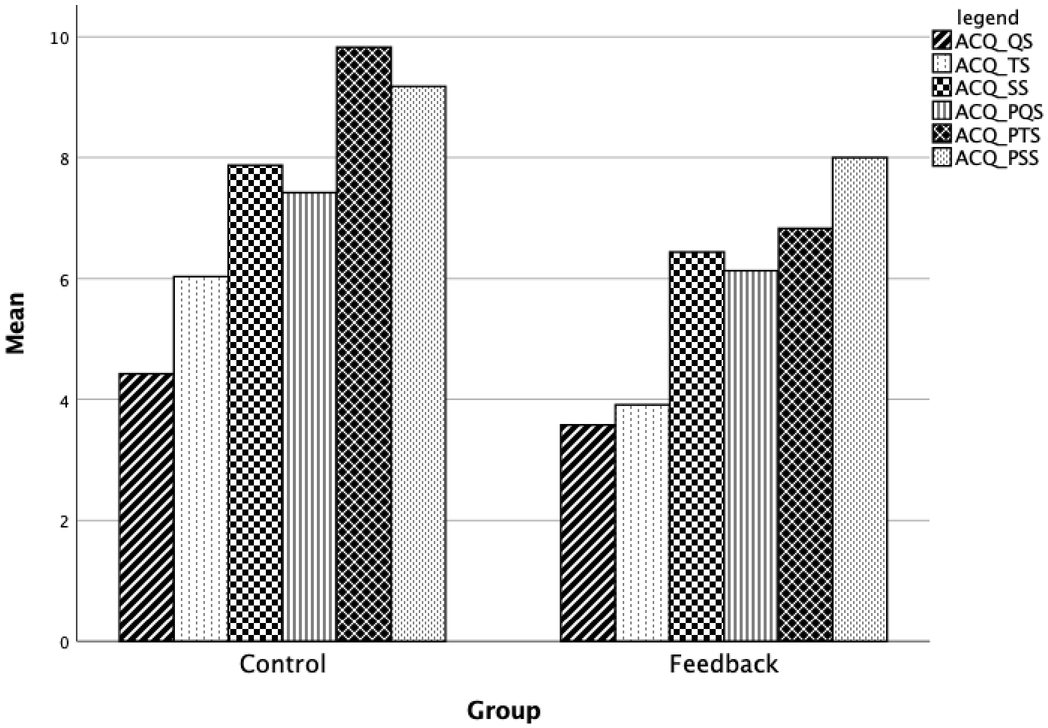


Figure 4.7. Group x PTD on CoP_{RMS-AP} in Acquisition Phase

CoP Variability - ML direction (CoP_{RMS-ML}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.51$, $p<.05$, it is corrected by the Huynh-Feldt estimation. There was no statistically significant interaction between group and postural task difficulty on CoP_{RMS-ML}, $F(4.538, 172.429)=2.00$, $p>.05$ and there was no main effect for groups, $F(1,38)=.37$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{RMS-ML} values between control group (M=4.56, SD=.73) and experimental group (M=4.42, SD=.76). However, there was a significant main effect of PTD, $F(4.538, 172.429)=170.98$, $p<.05$, partial

η^2=.82 (see figure 4.8), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{RMS\text{-}ML}$ Partial η^2 indicates large effect and that 82% of the variance of change in CoP values was explained by the main effect of PTD. The result of paired samples t-test showed that the difference between thirteen pairs were statistically significant, but the difference between a pair of TS (*M*=4.90, *SD*=.97) and SS (*M*=4.77, *SD*=.77), *t*(39)=1.23, *p*>.003 and a pair of PTS (*M*=5.59, *SD*=1.13) and PSS (*M*=5.56, *SD*=1.04) *t*(39)=.17, *p*>.003 was not statistically significant.

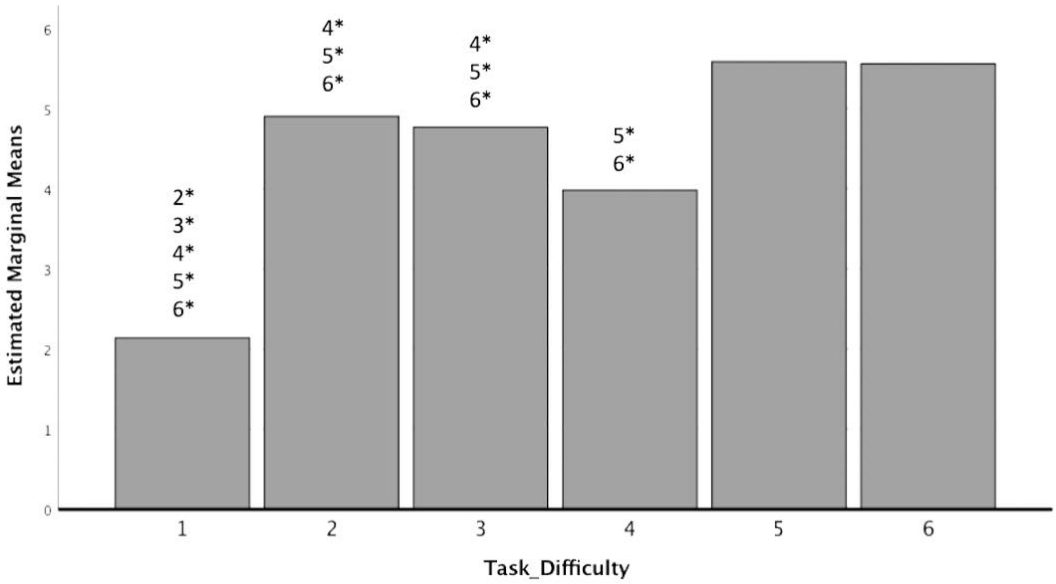


Figure 4.8. Main Effect of PTD on $CoP_{RMS\text{-}ML}$ in Acquisition Phase

CoP Variability -RD direction (CoPRMS-RD): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)$=.24, *p*<.05, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on $CoP_{RMS\text{-}RD}$, *F*(2.815, 106.972)=2.38, *p*>.05 but there was a main effect for groups, *F*(1,38)=9.58, *p*<.05, partial η^2=.20 suggesting that ignoring the postural task difficulty, there was a statistically significant difference on $CoP_{RMS\text{-}RD}$ values between control group (*M*=8.84, *SD*=1.68) and experimental group (*M*=7.39, *SD*=1.24) and partial η^2 indicates a large effect and that 20% of the variance of change in values can be explained by the main effect of groups. In addition, there was a significant main effect of PTD, *F*(2.815, 106.972)=122.99, *p*<.05, partial η^2=.76 (see figure 4.9), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{RMS-RD} Partial η^2 indicates a large effect and that 76% of the variance of change in CoP values was explained by the main effect of PTD. The result of paired samples t-test showed that the difference between fourteen pair was statistically significant *p*<.003, however, the difference between PTS (*M*=10.15, *SD*=3.10) and PSS (*M*=10.28, *SD*=1.86), *t*(39) .38, *p*>.003. was not statistically significant.

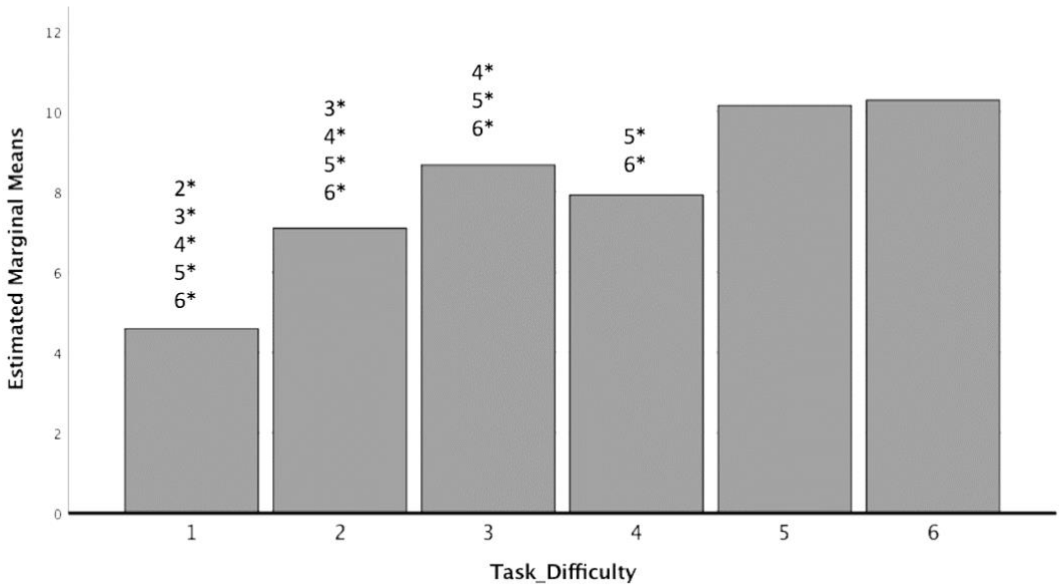


Figure 4.9. Main Effect of PTD on CoP_{RMS-RD} in Acquisition Phase

CoP Ellipse Area (CoP_{EA}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)$=.15, *p*<.05, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on CoP_{EA}, *F*(2.533, 96.254)=2.69, *p*>.05 but there was a main effect for groups, *F*(1,38)=5.48, *p*<.05, partial η^2=.13 suggesting that ignoring the postural task difficulty, there was a statistically significant difference on CoP_{EA} values between control group (*M*=672.31, *SD*=237.25) and experimental group (*M*=519.44, *SD*=170.51) and partial η^2 indicates a medium effect and that 13% of the variance of change in values can be explained by the main effect of groups. In addition, there was a significant main effect of PTD, $F(2.533, 96.254)=104.71$, $p<.05$, partial $\eta^2=.73$ (see figure 4.10), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{EA} Partial η^2 indicates a large effect and 73% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that the difference between thirteen pairs was statistically significant $p<.003$. Nevertheless, the difference between TS (*M*=467.40, *SD*=243.73) and PQS (*M*=505.05, *SD*=187.22), $t(39)=-1.28$, $p>.003$ and the difference between PTS (*M*=888.18, *SD*=451.42) and PSS (*M*=911.75, *SD*=302.77) $t(39)=-.50$, $p>.003$ was not statistically significant.

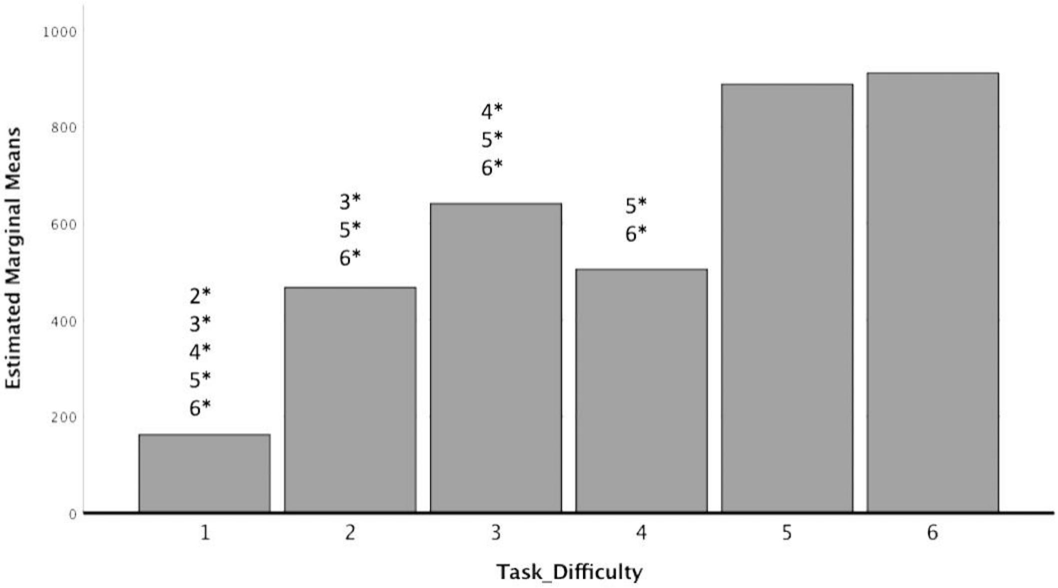


Figure 4.10. Main Effect of PTD on CoP_{EA} in Acquisition Phase

CoP Approximate Entropy (CoP_{ApEn}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.39$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. There was no statistically significant interaction between group and postural task difficulty on CoP_{ApEn}, $F(3.677, 139.728)=.59$, $p>.05$ (see figure 4.11) but there was a main effect for groups, $F(1,38)=16.70$, $p<.05$, partial $\eta^2=.31$

suggesting that ignoring the postural task difficulty, there was a statistically significant difference on CoP_{ApEn} values between control group (*M*=.09, *SD*=.02) and experimental group (*M*=.12, *SD*=.02) and partial η^2 indicates a large effect and that 31% of the variance of change in values can be explained by the main effect of groups. Likewise, there was a significant main effect of PTD, *F*(3.677, 139.728)=100.46, $p<.05$, partial η^2=.73, suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{ApEn} Partial η^2 indicates a large effect and that 73% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that the difference between twelve pairs was statistically significant $p<.003$. However, the difference between QS (*M*=.07, *SD*=.03) and PQS (*M*=.07, *SD*=.02), *t* (39)=.08, $p>.003$, the difference between TS (*M*=.12, *SD*=.03) and PSS (*M*=.13, *SD*=.03), *t* (39)=-2.77, $p>.003$, the difference between SS (*M*=.13, *SD*=.03) and PSS (*M*=.13, *SD*=.03), *t* (39)=1.23, $p>.003$ was not statistically significant.

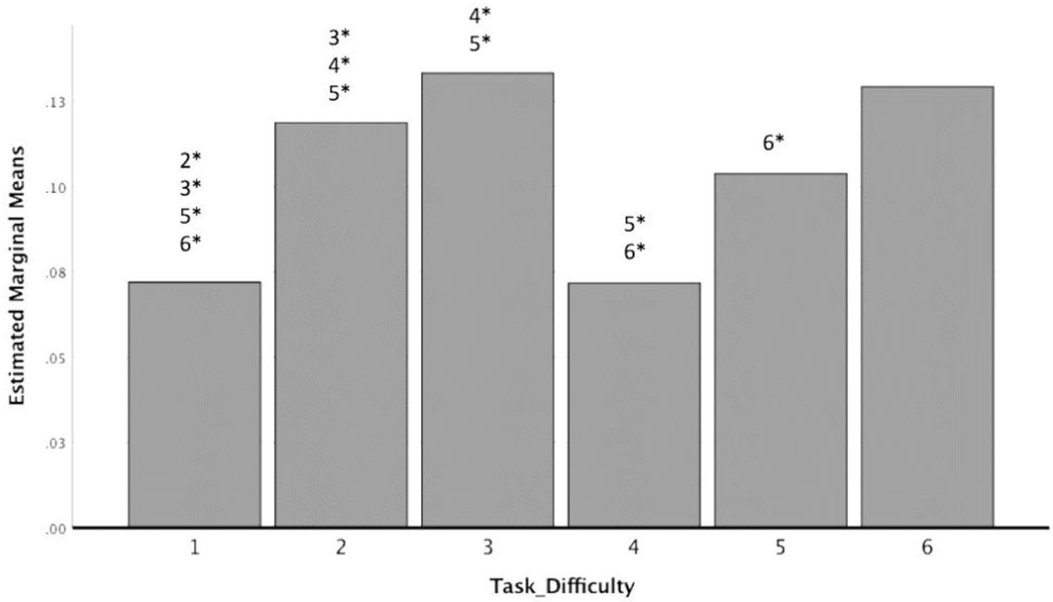


Figure 4.11. Main Effect of PTD on CoP_{ApEn} in Acquisition Phase

4.3. Postural Sway Findings in Retention Phase

A 2 x 6 (group x postural task difficulty) mixed-model ANOVAs was run separately to test if the postural sway CoP measures (VEL-AP, VEL-ML, VEL-RD, RANGE-AP, RANGE-ML, RANGE-RD, RMS-AP, RMS-ML, RMS-RD, EA, ApEn) differed between groups (+ feedback & no feedback) within six postural task difficulties (QS, TS, SS, PQS, PTS, PSS) in acquisition phase. All the assumptions (normality, homogeneity of variances, & sphericity) were checked. The assumption of normality and homogeneity were accepted as normal and when the assumption sphericity was not met, appropriate corrections were applied. The results showed that there was neither significant interaction between concurrent visual feedback and postural task difficulty nor the main effect of groups in all CoP parameters of postural sway. On the contrary, the main effect of postural task difficulty was found in all CoP parameters. The findings of interaction and main effects are presented tables below (see Table 4.9, Table 4.10, Table 4.11).

Table 4.9. Mixed Design ANOVA for CVF x PTD Interaction in Retention Phase

CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	24.44	2.72	8.98	.34	.776	.009
VEL-ML	15.47	2.18	7.09	.28	.777	.007
VEL-RD	35.92	2.41	14.91	.27	.800	.007
RANGE-AP	364.41	3.25	112.18	.97	.412	.025
RANGE-ML	24.24	3.20	7.58	.30	.838	.008
RANGE-RD	184.46	3.41	54.12	1.25	.296	.032
RMS-AP	*9.15*	*3.36*	*2.72*	*.64*	*.611*	*.016*
RMS-ML	*1.40*	*2.87*	*.49*	*.65*	*.576*	*.017*
RMS-RD	*6.85*	*3.44*	*2.00*	*.53*	*.686*	*.014*
EA	*115381.00*	*2.69*	*42978.80*	*.49*	*.667*	*.013*
ApEn	*.00*	*3.45*	*.00*	*1.13*	*.341*	*.029*

Table 4.10. Mixed Design ANOVA for Group (CVF) Main Effect in Retention Phase

CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	30.46	1	30.46	.27	.606	.007
VEL-ML	.905	1	.905	.01	.912	.000
VEL-RD	12.97	1	12.97	.06	.810	.002
RANGE-AP	4.49	1	4.49	.01	.928	.000
RANGE-ML	7.36	1	7.36	.05	.819	.001
RANGE-RD	4.45	1	4.45	.02	.879	.001
RMS-AP	*.13*	*1*	*.13*	*.01*	*.931*	*.000*
RMS-ML	*.01*	*1*	*.01*	*.00*	*.961*	*.000*
RMS-RD	*.06*	*1*	*.06*	*.00*	*.957*	*.000*
EA	*1161.60*	*1*	*1161.60*	*.00*	*.958*	*.000*
ApEn	*.00*	*1*	*.00*	*.60*	*.442*	*.016*

Table 4.11. Mixed Design ANOVA for PTD Main Effect in Retention Phase

CoP Parameters	*SS*	*df*	*MS*	*F*	*P*	η^2
VEL-AP	8849.22	2.72	3250.72	123.57	<.001*	.765
VEL-ML	12565.65	2.18	5762.09	225.19	<.001*	.856
VEL-RD	25407.57	2.41	10544.32	194.07	<.001*	.836
RANGE-AP	24495.47	3.25	7540.68	65.45	<.001*	.633
RANGE-ML	10237.79	3.20	3202.58	126.54	<.001*	.769
RANGE-RD	8253.74	3.41	2421.55	55.74	<.001*	.595
RMS-AP	*640.30*	*3.36*	*190.60*	*44.42*	*<.001**	*.539*
RMS-ML	*263.53*	*2.87*	*91.87*	*123.06*	*<.001**	*.764*
RMS-RD	*847.86*	*3.44*	*246.84*	*65.65*	*<.001**	*.633*
EA	*17036873.8*	*2.69*	*6346143.26*	*72.77*	*<.001**	*.657*
ApEn	*.19*	*3.45*	*.05*	*115.14*	*<.001**	*.752*

CoP Velocity - AP direction (CoP_{VEL-AP}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.07$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The result of analysis depicted that there were neither significant interaction between group and postural task difficulty on CoP_{VEL-AP}, $F(2.722, 103.445)=.34$, $p>.05$ nor main effect for groups, $F(1,38)=.27$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{VEL-AP} values between control group (M=16.22, SD=4.74) and experimental group (M=16.93, SD=3.89). However, there was a significant main effect of PTD, $F(2.722, 103.445)=123.57$, $p<.05$, partial η^2=.77 (see figure 4.12), suggesting that ignoring the effect of group, there was a statistically significant difference between

PTDs on CoP_{VEL-AP}. Partial η^2 indicates a large effect and that 77% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that each pair of PTD were significantly different from each other (p<.003) except SS (M=19.49, SD=5.39) and PTS (M=20.45, SD=7.43) t(39)=-1.27, p>.003.

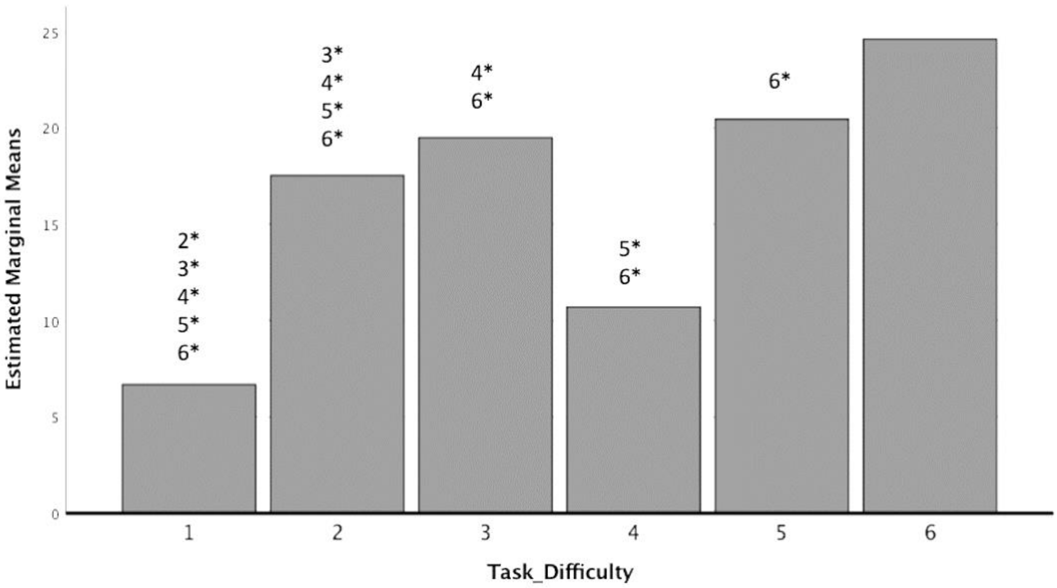


Figure 4.12. Main Effect of PTD on CoP_{VEL-AP} in Retention Phase

CoP Velocity - ML direction (CoP_{VEL-ML}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.02$, p<.05, it is corrected by the Greenhouse-Geisser estimation. The result of analysis depicted that there were neither significant interaction between group and postural task difficulty on CoP_{VEL-ML}, F(2.181, 82.868)=.28, p>.05 nor main effect for groups, F(1,38)=.01, p>.05, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{VEL-ML} values between control group (M=14.99, SD=3.57) and experimental group (M=14.87, SD=3.39). However, there was a significant main effect of PTD, F(2.181, 82.868)=225.19, p<.05, partial η^2=.86 (see figure 4.13), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{VEL-ML}. Partial η^2 indicates a large effect and that 86% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that each pair of PTD were significantly different from each other ($p<.003$) except SS (M=19.73, SD=4.77) and PTS (M=19.05, SD=5.25) $t(39)=-1.05$, $p>.003$.

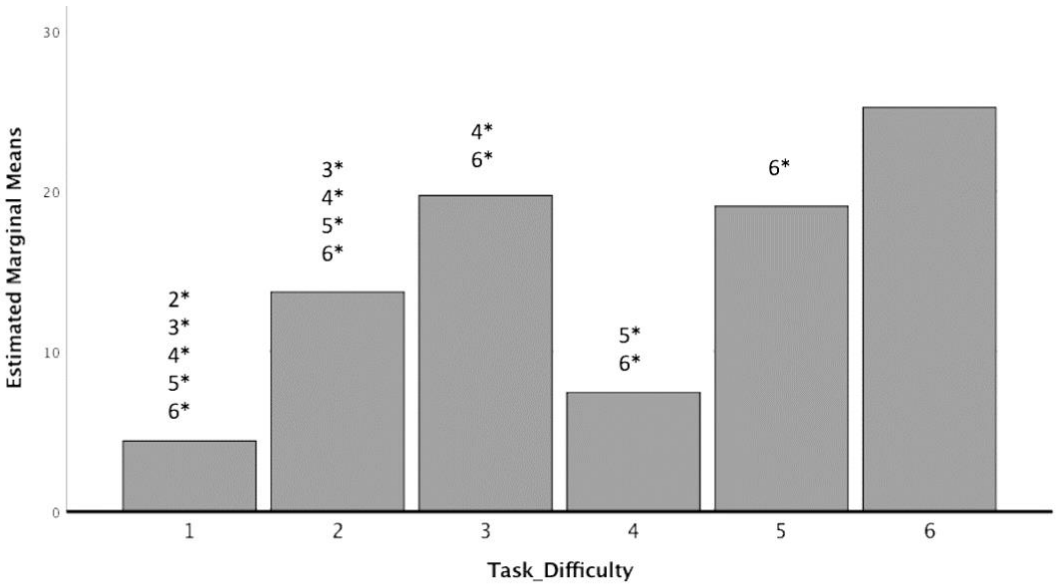


Figure 4.13. Main Effect of PTD on $CoP_{VEL\text{-}ML}$ in Retention Phase

CoP Velocity - RD direction ($CoP_{VEL\text{-}RD}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.05$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on $CoP_{VEL\text{-}RD}$, $F(2.410, 91.565)=.27$, $p>.05$ nor main effect for groups, $F(1,38)=.06$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{VEL\text{-}RD}$ values between control group (M=24.54, SD=6.46) and experimental group (M=25.00, SD=5.65). However, there was a significant main effect of PTD, $F(2.410, 91.565)=194.07$, $p<.05$, partial $\eta^2=.84$ (see figure 4.14), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{VEL\text{-}RD}$. Partial η^2 indicates a large effect and that 84% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that each pair of PTD were significantly different from each other ($p<.003$) except SS (M=30.71, SD=7.60) and PTS (M=31.00, SD=9.70) $t(39)=-0.29$, $p>.003$.

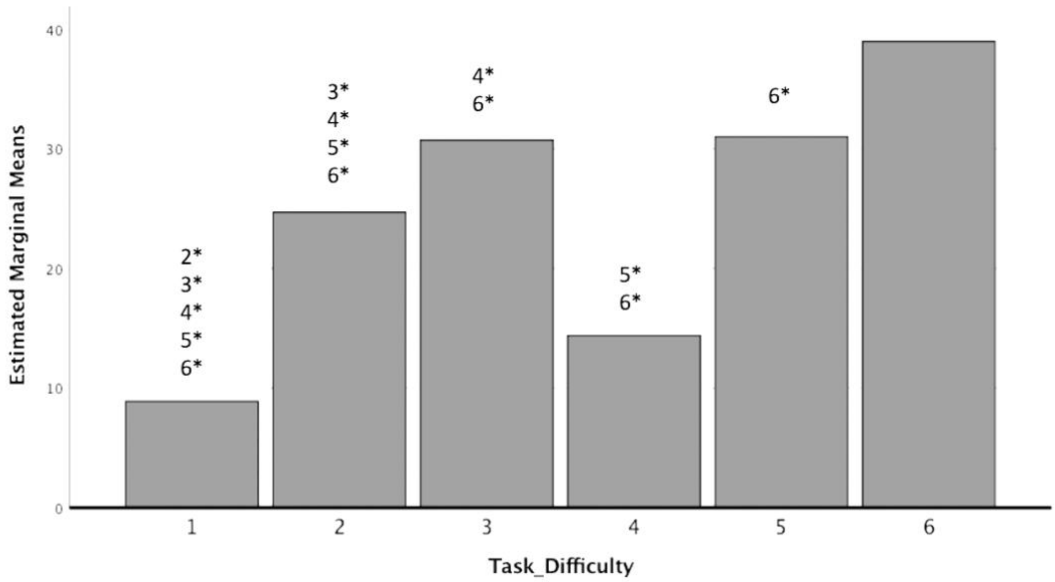


Figure 4.14. Main Effect of PTD on $CoP_{VEL\text{-}RD}$ in Retention Phase

CoP Range – AP direction ($CoP_{RANGE\text{-}AP}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.23$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on $CoP_{RANGE\text{-}AP}$, $F(3.248, 123.441)=.97$, $p>.05$ nor main effect for groups, $F(1,38)=.01$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{RANGE\text{-}AP}$ values between control group (M=42.39, SD=10.68) and experimental group (M=42.12, SD=8.04). However, there was a significant main effect of PTD, $F(3.248, 123.441)=65.45$, $p<.05$, partial $\eta^2=.63$ (see figure 4.15), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoPRANGE-AP. Partial η^2 indicates a large effect and that 63% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that twelve pairs of the PTD were significantly different from each other ($p<.003$). On the other hand, the difference between TS ($M=36.35$, $SD=16.06$) and PQS ($M=39.18$, $SD=8.31$), $t(39)=-1.26$, $p>.003$, the difference between SS ($M=43.65$, $SD=9.72$) and PQS ($M=39.18$, $SD=8.31$), $t(39)=3.06$, $p>.003$, the difference between PTS ($M=54.79$, $SD=15.28$) and PSS ($M=53.85$, $SD=12.54$), $t(39)=.54$, $p>.003$ were not statistically significant.

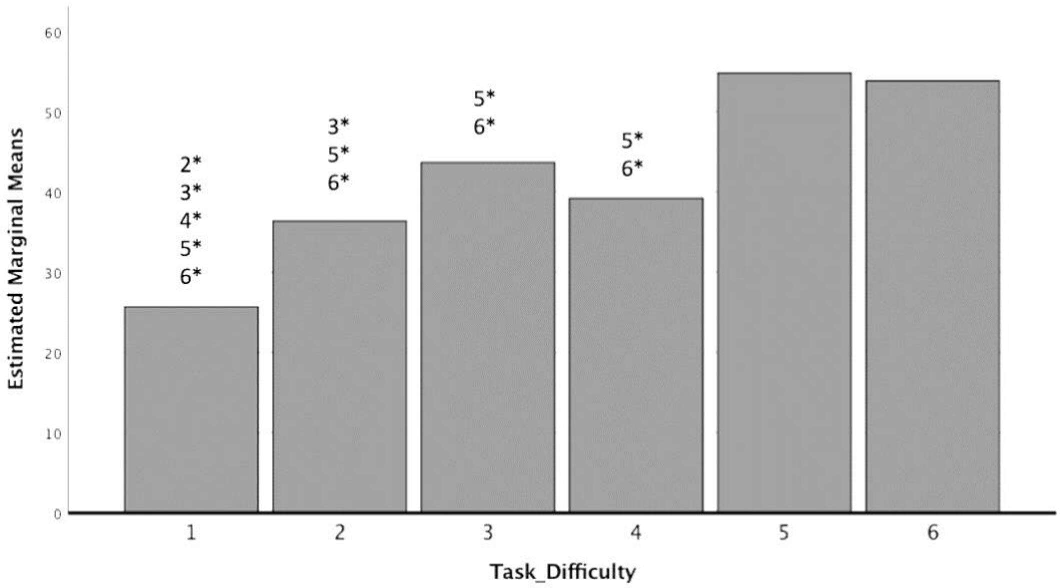


Figure 4.15. Main Effect of PTD on $CoP_{RANGE-AP}$ in Retention Phase

CoP Range – ML direction ($CoP_{RANGE-ML}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.33$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on $CoP_{RANGE-ML}$, $F(3.197, 121.476)=.30$, $p>.05$ nor main effect for groups, $F(1,38)=.05$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{RANGE-ML}$ values between control group ($M=26.32$, $SD=5.02$) and experimental group ($M=25.97$, $SD=4.57$). However, there was a significant main effect of PTD, $F(3.197, 121.476)=126.54$, $p<.05$, partial $\eta^2=.77$ (see figure 4.16), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{RANGE-ML}$. Partial η^2 indicates a large effect and that 77% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that thirteen pairs of the PTD were significantly different from each other (p<.003). On the other hand, the difference between TS (M=27.90, SD=6.06) and SS (M=27.34, SD=5.21), $t(39)$=.83, p>.003, the difference between PTS (M=33.42, SD=6.44) and PSS (M=31.43, SD=5.83), $t(39)$=2.25, p>.003, were not statistically significant.

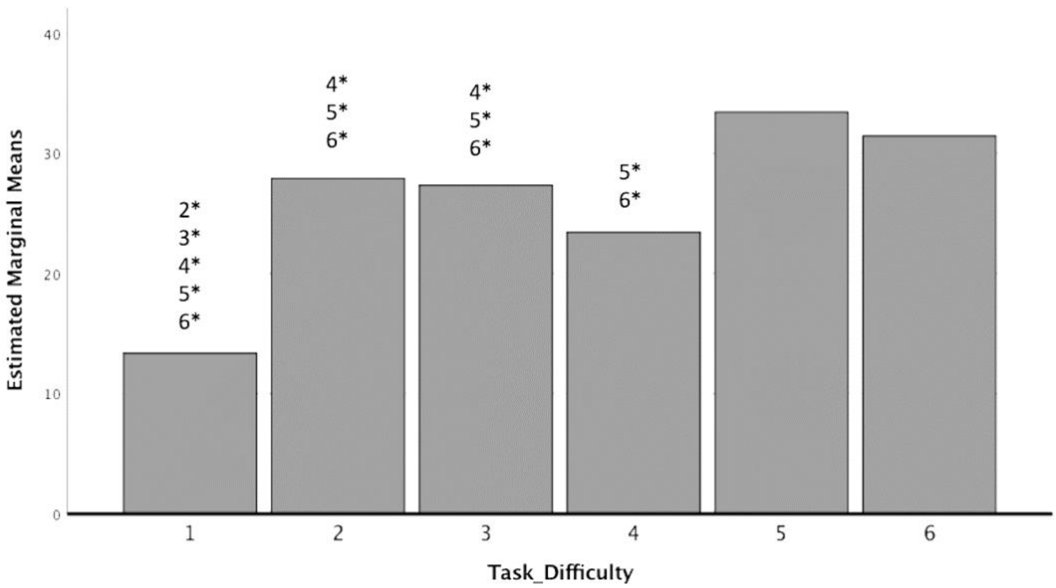


Figure 4.16. Main Effect of PTD on $CoP_{RANGE-ML}$ in Retention Phase

CoP Range – RD direction ($CoP_{RANGE-RD}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)$=.30, p<.05, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on $CoP_{RANGE-RD}$, F(3.408, 129.521)=.1.25, p>.05 nor main effect for groups, F(1,38)=.02, p>.05, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on $CoP_{RANGE-RD}$ values between control group (M=25.13, SD=6.46) and experimental group (M=24.86, SD=4.66). However, there was a significant main effect of PTD, F(3.408, 129.521)=55.74, $p<.05$, partial η^2=.60 (see figure 4.17), suggesting that ignoring the effect of group, there was a statistically significant difference between

PTDs on $CoP_{RANGE-RD}$. Partial η^2 indicates a large effect and that 60% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that eleven pairs of the PTD were significantly different from each other (p<.003). However, the difference between TS (M=23.04, SD=9.56) and SS (M=25.07, SD=5.82), t(39)=-1.97, p>.003, the difference between TS (M=23.04, SD=9.56) and PQS (M=22.49, SD=5.07), t(39)=.43, p >.003, the difference between SS (M=25.07, SD=5.82) and PQS (M=22.49, SD=5.07), t(39)=2.82, p>.003, the difference between PTS (M=32.98, SD=9.39) and PSS (M=31.15, SD=7.66), t(39)=1.48, p>.003, were not statistically significant.

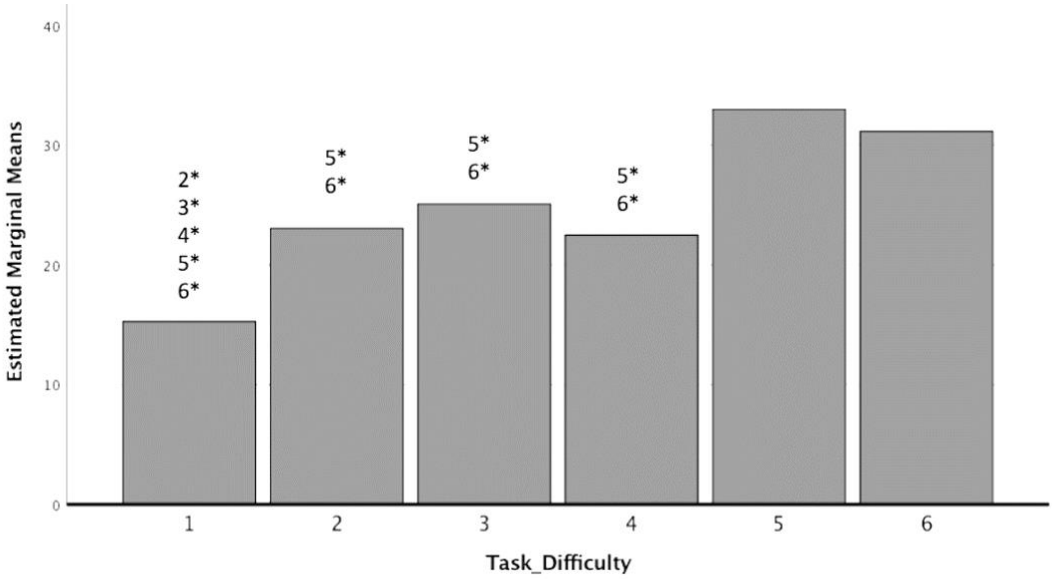


Figure 4.17. Main Effect of PTD on $CoP_{RANGE-RD}$ in Retention Phase

CoP Variability - AP direction (CoP_{RMS-AP}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)$=.22, p<.05, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on CoP_{RMS-AP}, F(3.359, 127.657)=.64, p>.05 nor main effect for groups, F(1,38)=.01, p>.05, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{RMS-AP} values between control group (M=7.47, SD=1.75) and experimental group (M=7.51, SD=1.61). However, there was a significant main effect of PTD, $F(3.359, 127.657)=44.42$, $p<.05$, partial $\eta^2=.54$ (see figure 4.18), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on $CoP_{RMS\text{-}AP}$. Partial η^2 indicates a large effect and that 54% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that twelve pairs of the PTD were significantly different from each other ($p<.003$). However, the difference between TS (M=6.41, SD=2.98) and PQS (M=7.06, SD=1.58), $t(39)=-1.53$, $p>.003$, the difference between SS (M=7.75, SD=1.80) and PQS (M=7.06, SD=1.58), $t(39)=2.43$, $p>.003$, the difference between PTS (M=9.84, SD=3.13) and PSS (M=9.00, SD=1.78), $t(39)=2.08$, $p>.003$, were not statistically significant.

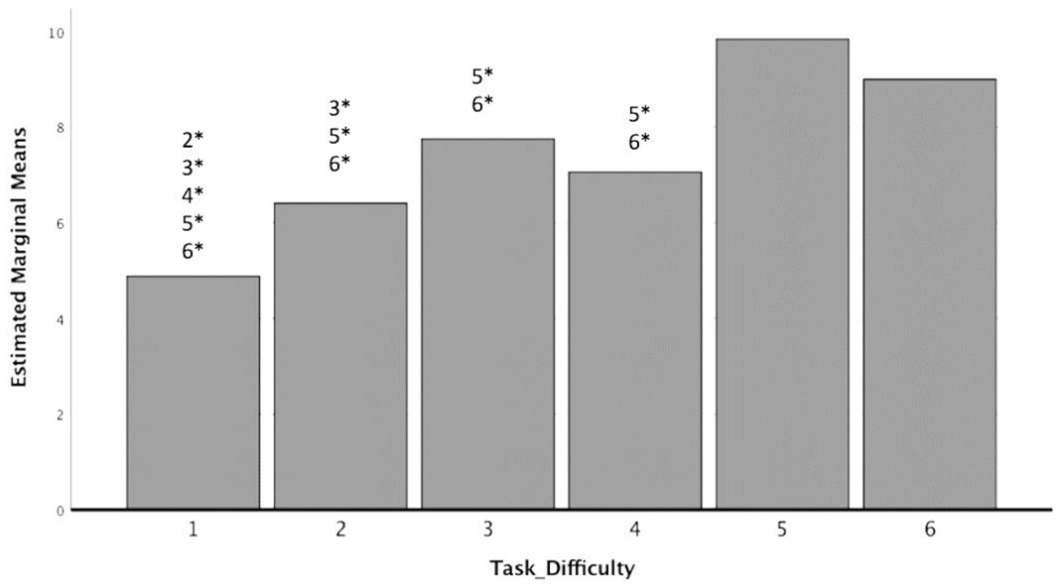


Figure 4.18. Main Effect of PTD on $CoP_{RMS\text{-}AP}$ in Retention Phase

CoP Variability - ML direction ($CoP_{RMS\text{-}ML}$): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.16$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on $CoP_{RMS\text{-}ML}$, $F(2.869, 109.009)=.65$, $p>.05$ nor main effect for groups, $F(1,38)=.00$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{RMS-ML} values between control group (*M*=4.51, *SD*=.94) and experimental group (*M*=4.50, *SD*=.78). However, there was a significant main effect of PTD, $F(2.869, 109.009)=123.06$, $p<.05$, partial $\eta^2=.76$ (see figure 4.19), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{RMS-ML}. Partial η^2 indicates a large effect and that 76% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that twelve pairs of the PTD were significantly different from each other ($p<.003$). However, the difference between TS (*M*=4.79, *SD*=.96) and SS (*M*=4.69, *SD*=.88), $t(39)=1.06$, $p>.003$, the difference between SS (*M*=4.69, *SD*=.88), and PQS (*M*=4.23, *SD*=1.03), $t(39)=3.06$, $p>.003$, the difference between PTS (*M*=5.56, *SD*=1.12) and PSS (*M*=5.39, *SD*=1.00), $t(39)=1.48$, $p>.003$, were not statistically significant.

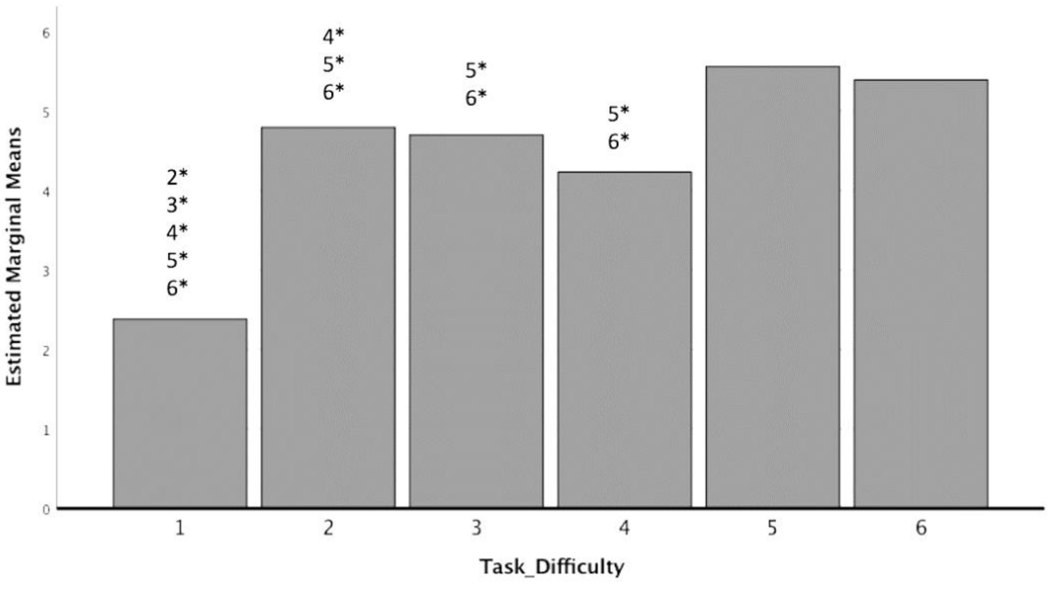


Figure 4.19. Main Effect of PTD on CoP_{RMS-ML} in Retention Phase

CoP Variability -RD direction (CoP_{RMS-RD}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.22$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on CoP_{RMS-RD}, $F(3.435, 130.527)=.53$, $p>.05$ nor main effect for groups, $F(1,38)=.00$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{RMS-RD} values between control group (M=8.82, SD=1.95) and experimental group (M=8.85, SD=1.73). However, there was a significant main effect of PTD, $F(3.435, 130.527)=65.65$, $p<.05$, partial $\eta^2=.63$ (see figure 4.20), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{RMS-RD}. Partial η^2 indicates a large effect and that 63% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that eleven pairs of the PTD were significantly different from each other ($p<.003$). However, the difference between TS (M=8.16, SD=2.83) and SS (M=9.10, SD=1.91), $t(39)=-2.95$, $p>.003$, the difference between TS (M=8.16, SD=2.83), and PQS (M=8.30, SD=1.75), $t(39)=-0.37$, $p>.003$, the difference between SS (M=9.10, SD=1.91) and PQS (M=8.30, SD=1.75), $t(39)=-2.86$, $p>.003$, the difference between PTS (M=11.40, SD=3.16) and PSS (M=10.53, SD=1.95), $t(39)=2.31$, $p>.003$ were not statistically significant.

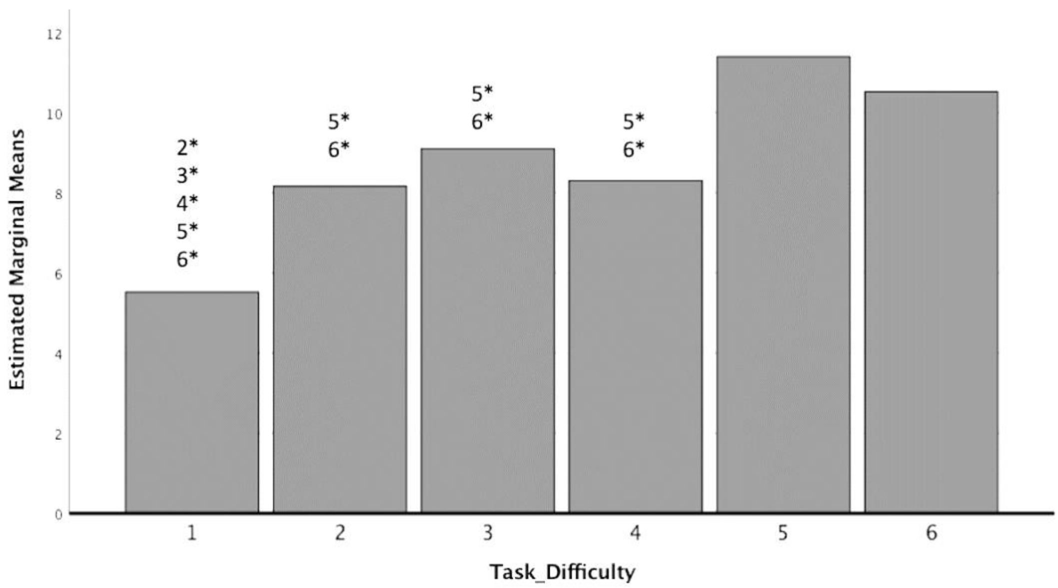


Figure 4.20. Main Effect of PTD on CoP_{RMS-RD} in Retention Phase

CoP Ellipse Area (CoP_{EA}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.13$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on CoP_{EA}, $F(2.685, 102.015)=.49$, $p>.05$ nor main effect for groups, $F(1,38)=.00$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{EA} values between control group (M=670.07, SD=284.59) and experimental group (M=674.47, SD=244.79). However, there was a significant main effect of PTD, $F(2.685, 102.015)=72.77$, $p<.05$, partial $\eta^2=.66$ (see figure 4.21), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{EA}. Partial η^2 indicates a large effect and that 66% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that thirteen pairs of the PTD were significantly different from each other ($p<.003$). However, the difference between TS (M=581.98, SD=349.31) and PQS (M=559.63, SD=239.80), $t(39)=.51$, $p>.003$, the difference between PTS (M=1044.70, SD=485.04), and PSS (M=926.98, SD=337.34), $t(39)=2.42$, $p>.003$, were not statistically significant.

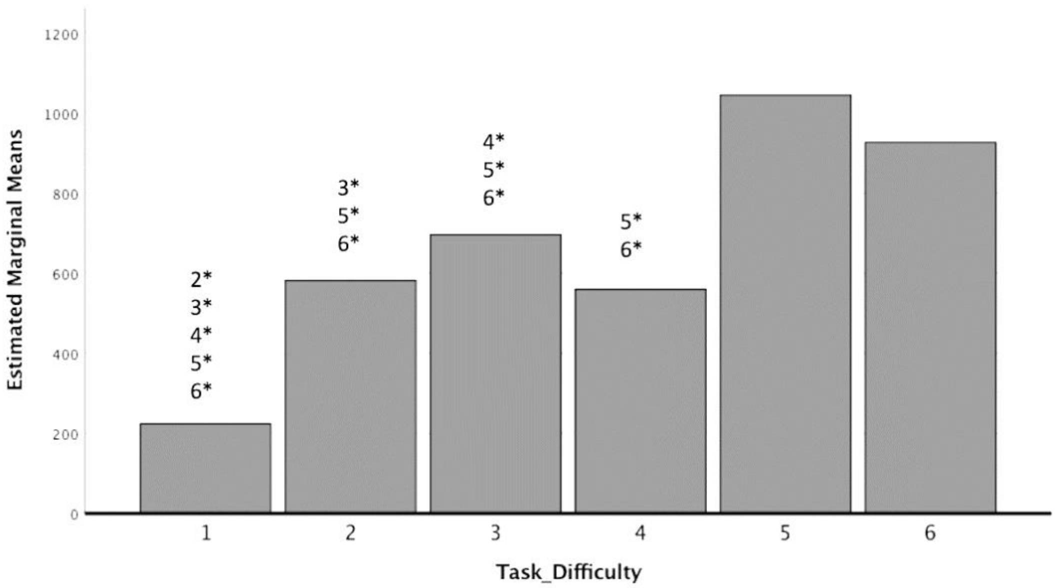


Figure 4.21. Main Effect of PTD on CoP_{EA} in Retention Phase

CoP Approximate Entropy (CoP_{ApEn}): The assumption of sphericity was not met as indicated by Mauchly's test, $X^2(14)=.29$, $p<.05$, it is corrected by the Greenhouse-Geisser estimation. The analysis showed that there were neither significant interaction between group and postural task difficulty on CoP_{ApEn}, $F(3.449, 131.052)=1.13$, $p>.05$ nor main effect for groups, $F(1,38)=.60$, $p>.05$, suggesting that ignoring the postural task difficulty, there was no statistically significant difference on CoP_{ApEn} values between control group ($M=.09$, $SD=.01$) and experimental group ($M=.10$, $SD=.02$). However, there was a significant main effect of PTD, $F(3.449, 131.052)=115.14$, $p<.05$, partial $\eta^2=.75$ (see figure 4.22), suggesting that ignoring the effect of group, there was a statistically significant difference between PTDs on CoP_{ApEn}. Partial η^2 indicates a large effect and that 75% of the variance of change in CoP values is explained by the main effect of PTD. The result of paired samples t-test showed that eleven pairs of the PTD were significantly different from each other ($p<.003$). However, the difference between QS ($M=.06$, $SD=.02$) and PQS ($M=.06$, $SD=.02$), $t(39)=-1.71$, $p>.003$, the difference between TS ($M=.11$, $SD=.03$), and SS ($M=.12$, $SD=.02$), $t(39)=-1.40$, $p>.003$, the difference between TS ($M=.11$, $SD=.03$) and PSS ($M=.13$, $SD=.03$), $t(39)=-2.36$, $p>.003$, the difference between SS ($M=.12$, $SD=.02$) and PSS ($M=.13$, $SD=.03$), $t(39)=-1.95$, $p>.003$ were not statistically significant.

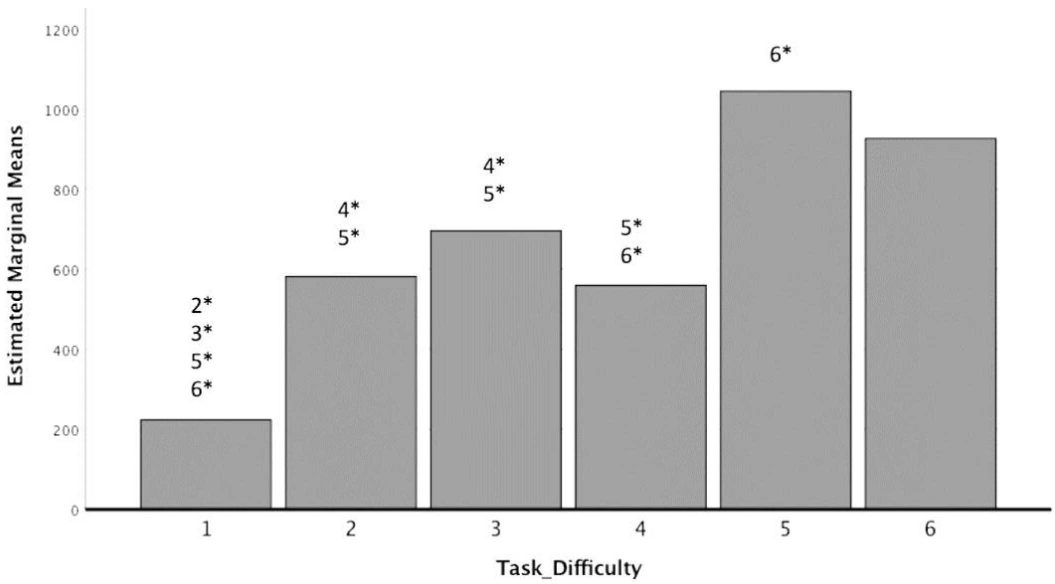


Figure 4.22. Main Effect of PTD on CoP_{ApEn} in Retention Phase

CHAPTER V

DISCUSSION

This study was designed to determine how concurrent visual feedback and postural task difficulty affect postural sway. To be more specific, the effect of these two factors on postural sway was examined separately for each of the eleven parameters for acquisition and retention phases. In this section, research issues will be discussed separately concerning the hypotheses proposed in the study as well as findings based on the current literature.

5.1. The Effects of CVF & PTD on Postural Sway in Acquisition Phase

To investigate the effects of concurrent visual feedback and postural task difficulty on postural sway in acquisition phase, the hypotheses were; a) there would be an interaction between concurrent visual feedback and postural task difficulty on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in acquisition phase, b) concurrent visual feedback would have an effect on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in acquisition phase, c) postural task difficulty would have an effect on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in acquisition phase. In the following section, these hypotheses were discussed on all postural sway parameters separately. Table 5.1 shows a summary of the results of acquisition phase.

Table 5.1. Summary of Significant & Non-Significant Results for CVF & PTD in Acquisition Phase

Sway Parameters	CVF x PTD Interaction	CVF Main Effect	PTD Main Effect
VEL-AP	NS	NS	*
VEL-ML	NS	NS	*
VEL-RD	NS	NS	*
RANGE-AP	NS	NS	*
RANGE-ML	NS	NS	*
RANGE-RD	NS	NS	*
RMS-AP	*	*	*
RMS-ML	NS	NS	*
RMS-RD	NS	*	*
EA	NS	*	*
ApEn	NS	*	*

Note. CVF: Concurrent Visual Feedback; PTD: Postural Task Difficulty; NS: Not Significant, *: Significant.

CoP Velocity – AP-ML-RD (CoP_{VEL-AP}, CoP_{VEL-ML}, CoP_{VEL-RD}): In terms of velocity in all directions (AP-ML-RD), there is only a main effect for PTD showed that only the last hypothesis (c) was accepted, depicted that postural task difficulty would affect postural sway velocity in the AP, ML, and RD directions.

Studies investigating the effects of concurrent feedback in different contexts have reported conflicting results. In terms of the effect of concurrent visual feedback on performance, the study by Janssen et al. (2009) showed that during various kinds of gait tasks, young adults reduced their sway velocity and trunk sway when they received feedback. The rationale behind the positive effect of feedback can be explained by the nature of postural control which is affected by cognitive processes such as attentional focus and it can be driven by instructions and feedback given to learners (Wulf, 2013). According to the constrained action hypothesis, internal focus of attention can be detrimental to learners, causing their movements to interfere with natural movements of the body (Wulf et al., 2001). Shea & Wulf (1999) supported the view by showing that concurrent visual feedback provided on a screen serves as a constant reminder to maintain the external focus of attention of learners and facilitates postural control. On the contrary, Wulf & Lewthwaite (2010) stated that even in circumstances where feedback induces an external focus of attention, conditions eliciting neuronal activations in the self-system and most probably it will result in decreased performance outcomes.

The results of our study showed the lack of effectiveness of concurrent visual feedback on performance even in difficult postural control tasks. Bechly et al. (2012) demonstrated that with the provision of concurrent visual feedback, subjects who have vestibular deficits showed greater improvement in balance performance compared to healthy age-matched subjects (control) and they showed the ceiling effect, which is reaching highest possible level in performance, as a potential reason for this lesser progression for the control subjects. Like the present thesis, subjects were chosen from healthy students and as they did not have to learn a new skill or a movement pattern, they did not feel further pressure on their system to execute the tasks. For this reason, one possible explanation for the nondifference between groups can be the ceiling effect.

Studies have been done based on the postural control model showed that when the rigidity of the system increases and the damping (i.e., reducing or preventing oscillations) decreases, sway velocity increases (Maurer & Peterka, 2005). In this thesis, the main effect of postural task difficulty on velocity for all directions may be addressed as the increase in stiffness and decrease in damping, because changing stance and sensory conditions of the tasks possibly resulted in modified system properties and adapt to new conditions to maintain postural control. As a result, participants either in the experimental group or in the control group showed increased postural sway velocity in proportion to the increase in the difficulty of the tasks.

CoP Range – AP- ML-RD ($CoP_{RANGE-AP}$, $CoP_{RANGE-ML}$, $CoP_{RANGE-RD}$): In terms of range in all directions (AP-ML-RD), there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, depicting that postural task difficulty would influence postural sway range in the AP, ML and RD directions.

The effect of concurrent visual feedback has been controversial as well as the effect of external and internal attention on postural control. Previous research has revealed that body sway is likely controlled by different control mechanisms based on the type of visual feedback information offered to subjects such as the external and internal focus of attention (Dault et al., 2003). In one of the studies, young and elderly healthy individuals and elderly stroke patients were tested with visual feedback which triggered the internal focus. During the trials of quiet stance, young adults were able to decrease the range of their sway in AP and ML directions (Dault et al., 2003). In this study, although the range of sway in the AP direction was visibly different between the control and experimental group, it was not statistically significant. On the other hand, in direct proportion to the results of our study Danna-Dos-Santos et al. (2008) failed to find a significant effect of visual feedback to decrease the postural sway of the participants. They suggested that the sway was already at its minimum level. Like our explanation, the participants could not benefit from feedback because, they already performed tasks to the best possible level (the ceiling effect), even if we increased the difficulty of the postural tasks. Moreover, the limited number of repetitions may have played a reverse role to reach a firmer conclusion and delivering visual feedback on CoP relocation or other factors related to body sway may not be an effective way to decrease postural sway in young healthy participants (Danna-Dos-Santos et al., 2008).

The result of this study showed a strong variance of PTD on a range of postural sway, especially in the AP direction. It has been stated that manipulation of the support surface and sensory input greatly affects the postural sway of young healthy adults (Muehlbauer et al., 2012). In another study, changing support areas with reduced dimensions of wooden boards resulted in increased sway (Mochizuki et al., 2006). Our results were positively related to the study which assessed 32 healthy participants’ sway range on the Biodex Balance System with three levels of difficulty. It was shown that, as postural task difficulty increased, postural sway range increased concomitantly (Barbado Murillo et al., 2012). Riccio (1993) proposed sway as a search mechanism testing the limits of stability for vertical position, according to this viewpoint, sway may occur because of both psychological and neuromechanical variables. The influence of the sway's search function can be minimized when a person stands in comfortable and secure conditions, resulting in a lesser sway.

CoP Variability – AP-ML-RD ($CoP_{RMS\text{-}AP}$, $CoP_{RMS\text{-}ML}$, $CoP_{RMS\text{-}RD}$): In terms of variability in AP direction, all hypotheses (a, b & c) were accepted. In the ML direction, only the last hypothesis (c) was accepted. In the RD direction, the second and the third hypotheses (b & c) were accepted. These results indicated that sway variability in the AP significantly varies between the control group and experimental group within six different postural control tasks, sway variability in the RD varies between groups and between PTD separately and only PTD affects sway variability in the ML.

Although studies have found varying results depending on whether the feedback given attracts internal or external attention or other effective strategies based on the postural control model, the results mostly agreed on the effect of visual information on the CoP variability. In the study of Lakhani & Mansfield (2015), in individuals who received concurrent visual feedback, the variability of the CoP was slightly lower. The research has found that when completing a motor task with visual feedback, postural sway is reduced in both directions, mostly in the AP direction (Dault et al., 2003). Parallel to this expression, it has been shown that vision had a more extensive and greater effect on sway variability in the AP direction than in the ML direction and it can be further concluded that vision is mostly tied to the ankle strategy for maintaining balance (Singh et al., 2012). Furthermore, body sway patterns in the AP and ML directions may imply different postural changes depending on ankle motion and hip load/unload mechanisms, respectively (Day et al., 1993; Winter et al., 1996). Physical factors such as weight, height, and body fat percentage can change postural strategies while standing still. For example, in research by Meng et al. (2016), it has been stated that postural performance in the AP direction may be affected by increased adiposity. They indicated that increased body fat in the abdomen formed the interaction between body mass and horizontal COM distance and resulted in increased ankle torque generation to maintain postural stability. In our study, weight distribution tried to be controlled by randomly allocated participants either experimental or control groups to eliminate the effect of weight differences. In connection with all these aforementioned information, in healthy young people, postural sway is likely controlled by a body segment orientation strategy that is predominantly reliant on ankle strategy (Horak & Nashner, 1986).

In general, decreased CoP variability has been observed in young adults and more challenging postural tasks. The possible explanation is that in the nervous system individuals have an adaptive mechanism to prevent them from falling (Shafizadeh et al., 2020). The strategy of minimizing COP variability has been recognized as an effective control mechanism against losing balance, particularly in increasingly difficult tasks (Van Wegen et al., 2002). Shafizadeh et al. (2020), found a strong relationship in the CoP variability that could point to the role of an active ankle strategy in reducing forward-backward oscillations during more demanding tasks like standing on a balance pad. In line with aforementioned information and the results of this study on postural sway variability, there is a link between postural task difficulty and concurrent visual information on postural sway variability.

CoP Ellipse Area (CoP_{EA}): In terms of the ellipse, the second (b) and the third (c) hypotheses were accepted and showed that there is an effect of concurrent visual feedback and postural task difficulty on the ellipse area of the CoP separately.

In the study of Dos Anjos et al. (2016), different provisions of visual feedback were utilized to see their effects on postural sway. According to the results, participants who were instructed to keep the CoP position as close as to the target located on the screen showed minimized sway areas. Another study that investigated the effect of continuous and discretized visual feedback on upright stance balance performance showed that the participants who received concurrent visual feedback showed a reduction in the sway area (D'Anna et al., 2015). The researchers cited the fact that continuous feedback activates the external focus of attention as the reason for this result because generally it has been known as a beneficial method for maintaining balance. The results of this study were in line with the studies. Concurrent visual feedback probably worked by directing participants' attention to external factors, therefore it may have enabled them to easily access the information needed to reduce the postural sway.

As shown in many studies, manipulation of stance conditions (i.e., bipedal, tandem, step, unipedal) and manipulation of sensory input such as vision or surface conditions influence postural sway even in young adults (Muehlbauer et al., 2012; Donath et al., 2016). The results found in this study can also be proof of the relationship between task difficulty and postural sway. However, when looking into little deeper to decide which task was more difficult compared to others, no definite judgment can be made according to the method in this study, because of the distinct nature of sway parameters and individual control mechanisms of the ankle and hip strategies as well as muscle strengths.

CoP Approximate Entropy (CoP_{ApEn}): In terms of measuring the regularity of CoP time series by approximate entropy, the second (b) and the third (c) hypotheses were accepted, and they showed that there is an effect of concurrent visual feedback and postural task difficulty on the regularity of CoP time series.

According to some researchers, complexity is about a system's ability to generate adaptive responses to stressors (Goldberger, 1996; Lipsitz, 2002). Therefore, more system complexity correlates with improved performance as well as healthy systems and it can be concluded that a loss of complexity is linked to a lower ability to adapt (Goldberger, 1996). Lower complexities can be encountered as the task becomes more challenging or when there is a motor control problem (Seigle et al., 2009). Additionally, some studies indicated that lower entropy values do not necessarily suggest less complexity; rather, it only implies more regularity depending on specific time series (Pincus et al., 1991; Richman & Moorman, 2000). However, there are some controversial hypotheses stating that high levels of complexity may indicate that the system is becoming less sustainable (Vaillancourt & Newell, 2002) and entropy was accepted as a metric for the disorder (chaos) and noise (Borg & Laxåback, 2010).

Barbado Murillo et al. (2012) found a loss of complexity in healthy participant’s timescales while increasing postural task difficulty assessed on the Biodex Balance System and they claimed that this could be an indication of the postural control system's improved ability to adjust to pressures brought by higher instability conditions on a stable platform. The research claimed that the changes in the activity of the central nervous system’s complex behaviors could be functional, but it might depend on the nature of the system's intrinsic dynamics and the constraints of the tasks (Vaillancourt & Newell, 2002). On the contrary, the result of our study showed that participants in the experimental group showed more irregular meaning complex time series, and complexity increased with increasing postural task difficulty. Increased complexity may reflect the motor system adjustments when postural stability was more adversely affected by challenging tasks (Shafizadeh et al., 2020). The feedback used in this study may have worked as a facilitator for the motor system adjustments to control posture and adapt to challenging postural positions. Moreover, another cause of increased complexity may be the dynamic and highly adaptive network of neuromuscular connections that regulates posture (Lipsitz, 1992b). Increased difficulty of postural tasks used in this study may have increased the adaptation of neuromuscular networks to maintain postural control. The results of this study were also in line with the findings reported by Baltich et al. (2014), in their research participants showed increased complexity when they tested on foam pads, and it has also been shown that participants have difficulties making appropriate postural adjustments.

As a summary, the results of this indicated interaction between CVF and PTD on the CoP sway variability only in the AP direction and group difference in the AP and RD direction. These results were supported by other studies (Lakhani & Mansfield, 2015; Dault et al., 2003), and the accepted rationale for the result is that the nervous system's adaptive control mechanisms worked to minimize CoP variability and stabilize the body especially in challenging postural tasks (Van Wegen et al., 2002). Furthermore, there was a relationship found between CoP variability and an ankle strategy to reduce forward-backward oscillations during challenging postural tasks (Shafizadeh et al., 2020). It seems possible that the results of this study could be attributed to the adaptive control mechanisms and the ankle strategy. Moreover, there was a group difference in terms of ellipse area and regularity of the CoP time series. Comparison of the findings with those of other studies confirms that concurrent visual feedback resulted in the reduction of sway area even in difficult postural tasks and this relationship may partly be explained by the characteristic of feedback which may activate the external focus of attention (Dos Anjos et al., 2016; D'Anna et al., 2015). The present results raise the possibility that concurrent feedback can prevent cognitive overload (Wulf & Shea, 2002) and allow individuals to reach specific information to perform complex tasks with direct attention externally. In addition, the guiding function of feedback might have assisted learners to understand components of complex motor tasks (Huegel & O'Malley, 2010).

The results of entropy measures in this study showed that participants in the experimental group showed greater complexity compared to the control, and besides that with increased task difficulty entropy was increased likewise. These results agreed with the views expressed by Vaillancourt & Newell, (2002). They associated high levels of complexity with the system's feature of becoming less sustainable and a metric for the disorder. According to our point of view and in line with other researchers' opinions (Shafizadeh et al., 2020; Lipsitz, 1992b; Baltich et al., 2014), concurrent feedback and task constraints might have increased motor system adjustments and dynamic, highly adaptive network of neuromuscular connections resulted in more complex signals.

Postural task difficulty was found effective for all CoP parameters assessed in this study. There are some possible explanations for this result. Firstly, the inverse relationship between the rigidity or joint stiffness and the damping mechanism might result in increased CoP values (Maurer & Peterka, 2005). Because changing the BoS and surface properties during a quiet stance could have resulted in increased stiffness and decreased damping in the neuromuscular system. Secondly, as suggested by Riccio (1993), sway is a search mechanism that tests the limits of stability to maintain balance in the vertical position. Sway may occur through the contribution of both psychological and neuromechanical factors, for this reason when an individual tries to stand on uncomfortable and insecure positions the search function of the sway could be maximized and resulted in increased values of the CoP parameters.

Contrary to the results found for some parameters in this study, it has been shown that postural control could be improved with visual feedback (Cawsey et al., 2009; Rougier et al., 2004) when this external information serves as a facilitator to the existing natural visual, proprioceptive, and vestibular information (Giansanti et al., 2009). Getting the desired results from feedback depends on some factors such as frequency of feedback (Shea & Wulf, 1999), magnification of feedback (Cawsey et al., 2009; Jehu et al., 2015) type of sensory feedback (Sienko et al., 2018). These factors could be carefully regulated to avoid interference between augmented information and the sensory system’s natural contribution to balance regulation. Studies showed that individuals with unhealthy systems which could affect postural control obtained greater benefits from augmented information such as individuals with vestibular deficits (Bechly et al. (2012) and stroke patients (Chen et al., 2015). They proposed the ceiling effect as a potential reason for this lesser progression for the healthy subjects. In the light of this information, we might speculate that concurrent feedback used in this study might be redundant. Since participants have a healthy system meaning not having any diseases affecting postural control, feedback could interfere with their own sensory system even though we set some postural tasks with different difficulties to overcome this possibility.

5.2. The Effects of CVF & PTD on Postural Sway in Retention Phase

To investigate the effects of concurrent visual feedback and postural task difficulty on postural sway for retention, the formulated hypotheses were; a) there would be an interaction between concurrent visual feedback and postural task difficulty on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in retention, b) concurrent visual feedback would have an effect on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in retention, c) postural task difficulty would have an effect on postural sway velocity (AP-ML-RD), variability (AP-ML-RD), range (AP-ML-RD), ellipse area and regularity (i.e., approximate entropy) measured in retention. In the following section, these hypotheses were discussed on all postural sway parameters separately. Table 5.2 shows a summary of the results of retention phase.

CoP Velocity – AP-ML-RD (CoP_{VEL-AP}, CoP_{VEL-ML}, CoP_{VEL-RD}): In terms of velocity in all directions (AP-ML-RD) measured in retention, there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, and it showed that postural task difficulty would affect postural sway velocity in the AP, ML and RD directions. When we compared the results of retention and acquisition phases to find out whether there was a permanent effect of concurrent feedback or not, there was no difference between them, and it showed that concurrent visual feedback had no permanent and significant effect on the velocity of the CoP measures. According to the guidance hypothesis, concurrent feedback decreased learning assessed on retention tests while benefiting only performance in acquisition (Schmith., 1991). In this study, there was also no decreased performance on retention according to mean results. The result of the study conducted by Goodwin & Goggin (2018), showed that both older adults and younger adults will be dependent on the feedback if they get 100% concurrent visual feedback during acquisition phase, and both groups will perform badly on a no-feedback retention test while they are performing continuous balance tasks. However, Sigrist et al. (2012) stated that the more challenging the task, the more the learners can benefit from concurrent feedback. Shea & Wulf (1999) indicated concurrent feedback as an effective method when retaining complex postural control tasks. As a result of these conflicting findings, researchers pointed out that the principles of providing feedback to simple motor skills cannot be generalized to complex motor skills (Wulf & Shea, 2002; Guadagnoli & Lee, 2004).

Table 5.2. Summary of Significant & Non-Significant Results for CVF & PTD in Retention Phase

Sway Parameters	CVF x PTD Interaction	CVF Main Effect	PTD Main Effect
VEL-AP	NS	NS	*
VEL-ML	NS	NS	*
VEL-RD	NS	NS	*
RANGE-AP	NS	NS	*
RANGE-ML	NS	NS	*
RANGE-RD	NS	NS	*
RMS-AP	NS	NS	*
RMS-ML	NS	NS	*
RMS-RD	NS	NS	*
EA	NS	NS	*
ApEn	NS	NS	*

Note. CVF: Concurrent Visual Feedback; PTD: Postural Task Difficulty; NS: Not Significant, *: Significant.

In this study, even though the results did not show significance there was either no decrease in experimental group mean scores on difficult tasks or there was an improvement in retention. Ruhe et al. (2010) stated that two 120-second trials were needed for the COP mean velocity to appropriately observe postural control changes. In this study, an average of three repetitions were utilized for the analyses. Ruhe et. al. (2010) further recommended that three to five repetitions yielded acceptable reliability for most of the CoP variables. However, as far as we know there were no set number and duration of repetitions to reach valid and reliable results for observing the effects and after-effects of concurrent visual feedback concerning postural task difficulty. Feedback conditions in this study were limited to one day and the number of three repetitions with feedback may not be sufficient to produce lasting effects on the parameter of velocity. According to this, we might speculate that the feedback conditions in this study may not be appropriate to observe the effects of concurrent feedback on difficult postural control tasks in terms of permanency. In general, the association between the number of training sessions with sensory augmentation and the retention/carry-over effects hasn't been thoroughly studied, although the few studies that comprised more than 10 sessions seem to show advantages over training without the addition of sensory feedback (Sienko et al., 2017).

CoP Range – AP- ML-RD ($CoP_{RANGE\text{-}AP}$, $CoP_{RANGE\text{-}ML}$, $CoP_{RANGE\text{-}RD}$): In terms of range in all directions (AP-ML-RD) measured in retention, there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, depicted that postural task difficulty would influence postural sway range in the AP, ML and RD directions.

The mean values of the groups showed that the experimental group's range of CoP was lesser than the control group in acquisition phase, but in retention phase, their scores were roughly the same as the control group. However, these results could not reach the level of significance. Studies showed that visual feedback improved postural control (Cawsey et al., 2009; Rougier et al., 2004) when it provides additional artificial visual information on body sway in addition to the existing natural visual, proprioceptive, and vestibular information (Giansanti et al., 2009). However, the desired effects of visual information can be affected by some factors such as frequency of feedback (Shea & Wulf., 1999), magnification of feedback (Cawsey et al., 2009; Jehu et al., 2015) type of sensory feedback (Sienko et al., 2018). It has been shown that there is a tradeoff since sensory information could interfere with the sensory systems' normal contribution to balance regulation. As far as we know, the sensory systems of the participants were intact, and they did not need any further augmented information. For this reason, interference might happen among participants in this study.

On the other hand, it has been stated that longer-term sensory augmentation training gives the nervous system more time to create the best combinations and weights of sensory inputs, it may have an impact on sensory integration and context-specific adaptation. It has been concluded hereby that sensory augmentation utilized for balance rehabilitation may result in positive changes in sensory integration that are maintained even when a sensory augmentation device was not used indefinitely (Sienko et al., 2018). In our study, due to the short period of training with visual feedback, participants could not create specific integration and for this reason, adaptation to conditions and effects of feedback might not be sustained in retention.

CoP Variability – AP-ML-RD (CoP_{RMS-AP}, CoP_{RMS-ML}, CoP_{RMS-RD}): In terms of variability in all directions (AP-ML-RD) measured in retention, there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, depicted that postural task difficulty would have an effect on postural sway variability in the AP, ML and RD directions.

The study was undertaken to evaluate the influence on the control of a basic quiet standing balance task of delivering feedback from the COG versus feedback from the CoP (Lakhani & Mansfield., 2015). 32 young adults aged between 20-35 years old were included in the study. RMSE (variability) which was the primary measure of postural sway, showed a greater reduction in scores of the group who received CoG feedback compared to the group who received CoP feedback, but they pointed out that learning did not take place, because these effects did not carry over to the situation where the visual feedback was absent. In addition, they stated that there was no control group in their study to show whether an automatic control was achieved through concurrent feedback or not. Likewise in this study, we found the same results in the AP and RD directions even though we used CoP feedback and included a control group. Lakhani & Mansfield (2015) suggested a potential reason which was the floor effect of the low RMS values, which indicated the high level of baseline postural control highlighted with low variability values. Therefore, we included difficult postural tasks as they suggested but the results were the same and maybe the difficulty level should have been adjusted individually to see distinctive results of concurrent feedback. The retention results were also proven by another study. It was shown that in the concurrent feedback group and control group motor performance was not maintained in retention and it was possible that the practice period wasn't long enough to notice changes in the performance (Marco-Ahulló et al., 2018).

CoP Ellipse Area (CoP_{EA}): In terms of ellipse area measured in retention, there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, showed that postural task difficulty would affect ellipse are of the postural sway in the AP, ML, and RD directions.

Although significant improvement was found in the CoP ellipse area trajectories between groups in acquisition phase, these results could not be preserved in retention tests the same as the other CoP parameters. There are some mechanisms put forward to explain how information is integrated and utilized by the CNS during postural control, but these mechanisms were not fully understood. According to the dominant theory, observed balance improvements are the result of sensory reweighting since feedback from body motion provides the central nervous system (CNS) with a correlate to inputs from its intact sensory channels (such as vision and proprioception), subjects who receive sensory augmentation come to rely more and more on these intact systems (Sienko et al., 2017). As a result, when this information (feedback) is withdrawn, improvements in the acquisition phase could not carry over. On the other hand, participants might have developed context-specific adaptation during the trials with feedback. Context-specific adaptation was explained as creating a novel sensorimotor program with the repeated usage of the device or information and it can only be accessed when the device is used (Lee et al., 2012; Lee et al., 2013). As we stated for other parameters of the CoP, one training day with three trials for each task with concurrent feedback might not be sufficient to make permanent changes in the postural control mechanisms of young people especially working with difficult postural tasks.

CoP Approximate Entropy (CoP$_{ApEn}$): In terms of regularity measured in retention, there is only a main effect for PTD showing that only the last hypothesis (c) was accepted, demonstrating that postural task difficulty would affect the regularity of CoP time series in the AP, ML, and RD directions.

Recently, it has been claimed that interactions between a system's inherent dynamics and performance task restrictions determine whether the complexity of a behavioral or physiological system increases or decreases (Vaillancourt & Newell, 2002). As demonstrated in the study, participants adjusted their postural control dynamics in response to the complexity of the challenge and the availability of biofeedback (Caballero Sánchez et al., 2016). The results of our study were like this research in terms of acquisition variables. In the absence of feedback, participants concentrated on preventing falls. On the other hand, they attempted to adjust their CoP to the set target under the feedback settings by making more modifications (Caballero Sánchez et al., 2016). Likewise, in this study results of the retention showed that participants in the experimental group depicted similar entropy values to the control group. It could be an indication of the decreased number of adjustments in the absence of feedback. However, as the difficulty of postural tasks increased, entropy values were increased in both groups. In line with these results, we might speculate that without feedback and less difficult postural conditions participants decreased the number of adjustments in their control mechanisms resulting in more regular time series which means a more predictable process.

As a summary, the retention aimed to reveal if there were any retention and permanent effect of concurrent visual feedback on postural tasks with different difficulties. When the general results are examined, although the mean values of some parameters differ, no significant difference has emerged in any of them, and the effects have not been carried over to retention measurements. The best possible reason for this result could be the number of trials and the fact that these trials were limited to only one day. It has been speculated that sensory augmentation training with long time intervals could provide the nervous system more time for creating the best combination of sensory weighting and result in better sensory integration and adaptation to specific contexts (Sienko et al., 2018).

Moreover, the result of the study carried out by Sienko et al. (2018) highlighted that favorable modifications in sensory integration caused by long-term augmented training could be maintained even in conditions without augmented information. The association between the number of training sessions with sensory augmentation and the retentive and/or carry-over effects hasn't been thoroughly studied, but the review from Sienko et al. (2017) stated that a handful of studies that comprised more than 10 sessions seem to show advantages over training without the addition of any sensory information. However, as far as we know, there were no predetermined trial numbers for each task or duration of training for monitoring the effects and after-effects of concurrent visual feedback concerning postural task difficulty.

CHAPTER VI

CONCLUSION

The present research aimed to examine the effects of concurrent visual feedback and postural task difficulty on postural sway velocity, variability, range, ellipse area, and regularity. In terms of the acquisition phase, the variability parameter in the forward-backward direction significantly varied between the control group and concurrent visual feedback group within six different postural control tasks. It indicates that concurrent visual feedback improves postural control while performing difficult postural tasks. In addition, ignoring the main effect of postural task difficulty variability in the antero-posterior and resultant-distance directions, ellipse area and entropy parameters vary between the control group and concurrent visual feedback group during acquisition phase. When participants were provided concurrent visual feedback in acquisition phase, their CoP variability in the antero-posterior and resultant-distance directions, ellipse area, and regularity decrease thereby improving postural control. On the other hand, both the results of acquisition and retention measures indicated that postural task difficulty had a significant effect on all postural sway parameters.

According to the results, we can implicate that concurrent feedback could be a beneficial method to improve postural control in healthy adults. What is more, even old people or people with postural control deficits could be benefited from concurrent feedback by making some modifications on the functions of feedback. For example, in clinical settings for enhancing or relearning postural control, therapists could modify concurrent feedback sources from visual to tactile for patients who have visual problems or blind patients.

6.1. Further Studies

Further research needs to examine more closely the links between concurrent visual feedback and postural task difficulty. Few modifications and methodological changes should be considered. Firstly, longer acquisition phase in terms of days and task repetitions per day should be planned carefully to reveal the behavioral change or detrimental effects of frequent feedback on postural control. Future studies should compare the different numbers of concurrent feedback sessions to yield additional knowledge in terms of the acquisition and retention effects of concurrent feedback on difficult tasks. Secondly, six different postural tasks that was used in this study may not have been sufficient to create the necessary challenges for young and healthy adults. For this reason, further studies should focus on determining the personalized difficulty level for each participant or the profile of the participants should be changed completely such as including participants with vestibular deficits or other problems which can affect postural control and hence our understanding of the postural control. Finally, concomitant electromyography (EMG) recordings might be included to have a better understanding of the role of muscles in postural control mechanisms. Ankle and hip strategies vary according to different positions of body parts and vision since it has been stated that vision and the ankle strategy for maintaining balance are primarily connected (Singh et al., 2012). In this way, more precise judgments can be made by gaining more information about the effect of feedback, motor control systems, and other body strategies while maintaining postural control.

REFERENCES

Abellan Van Kan, G., Rolland, Y., Andrieu, S., Bauer, J., Beauchet, O., Bonnefoy, M., Cesari, M., Donini, L., Gillette-Guyonnet, S., Inzitari, M., Nourhashemi, F., Onder, G., Ritz, P., Salva, A., Visser, M., & Vellas, B. (2009). Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. The Journal of Nutrition, Health & Aging, 13(10), 881–889. https://doi.org/10.1007/s12603-009-0246-z

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychological Bulletin*, *101*(1), 41–74. https://doi.org/10.1037/0033-2909.101.1.41

Amiridis, I. G., Hatzitaki, V., & Arabatzi, F. (2003). Age-induced modifications of static postural control in humans. *Neuroscience Letters*, *350*(3), 137–140. https://doi.org/10.1016/s0304-3940(03)00878-4

Anderson, D. I., Magill, R. A., Sekiya, H., & Ryan, G. (2005). Support for an Explanation of the Guidance Effect in Motor Skill Learning. *Journal of Motor Behavior*, *37*(3), 231–238. https://doi.org/10.3200/jmbr.37.3.231-238

Asseman, F. B., Caron, O., & Crémieux, J. (2008). Are there specific conditions for which expertise in gymnastics could have an effect on postural control and performance? *Gait & Posture*, *27*(1), 76–81. https://doi.org/10.1016/j.gaitpost.2007.01.004

Ballardini, G., Florio, V., Canessa, A., Carlini, G., Morasso, P., & Casadio, M. (2020). Vibrotactile feedback for improving standing balance. *Frontiers in Bioengineering and Biotechnology*, *8*. https://doi.org/10.3389/fbioe.2020.00094

Baltich, J., von Tscharner, V., Zandiyeh, P., & Nigg, B. M. (2014). Quantification and reliability of center of pressure movement during balance tasks of varying difficulty. *Gait & Posture*, *40*(2), 327–332. https://doi.org/10.1016/j.gaitpost.2014.04.208

Barbado Murillo, D., Sabido Solana, R., Vera-Garcia, F. J., Gusi Fuertes, N., & Moreno, F. J. (2012). Effect of increasing difficulty in standing balance tasks with visual feedback on postural sway and EMG: Complexity and performance. *Human Movement Science*, *31*(5), 1224–1237. https://doi.org/10.1016/j.humov.2012.01.002

Bauby, C. E., & Kuo, A. D. (2000). Active control of lateral balance in human walking. *Journal of Biomechanics*, *33*(11), 1433–1440. https://doi.org/10.1016/s0021-9290(00)00101-9

Bechly, K. E., Carender, W. J., Myles, J. D., & Sienko, K. H. (2012). Determining the preferred modality for real-time biofeedback during balance training. *Gait & Posture*, *37*(3), 391–396. https://doi.org/10.1016/j.gaitpost.2012.08.007

Benaim, C., Pérennou, D. A., Villy, J., Rousseaux, M., & Pelissier, J. Y. (1999). Validation of a Standardized Assessment of Postural Control in Stroke Patients. *Stroke*, *30*(9), 1862–1868. https://doi.org/10.1161/01.str.30.9.1862

Benda, B., Riley, P., & Krebs, D. (1994). Biomechanical relationship between center of gravity and center of pressure during standing. *IEEE Transactions on Rehabilitation Engineering*, *2*(1), 3–10. https://doi.org/10.1109/86.296348

Berg, K. (1989). Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada*, *41*(6), 304–311. https://doi.org/10.3138/ptc.41.6.304

Bernstein, N. (1967). *The co-ordination and regulation of movement.* London, UK: Pergamon.

Bilodeau, E. A., & Bilodeau, I. M. (1961). Motor-Skills Learning. *Annual Review of Psychology*, *12*(1), 243–280. https://doi.org/10.1146/annurev.ps.12.020161.001331

Bilodeau, E. A., Bilodeau, I. M., & Schumsky, D. A. (1959). Some effects of introducing and withdrawing knowledge of results early and late in practice. *Journal of Experimental Psychology*, *58*(2), 142–144. https://doi.org/10.1037/h0040262

Bisdorff, A. R., Wolsley, C. J., Anastasopoulos, D., Bronstein, A. M., & Gresty, M. A. (1996). The Perception of body verticality (subjective postural vertical) in peripheral and central vestibular disorders. *Brain*, *119*(5), 1523–1534. https://doi.org/10.1093/brain/119.5.1523

Borg, F. G., & Laxåback, G. (2010). Entropy of balance - some recent results. *Journal of NeuroEngineering and Rehabilitation*, *7*(1). https://doi.org/10.1186/1743-0003-7-38

Brewer, B. R., Klatzky, R., & Matsuoka, Y. (2008). Visual feedback distortion in a robotic environment for hand rehabilitation. *Brain Research Bulletin*, *75*(6), 804–813. https://doi.org/10.1016/j.brainresbull.2008.01.006

Broglio, S. P., Collins, M. W., Williams, R. M., Mucha, A., & Kontos, A. P. (2015). Current and Emerging Rehabilitation for Concussion. *Clinics in Sports Medicine*, *34*(2), 213–231. https://doi.org/10.1016/j.csm.2014.12.005

Bruyneel, A., Mesure, S., Paré, J., & Bertrand, M. (2010). Organization of postural equilibrium in several planes in ballet dancers. *Neuroscience Letters*, *485*(3), 228–232. https://doi.org/10.1016/j.neulet.2010.09.017

Buchanan, J. J., & Wang, C. (2012). Overcoming the guidance effect in motor skill learning: Feedback all the time can be beneficial. *Experimental Brain Research*, *219*(2), 305–320. https://doi.org/10.1007/s00221-012-3092-x

Caballero Sánchez, C., Barbado Murillo, D., Davids, K., & Moreno Hernández, F. J. (2016). Variations in task constraints shape emergent performance outcomes and complexity levels in balancing. *Experimental Brain Research*, *234*(6), 1611–1622. https://doi.org/10.1007/s00221-016-4563-2

Camicioli, R., Howieson, D., Lehman, S., & Kaye, J. (1997). Talking while walking: The effect of a dual task in aging and Alzheimer's disease. *Neurology*, *48*(4), 955–958. https://doi.org/10.1212/wnl.48.4.955

Cawsey, R. P., Chua, R., Carpenter, M. G., & Sanderson, D. J. (2009). To what extent can increasing the magnification of visual feedback of the centre of pressure position change the control of quiet standing balance? *Gait & Posture*, *29*(2), 280–284. https://doi.org/10.1016/j.gaitpost.2008.09.007

Chen, J. L., Fujii, S., & Schlaug, G. (2015). The use of augmented auditory feedback to improve arm reaching in stroke: A case series. *Disability and Rehabilitation*, *38*(11), 1115–1124. https://doi.org/10.3109/09638288.2015.1076530

Chew, V. (1966). Confidence, Prediction, and Tolerance Regions for the Multivariate Normal Distribution. *Journal of the American Statistical Association*, *61*(315), 605–617. https://doi.org/10.1080/01621459.1966.10480892

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). Exercise and Physical Activity for Older Adults. *Medicine & Science in Sports & Exercise*, *41*(7), 1510–1530. https://doi.org/10.1249/mss.0b013e3181a0c95c

Cimadoro, G., Paizis, C., Alberti, G., & Babault, N. (2013). Effects of different unstable supports on EMG activity and balance. *Neuroscience Letters*, *548*, 228–232. https://doi.org/10.1016/j.neulet.2013.05.025

Clifford, A. M., & Holder-Powell, H. (2010). Postural control in healthy individuals. *Clinical Biomechanics*, *25*(6), 546–551. https://doi.org/10.1016/j.clinbiomech.2010.03.005

Cohen, H., Heaton, L. G., Congdon, S. L., & Jenkins, H. A. (1996). Changes in Sensory Organization Test Scores with Age. *Age and Ageing*, *25*(1), 39–44. https://doi.org/10.1093/ageing/25.1.39

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Coker, C. (2017). *Motor Learning and Control for Practitioners* (4th ed.). Routledge.

Cole, J. D., & Sedgwick, E. M. (1992). The perceptions of force and of movement in a man without large myelinated sensory afferents below the neck. *The Journal of Physiology*, *449*(1), 503–515. https://doi.org/10.1113/jphysiol.1992.sp019099

Collins, J. J., de Luca, C. J., Burrows, A., & Lipsitz, L. A. (1995). Age-related changes in open-loop and closed-loop postural control mechanisms. *Experimental Brain Research*, *104*(3), 480–492. https://doi.org/10.1007/bf00231982

D'Anna, C., Schmid, M., Bibbo, D., Bertollo, M., Comani, S., & Conforto, S. (2015). The Effect of Continuous and Discretized Presentations of Concurrent Augmented Visual Biofeedback on Postural Control in Quiet Stance. *PLOS ONE*, *10*(7), e0132711. https://doi.org/10.1371/journal.pone.0132711

Danna-Dos-Santos, A., Degani, A. M., Zatsiorsky, V. M., & Latash, M. L. (2008). Is Voluntary Control of Natural Postural Sway Possible? *Journal of Motor Behavior*, *40*(3), 179–185. https://doi.org/10.3200/jmbr.40.3.179-185

Dault, M. C., de Haart, M., Geurts, A. C., Arts, I. M., & Nienhuis, B. (2003). Effects of visual center of pressure feedback on postural control in young and elderly healthy adults and in stroke patients. *Human Movement Science*, *22*(3), 221–236. https://doi.org/10.1016/s0167-9457(03)00034-4

Day, B. L., Steiger, M. J., Thompson, P. D., & Marsden, C. D. (1993). Effect of vision and stance width on human body motion when standing: Implications for afferent control of lateral sway. *The Journal of Physiology*, *469*(1), 479–499. https://doi.org/10.1113/jphysiol.1993.sp019824

Donath, L., Kurz, E., Roth, R., Zahner, L., & Faude, O. (2016). Leg and trunk muscle coordination and postural sway during increasingly difficult standing balance tasks in young and older adults. *Maturitas*, *91*, 60–68. https://doi.org/10.1016/j.maturitas.2016.05.010

Dos Anjos, F., Lemos, T., & Imbiriba, L. A. (2016). Does the type of visual feedback information change the control of standing balance? *European Journal of Applied Physiology*, *116*(9), 1771–1779. https://doi.org/10.1007/s00421-016-3434-7

Duarte, M., & Freitas, S. M. (2010). Revision of posturography based on force plate for balance evaluation. *Revista brasileira de fisioterapia (Sao Carlos (Sao Paulo, Brazil))*, *14*(3), 183–192.

Duncan, P. W., Weiner, D. K., Chandler, J., & Studenski, S. (1990). Functional Reach: A New Clinical Measure of Balance. *Journal of Gerontology*, *45*(6), M192–M197. https://doi.org/10.1093/geronj/45.6.m192

Dunham, P., & Mueller, R. (1993). Effect of fading knowledge of results on acquisition, retention, and transfer of a simple motor task. *Perceptual and Motor Skills*, *77*(3_suppl), 1187–1192. https://doi.org/10.2466/pms.1993.77.3f.1187

Edwards, W. H. (2011). *Motor learning and control: From theory to practice*. Wadsworth Cengage Learning.

Fitzgerald, B. (1996). A review of the sharpened Romberg test in diving medicine. *SPUMS Journal / South Pacific Underwater Medicine Society, 26*(3), 142-146.

Foerster, O. (1936). The motor cortex in man in the light of Hughlings Jackson's doctrines. *Brain*, *59*(2), 135–159. https://doi.org/10.1093/brain/59.2.135

Franchignoni, F., Horak, F., Godi, M., Nardone, A., & Giordano, A. (2010). Using psychometric techniques to improve the Balance Evaluation Systems Test: the mini-BESTest. *Journal of Rehabilitation Medicine*, *42*(4), 323–331. https://doi.org/10.2340/16501977-0537

Fujii, S., Lulic, T., & Chen, J. L. (2016). More Feedback Is Better than Less: Learning a Novel Upper Limb Joint Coordination Pattern with Augmented Auditory Feedback. *Frontiers in Neuroscience*, *10*. https://doi.org/10.3389/fnins.2016.00251

Fujiwara, K., Toyama, H., Kiyota, T., & Maeda, K. (2006). Postural muscle activity patterns during standing at rest and on an oscillating floor. *Journal of Electromyography and Kinesiology*, *16*(5), 448–457. https://doi.org/10.1016/j.jelekin.2005.08.008

Gardner, M. M. (2000). Exercise in preventing falls and fall related injuries in older people: a review of randomised controlled trials. *British Journal of Sports Medicine*, *34*(1), 7–17. https://doi.org/10.1136/bjsm.34.1.7

Giansanti, D., Dozza, M., Chiari, L., Maccioni, G., & Cappello, A. (2009). Energetic assessment of trunk postural modifications induced by a wearable audio-biofeedback system. *Medical Engineering & Physics*, *31*(1), 48–54. https://doi.org/10.1016/j.medengphy.2008.04.004

Gibson, J. J. (1966). *Senses considered as Perceptual Systems*. Greenwood Press.

Goldberger, A. (1996). Non-linear dynamics for clinicians: chaos theory, fractals, and complexity at the bedside. *The Lancet*, *347*(9011), 1312–1314. https://doi.org/10.1016/s0140-6736(96)90948-4

Goodwin, J. E., & Goggin, N. L. (2018). An Older Adult Study of Concurrent Visual Feedback in Learning Continuous Balance. *Perceptual and Motor Skills*, *125*(6), 1160–1172. https://doi.org/10.1177/0031512518795758

Gregg, E. W., Pereira, M. A., & Caspersen, C. J. (2000). Physical Activity, Falls, and Fractures Among Older Adults: A Review of the Epidemiologic Evidence. *Journal of the American Geriatrics Society*, *48*(8), 883–893. https://doi.org/10.1111/j.1532-5415.2000.tb06884.x

Grigg, P. (1994). Peripheral neural mechanisms in proprioception. *Journal of Sport Rehabilitation*, *3*(1), 2–17. https://doi.org/10.1123/jsr.3.1.2

Grillner, S. (1981). Control of Locomotion in Bipeds, Tetrapods, and Fish. *Comprehensive Physiology*, 1179–1236. https://doi.org/10.1002/cphy.cp010226

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior*, *36*(2), 212–224. https://doi.org/10.3200/jmbr.36.2.212-224

Günther, M., Grimmer, S., Siebert, T., & Blickhan, R. (2009). All leg joints contribute to quiet human stance: A mechanical analysis. *Journal of Biomechanics*, *42*(16), 2739–2746. https://doi.org/10.1016/j.jbiomech.2009.08.014

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Scherr, P. A., & Wallace, R. B. (1994). A Short Physical Performance Battery Assessing Lower Extremity Function: Association with Self-Reported Disability and Prediction of Mortality and Nursing Home Admission. *Journal of Gerontology*, *49*(2), M85–M94. https://doi.org/10.1093/geronj/49.2.m85

Guskiewicz, K. M. (2011). Balance Assessment in the Management of Sport-Related Concussion. *Clinics in Sports Medicine*, *30*(1), 89–102. https://doi.org/10.1016/j.csm.2010.09.004

Hageman, P. A., Leibowitz, J. M., & Blanke, D. (1995). Age and gender effects on postural control measures. *Archives of Physical Medicine and Rehabilitation*, *76*(10), 961–965. https://doi.org/10.1016/s0003-9993(95)80075-1

Horak, F. B. (1987). Clinical Measurement of Postural Control in Adults. *Physical Therapy*, *67*(12), 1881–1885. https://doi.org/10.1093/ptj/67.12.1881

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35*(suppl_2), ii7–ii11. https://doi.org/10.1093/ageing/afl077

Horak, F. B., & Macpherson, J. M. (1996). Postural orientation and Equilibrium. *Comprehensive Physiology*, 255–292. https://doi.org/10.1002/cphy.cp120107

Horak, F. B., & Nashner, L. M. (1986). Central programming of postural movements: adaptation to altered support-surface configurations. *Journal of Neurophysiology*, *55*(6), 1369–1381. https://doi.org/10.1152/jn.1986.55.6.1369

Horak, F. B., and Macpherson, J. M. (1995). "Postural Orientation and Equilibrium," in *Integration of motor, circulatory, respiratory and metabolic control during exercise*. Section 12, eds J. Shepard, and L. Rowell (New York, NY: Handbook of Physiology; Oxford University Press), 1–39.

Horak, F. B., Wrisley, D. M., & Frank, J. (2009). The Balance Evaluation Systems Test (BESTest) to Differentiate Balance Deficits. *Physical Therapy*, *89*(5), 484–498. https://doi.org/10.2522/ptj.20080071

Horak, F., & Kuo, A. (2000). Postural Adaptation for Altered Environments, Tasks, and Intentions. *Biomechanics and Neural Control of Posture and Movement*, 267–281. https://doi.org/10.1007/978-1-4612-2104-3_19

Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Doré, J., Marceau, P., Marceau, S., Tremblay, A., & Teasdale, N. (2007). Body weight is a strong predictor of postural stability. *Gait & Posture*, *26*(1), 32–38. https://doi.org/10.1016/j.gaitpost.2006.07.005

Huegel, J. C., & O'Malley, M. K. (2010). Progressive haptic and visual guidance for training in a virtual dynamic task. *2010 IEEE Haptics Symposium*. https://doi.org/10.1109/haptic.2010.5444632

Huurnink, A., Fransz, D. P., Kingma, I., & van Dieën, J. H. (2013). Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. *Journal of Biomechanics*, *46*(7), 1392–1395. https://doi.org/10.1016/j.jbiomech.2013.02.018

Hytönen, M., Pyykkö, I., Aalto, H., & Starck, J. (1993). Postural Control and Age. *Acta Oto-Laryngologica*, *113*(2), 119–122. https://doi.org/10.3109/00016489309135778

Ivanenko, Y., & Gurfinkel, V. S. (2018). Human Postural Control. *Frontiers in Neuroscience*, *12*. https://doi.org/10.3389/fnins.2018.00171

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., & Cauraugh, J. H. (1997). Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport*, *68*(4), 269–279. https://doi.org/10.1080/02701367.1997.10608008

Janssen, L. J., Verhoeff, L. L., Horlings, C. G., & Allum, J. H. (2009). Directional effects of biofeedback on trunk sway during gait tasks in healthy young subjects. *Gait & Posture*, *29*(4), 575–581. https://doi.org/10.1016/j.gaitpost.2008.12.009

Jehu, D. A., Thibault, J., & Lajoie, Y. (2015). Magnifying the Scale of Visual Biofeedback Improves Posture. *Applied Psychophysiology and Biofeedback*, *41*(2), 151–155. https://doi.org/10.1007/s10484-015-9324-7

Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S. A., & Hudspeth, A. J. (2013). *Principles of Neural Science* (5th ed.). McGraw-Hill Education.

Karnath, H. O., Ferber, S., & Dichgans, J. (2000). The neural representation of postural control in humans. *Proceedings of the National Academy of Sciences*, *97*(25), 13931–13936. https://doi.org/10.1073/pnas.240279997

Karnath, H. O., Fetter, M., & Niemeier, M. (1998). Disentangling Gravitational, Environmental, and Egocentric Reference Frames in Spatial Neglect. *Journal of Cognitive Neuroscience*, *10*(6), 680–690. https://doi.org/10.1162/089892998563095

Keppel, G., & Wickens, T. D. (2004). *Design and analysis: A researcher's handbook*. Pearson Prentice Hall.

Lai, Q., & Shea, C. H. (1998). Generalized Motor Program (GMP) learning: Effects of reduced frequency of knowledge of results and practice variability. *Journal of Motor Behavior*, *30*(1), 51–59. https://doi.org/10.1080/00222899809601322

Lakhani, B., & Mansfield, A. (2015). Visual feedback of the centre of gravity to optimize standing balance. *Gait & Posture*, *41*(2), 499–503. https://doi.org/10.1016/j.gaitpost.2014.12.003

Lee, B. C., Martin, B. J., & Sienko, K. H. (2012). Directional postural responses induced by vibrotactile stimulations applied to the torso. *Experimental Brain Research*, *222*(4), 471–482. https://doi.org/10.1007/s00221-012-3233-2

Lee, B. C., Martin, B. J., Ho, A., & Sienko, K. H. (2013). Postural Reorganization Induced by Torso Cutaneous Covibration. *Journal of Neuroscience*, *33*(18), 7870–7876. https://doi.org/10.1523/jneurosci.4715-12.2013

Lee, D. N., & Young, D. S. (1986). Gearing action to the environment. *Generation and Modulation of Action Patterns*, 217–230. https://doi.org/10.1007/978-3-642-71476-4_16

Lee, T. D., & Carnahan, H. (1990). Bandwidth knowledge of results and motor learning: More than just a relative frequency effect. *The Quarterly Journal of Experimental Psychology Section A*, *42*(4), 777–789. https://doi.org/10.1080/14640749008401249

Liang, Y., Hiley, M., & Kanosue, K. (2019). The effect of contact sport expertise on postural control. *PLOS ONE*, *14*(2), e0212334. https://doi.org/10.1371/journal.pone.0212334

Lipsitz, L. A. (1992b). Loss of “complexity” and aging. Potential applications of fractals and chaos theory to senescence. *JAMA: The Journal of the American Medical Association*, *267*(13), 1806–1809. https://doi.org/10.1001/jama.267.13.1806

Lipsitz, L. A. (2002). Dynamics of Stability: The Physiologic Basis of Functional Health and Frailty. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *57*(3), B115–B125. https://doi.org/10.1093/gerona/57.3.b115

Liu, Y., Cao, C., & Yan, J. H. (2013). Functional aging impairs the role of feedback in motor learning. *Geriatrics & Gerontology International*, *13*(4), 849–859. https://doi.org/10.1111/ggi.12013

MacRae, P. G., Lacourse, M., & Moldavon, R. (1992). Physical Performance Measures That Predict Faller Status in Community-Dwelling Older Adults. *Journal of Orthopaedic & Sports Physical Therapy*, *16*(3), 123–128. https://doi.org/10.2519/jospt.1992.16.3.123

Magill, R. A. (1998). Knowledge is more than we can talk about: Implicit learning in motor skill acquisition. *Research Quarterly for Exercise and Sport*, *69*(2), 104–110. https://doi.org/10.1080/02701367.1998.10607676

Magill, R. A., & Wood, C. A. (1986). Knowledge of Results Precision as a Learning Variable in Motor Skill Acquisition. *Research Quarterly for Exercise and Sport*, *57*(2), 170–173. https://doi.org/10.1080/02701367.1986.10762195

Magill, R., & Anderson, D. (2017). *Motor Learning and Control: Concepts and Applications* (11th ed.). McGraw Hill.

Mak, M., & Horak, F. B. (2014). Balance training. In *Textbook of Neural Repair and Rehabilitation* (2nd ed., Vol. 2, pp. 105–119). Cambridge University Press.

Maki, B. E., Edmondstone, M. A., & McIlroy, W. E. (2000). Age-Related Differences in Laterally Directed Compensatory Stepping Behavior. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *55*(5), M270–M277. https://doi.org/10.1093/gerona/55.5.m270

Maki, B. E., Holliday, P. J., & Fernie, G. R. (1990). Aging and Postural Control. *Journal of the American Geriatrics Society*, *38*(1), 1–9. https://doi.org/10.1111/j.1532-5415.1990.tb01588.x

Mancini, M., Salarian, A., Carlson-Kuhta, P., Zampieri, C., King, L., Chiari, L., & Horak, F. B. (2012). ISway: A sensitive, valid and reliable measure of postural control. *Journal of NeuroEngineering and Rehabilitation*, *9*(1), 59. https://doi.org/10.1186/1743-0003-9-59

Marco-Ahulló, A., Sánchez-Tormo, A., García-Pérez, J. A., Villarrasa-Sapiña, I., González, L. M., & García-Massó, X. (2018). Effect of Concurrent Visual Feedback Frequency on Postural Control Learning in Adolescents. *Journal of Motor Behavior*, *51*(2), 193–198. https://doi.org/10.1080/00222895.2018.1454397

Marschall, F., Bund, A., & Wiemeyer, J. (2007). Does frequent augmented feedback really degrade learning? A meta-analysis. Retrieved 2007, from https://www.sportwissenschaft.de/fileadmin/pdf/BuT/marschall.pdf.

Massion, J. (1994). Postural control system. *Current Opinion in Neurobiology*, *4*(6), 877–887. https://doi.org/10.1016/0959-4388(94)90137-6

Maurer, C., & Peterka, R. J. (2005). A New Interpretation of Spontaneous Sway Measures Based on a Simple Model of Human Postural Control. *Journal of Neurophysiology*, *93*(1), 189–200. https://doi.org/10.1152/jn.00221.2004

Meng, H., O'Connor, D. P., Lee, B. C., Layne, C. S., & Gorniak, S. L. (2016). Effects of adiposity on postural control and cognition. Gait & Posture, 43, 31–37. https://doi.org/10.1016/j.gaitpost.2015.10.012

McCollum, G., & Leen, T. K. (1989). Form and Exploration of Mechanical Stability Limits in Erect Stance. *Journal of Motor Behavior*, *21*(3), 225–244. https://doi.org/10.1080/00222895.1989.10735479

McMorris, T. (2004). *Acquisition and performance of sports skills*. Wiley.

Merletti, R., & Parker, P. J. (2004). *Electromyography: Physiology, Engineering, and Non-Invasive Applications* (1st ed.). NJ, USA: Wiley-IEEE Press.

Mochizuki, L., Duarte, M., Amadio, A. C., Zatsiorsky, V. M., & Latash, M. L. (2006). Changes in Postural Sway and Its Fractions in Conditions of Postural Instability. *Journal of Applied Biomechanics*, *22*(1), 51–60. https://doi.org/10.1123/jab.22.1.51

Moinuddin, A., Goel, A., & Sethi, Y. (2021). The role of augmented feedback on motor learning: A systematic review. *Cureus*. https://doi.org/10.7759/cureus.19695

Morris, D., Tan, H., Barbagli, F., Chang, T., & Salisbury, K. (2007). Haptic feedback enhances force skill learning. *Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07)*. https://doi.org/10.1109/whc.2007.65

Muehlbauer, T., Roth, R., Bopp, M., & Granacher, U. (2012). An exercise sequence for progression in balance training. *Journal of Strength and Conditioning Research*, *26*(2), 568–574. https://doi.org/10.1519/jsc.0b013e318225f3c4

Nakamura, H., Tsuchida, T., & Mano, Y. (2001). The assessment of posture control in the elderly using the displacement of the center of pressure after forward platform translation. *Journal of Electromyography and Kinesiology*, *11*(6), 395–403. https://doi.org/10.1016/s1050-6411(01)00016-5

Oullier, O., Bardy, B. G., Stoffregen, T. A., & Bootsma, R. J. (2002). Postural coordination in looking and tracking tasks. *Human Movement Science*, *21*(2), 147–167. https://doi.org/10.1016/s0167-9457(02)00093-3

Paillard, T., & Noé, F. (2015). Techniques and Methods for Testing the Postural Function in Healthy and Pathological Subjects. *BioMed Research International*, *2015*, 1–15. https://doi.org/10.1155/2015/891390

Palazzo, F., Nardi, A., Lamouchideli, N., Caronti, A., Alashram, A., Padua, E., & Annino, G. (2021). The effect of age, sex and a firm-textured surface on postural control. *Experimental Brain Research*, *239*(7), 2181–2191. https://doi.org/10.1007/s00221-021-06063-2

Panjan, A., & Sarabon, N. (2010). Review of Methods for the Evaluation of Human Body Balance. *Sport Science Review*, *19*(5–6). https://doi.org/10.2478/v10237-011-0036-5

Park, J. H., Kang, Y. J., & Horak, F. B. (2015). What Is Wrong with Balance in Parkinson's Disease? *Journal of Movement Disorders*, *8*(3), 109–114. https://doi.org/10.14802/jmd.15018

Park, J. H., Shea, C. H., & Wright, D. L. (2000). Reduced-Frequency Concurrent and Terminal Feedback: A Test of the Guidance Hypothesis. *Journal of Motor Behavior*, *32*(3), 287–296. https://doi.org/10.1080/00222890009601379

Patton, J. L., Wei, Y. J., Bajaj, P., & Scheidt, R. A. (2013). Visuomotor Learning Enhanced by Augmenting Instantaneous Trajectory Error Feedback during Reaching. *PLoS ONE*, *8*(1), e46466. https://doi.org/10.1371/journal.pone.0046466

Pavol, M. J. (2005). Detecting and understanding differences in postural sway. focus on "a new interpretation of spontaneous sway measures based on a simple model of human postural control." *Journal of Neurophysiology*, *93*(1), 20–21. https://doi.org/10.1152/jn.00864.2004

Peterka, R. J. (2002). Sensorimotor Integration in Human Postural Control. *Journal of Neurophysiology*, *88*(3), 1097–1118. https://doi.org/10.1152/jn.2002.88.3.1097

Pincus, S. M. (1991). Approximate entropy as a measure of system complexity. *Proceedings of the National Academy of Sciences*, *88*(6), 2297–2301. https://doi.org/10.1073/pnas.88.6.2297

Pincus, S. M. (1995). Quantifying complexity and regularity of neurobiological systems. *Methods in Neurosciences*, 336–363. https://doi.org/10.1016/s1043-9471(06)80040-6

Pincus, S. M., Gladstone, I. M., & Ehrenkranz, R. A. (1991). A regularity statistic for medical data analysis. *Journal of Clinical Monitoring*, *7*(4), 335–345. https://doi.org/10.1007/bf01619355

Pinsault, N., & Vuillerme, N. (2009). Test–retest reliability of centre of foot pressure measures to assess postural control during unperturbed stance. *Medical Engineering & Physics*, *31*(2), 276–286. https://doi.org/10.1016/j.medengphy.2008.08.003

Platz, T., Winter, T., Müller, N., Pinkowski, C., Eickhof, C., & Mauritz, K.-H. (2001). Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: A single-blind, randomized, controlled trial. *Archives of Physical Medicine and Rehabilitation*, *82*(7), 961–968. https://doi.org/10.1053/apmr.2001.23982

Podsiadlo, D., & Richardson, S. (1991). The Timed "Up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons. *Journal of the American Geriatrics Society*, *39*(2), 142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x

Pollock, A. S., Durward, B. R., Rowe, P. J., & Paul, J. P. (2000). What is balance? *Clinical Rehabilitation*, *14*(4), 402–406. https://doi.org/10.1191/0269215500cr342oa

Prieto, T., Myklebust, J., Hoffmann, R., Lovett, E., & Myklebust, B. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Transactions on Biomedical Engineering*, *43*(9), 956–966. https://doi.org/10.1109/10.532130

Prince, F., Corriveau, H., Hébert, R., & Winter, D. A. (1997). Gait in the elderly. *Gait & Posture*, *5*(2), 128–135. https://doi.org/10.1016/s0966-6362(97)01118-1

Quijoux, F., Nicolaï, A., Chairi, I., Bargiotas, I., Ricard, D., Yelnik, A., Oudre, L., Bertin-Hugault, F., Vidal, P., Vayatis, N., Buffat, S., & Audiffren, J. (2021). A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code*. *Physiological Reports*, *9*(22). https://doi.org/10.14814/phy2.15067

Ramdani, S., Seigle, B., Lagarde, J., Bouchara, F., & Bernard, P. L. (2009). On the use of sample entropy to analyze human postural sway data. *Medical Engineering & Physics*, *31*(8), 1023–1031. https://doi.org/10.1016/j.medengphy.2009.06.004

Reeve, T. G., Dornier, L. A., & Weeks, D. J. (1990). Precision of Knowledge of Results: Consideration of the Accuracy Requirements Imposed by the Task. *Research Quarterly for Exercise and Sport*, *61*(3), 284–290. https://doi.org/10.1080/02701367.1990.10608693

Riccio, G.E. (1993). Information in movement variability about the qualitative dynamics of posture and orientation. In K.M. Newell & D.M. Corcos (Eds.), *Variability and motor control* (pp. 317-358). Champaign, IL: Human Kinetics.

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology-Heart and Circulatory Physiology*, *278*(6), H2039–H2049. https://doi.org/10.1152/ajpheart.2000.278.6.h2039

Rosso, A. L., Cenciarini, M., Sparto, P. J., Loughlin, P. J., Furman, J. M., & Huppert, T. J. (2017). Neuroimaging of an attention demanding dual-task during dynamic postural control. *Gait & Posture*, *57*, 193–198. https://doi.org/10.1016/j.gaitpost.2017.06.013

Rougier, P., Farenc, I., & Berger, L. (2004). Modifying the gain of the visual feedback affects undisturbed upright stance control. *Clinical Biomechanics*, *19*(8), 858–867. https://doi.org/10.1016/j.clinbiomech.2004.04.013

Ruhe, A., Fejer, R., & Walker, B. (2010). The test–retest reliability of center of pressure measures in bipedal static task conditions – a systematic review of the literature. *Gait & Posture*, *32*(4), 436–445. https://doi.org/10.1016/j.gaitpost.2010.09.012

Saito, H., Yamanaka, M., Kasahara, S., & Fukushima, J. (2014). Relationship between improvements in motor performance and changes in anticipatory postural adjustments during whole-body reaching training. *Human Movement Science*, *37*, 69–86. https://doi.org/10.1016/j.humov.2014.07.001

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, *95*(3), 355–386. https://doi.org/10.1037/0033-2909.95.3.355

Santos, M. J., Kanekar, N., & Aruin, A. S. (2010). The role of anticipatory postural adjustments in compensatory control of posture: 2. Biomechanical analysis. *Journal of Electromyography and Kinesiology*, *20*(3), 398–405. https://doi.org/10.1016/j.jelekin.2010.01.002

Sasagawa, S., Ushiyama, J., Kouzaki, M., & Kanehisa, H. (2009). Effect of the hip motion on the body kinematics in the sagittal plane during human quiet standing. *Neuroscience Letters*, *450*(1), 27–31. https://doi.org/10.1016/j.neulet.2008.11.027

Schmidt, R. A. (1991). Frequent augmented feedback can degrade learning: Evidence and interpretations. *Tutorials in Motor Neuroscience*, 59–75. https://doi.org/10.1007/978-94-011-3626-6_6

Schmidt, R. A., & Lee, T. D. (2011). *Motor control and learning a behavioral emphasis* (5th ed.). Human Kinetics.

Schmidt, R. A., & Lee, T. D. (2014). *Motor learning and performance: From principles to application*. Human Kinetics.

Schmidt, R. A., & Wrisberg, C. A. (2004). *Motor learning and performance: A problem-based learning approach*. Human Kinetics.

Schmidt, R. A., & Wrisberg, C. A. (2008). *Motor learning and performance: A situation-based learning approach*. Human Kinetics.

Schmidt, R. A., & Wulf, G. (1997). Continuous Concurrent Feedback Degrades Skill Learning: Implications for Training and Simulation. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *39*(4), 509–525. https://doi.org/10.1518/001872097778667979

Schmidt, R. A., Young, D. E., Swinnen, S., & Shapiro, D. C. (1989). Summary knowledge of results for skill acquisition: Support for the guidance hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(2), 352–359. https://doi.org/10.1037/0278-7393.15.2.352

Schubert, P., & Kirchner, M. (2014). Ellipse area calculations and their applicability in posturography. *Gait & Posture*, *39*(1), 518–522. https://doi.org/10.1016/j.gaitpost.2013.09.001

Seigle, B., Ramdani, S., & Bernard, P. L. (2009). Dynamical structure of center of pressure fluctuations in elderly people. *Gait & Posture*, *30*(2), 223–226. https://doi.org/10.1016/j.gaitpost.2009.05.005

Shafizadeh, M., Parvinpour, S., Balali, M., & Shabani, M. (2020). Effects of age and task difficulty on postural sway, variability and complexity. *Adaptive Behavior*, *29*(6), 617–625. https://doi.org/10.1177/1059712320963974

Sharma, D. A., Chevidikunnan, M. F., Khan, F. R., & Gaowgzeh, R. A. (2016). Effectiveness of knowledge of result and knowledge of performance in the learning of a skilled motor activity by healthy young adults. *Journal of Physical Therapy Science*, *28*(5), 1482–1486. https://doi.org/10.1589/jpts.28.1482

Shea, C. H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science*, *18*(4), 553–571. https://doi.org/10.1016/s0167-9457(99)00031-7

Sherrington, C. S. (1906). *The Integrative Action of the Nervous System*. Amsterdam University Press.

Shumway-Cook, A. & Woollacott, M. H. (1995). *Motor Control: Theory and Practical Applications* (2nd ed.). Williams & Wilkins.

Shumway-Cook, A., & Woollacott, M. H. (2017). *Motor control: Translating research into clinical practice*. (5th ed.) Philadelphia: Wolters Kluwer.

Sienko, K. H., Seidler, R. D., Carender, W. J., Goodworth, A. D., Whitney, S. L., & Peterka, R. J. (2018). Potential Mechanisms of Sensory Augmentation Systems on Human Balance Control. *Frontiers in Neurology*, *9*. https://doi.org/10.3389/fneur.2018.00944

Sienko, K., Whitney, S., Carender, W., & Wall, C. (2017). The role of sensory augmentation for people with vestibular deficits: Real-time balance aid and/or rehabilitation device? *Journal of Vestibular Research*, *27*(1), 63–76. https://doi.org/10.3233/ves-170606

Sigrist, R. (2011). Visual and auditory augmented concurrent feedback in a complex motor task. *Presence: Teleoperators and Virtual Environments*, *20*(1), 15–32. https://doi.org/10.1162/pres_a_00032

Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2012). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review*, *20*(1), 21–53. https://doi.org/10.3758/s13423-012-0333-8

Singh, N. B., Taylor, W. R., Madigan, M. L., & Nussbaum, M. A. (2012). The spectral content of postural sway during quiet stance: Influences of age, vision and somatosensory inputs. *Journal of Electromyography and Kinesiology*, *22*(1), 131–136. https://doi.org/10.1016/j.jelekin.2011.10.007

Snodgrass, S. J., Rivett, D. A., Robertson, V. J., & Stojanovski, E. (2010). Real-time feedback improves accuracy of manually applied forces during cervical spine mobilisation. *Manual Therapy*, *15*(1), 19–25. https://doi.org/10.1016/j.math.2009.05.011

Social Sciences. (1967). *Human Memory: A Proposed System and Its Control Processes*. Institute for Mathematical Studies in Social Sciences.

Sparrow, W. A., & Summers, J. J. (1992). Performance on trials without knowledge of results (KR) in reduced relative frequency presentations of KR. *Journal of Motor Behavior*, *24*(2), 197–209. https://doi.org/10.1080/00222895.1992.9941615

Stanford University. Institute for Mathematical Studies in the Social Sciences, Atkinson, R. C., Shiffrin, R. M., & Stanford University. Institute for Mathematical Studies in the Social Sciences

Sundstrup, E., Jakobsen, M. D., Andersen, J. L., Randers, M. B., Petersen, J., Suetta, C., Aagaard, P., & Krustrup, P. (2010). Muscle function and postural balance in lifelong trained male footballers compared with sedentary elderly men and youngsters. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 90–97. https://doi.org/10.1111/j.1600-0838.2010.01092.x

Thorndike, E. L. (1898). Animal Intelligence: An experimental study of the associative processes in animals. https://doi.org/10.1037/10780-000

Thorndike, E. L. (1927). The Law of Effect. *The American Journal of Psychology*, *39*(1/4), 212. https://doi.org/10.2307/1415413

Thorndike, E. L. (1931). *Human learning*. New York: Century.

Tinetti, M. E., Baker, D. I., McAvay, G., Claus, E. B., Garrett, P., Gottschalk, M., Koch, M. L., Trainor, K., & Horwitz, R. I. (1994). A Multifactorial Intervention to Reduce the Risk of Falling among Elderly People Living in the Community. *New England Journal of Medicine*, *331*(13), 821–827. https://doi.org/10.1056/nejm199409293311301

Vaillancourt, D. E., & Newell, K. M. (2002). Changing complexity in human behavior and physiology through aging and disease. *Neurobiology of Aging*, *23*(1), 1–11. https://doi.org/10.1016/s0197-4580(01)00247-0

Van Dijk, H., Jannink, M., & Hermens, H. (2005). Effect of augmented feedback on motor function of the affected upper extremity in rehabilitation patients: A systematic review of randomized controlled trials. *Journal of Rehabilitation Medicine*, *37*(4), 202–211. https://doi.org/10.1080/16501970510030165

Van Wegen, E., Van Emmerik, R., & Riccio, G. (2002). Postural orientation: Age-related changes in variability and time-to-boundary. *Human Movement Science*, *21*(1), 61–84. https://doi.org/10.1016/s0167-9457(02)00077-5

Vander Linden, D. W., Cauraugh, J. H., & Greene, T. A. (1993). The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Physical Therapy*, *73*(2), 79–87. https://doi.org/10.1093/ptj/73.2.79

Vellas, B. J., Wayne, S. J., Romero, L., Baumgartner, R. N., Rubenstein, L. Z., & Garry, P. J. (1997). One-Leg Balance Is an Important Predictor of Injurious Falls in Older Persons. *Journal of the American Geriatrics Society*, *45*(6), 735–738. https://doi.org/10.1111/j.1532-5415.1997.tb01479.x

Verschueren, S. M., Swinnen, S. P., Dom, R., & De Weerdt, W. (1997). Interlimb coordination in patients with parkinson's disease: Motor learning deficits and the importance of augmented information feedback. *Experimental Brain Research*, *113*(3), 497–508. https://doi.org/10.1007/pl00005602

Weeks, D. L., & Kordus, R. N. (1998). Relative frequency of knowledge of performance and Motor Skill Learning. *Research Quarterly for Exercise and Sport*, *69*(3), 224–230. https://doi.org/10.1080/02701367.1998.10607689

Winstein, C. J. (1991). Knowledge of results and motor learning—implications for physical therapy. *Physical Therapy*, *71*(2), 140–149. https://doi.org/10.1093/ptj/71.2.140

Winstein, C. J., & Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(4), 677–691. https://doi.org/10.1037/0278-7393.16.4.677

Winstein, C. J., Pohl, P. S., Cardinale, C., Green, A., Scholtz, L., & Waters, C. S. (1996). Learning a partial-weight-bearing skill: Effectiveness of two forms of feedback. *Physical Therapy*, *76*(9), 985–993. https://doi.org/10.1093/ptj/76.9.985

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture*, *3*(4), 193–214. https://doi.org/10.1016/0966-6362(96)82849-9

Winter, D. A., MacKinnon, C. D., Ruder, G. K., & Wieman, C. (1993). Chapter 32 an integrated EMG/biomechanical model of upper body balance and posture during human gait. *Natural and Artificial Control of Hearing and Balance*, 359–367. https://doi.org/10.1016/s0079-6123(08)62295-5

Winter, D. A., Prince, F., Frank, J. S., Powell, C., & Zabjek, K. F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology*, *75*(6), 2334–2343. https://doi.org/10.1152/jn.1996.75.6.2334

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport and Exercise Psychology*, *6*(1), 77–104. https://doi.org/10.1080/1750984x.2012.723728

Wulf, G., & Lewthwaite, R. (2010). Effortless Motor Learning? An external focus of attention enhances movement effectiveness and efficiency. *Effortless Attention*. https://doi.org/10.7551/mitpress/8602.003.0004

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The optimal theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review*, *9*(2), 185–211. https://doi.org/10.3758/bf03196276

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review*, *9*(2), 185–211. https://doi.org/10.3758/bf03196276

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology Section A*, *54*(4), 1143–1154. https://doi.org/10.1080/713756012

Wulf, G., Shea, C. H., & Matschiner, S. (1998). Frequent feedback enhances complex motor skill learning. *Journal of Motor Behavior*, *30*(2), 180–192. https://doi.org/10.1080/00222899809601335

Wulf, G., Shea, C., & Park, J. H. (2001). Attention and Motor Performance: Preferences for and Advantages of an External Focus. *Research Quarterly for Exercise and Sport*, *72*(4), 335–344. https://doi.org/10.1080/02701367.2001.10608970

Zhu, B., & Kaber, D. (2012). A review of sensory feedback and skill learning for rehabilitation. *Advances in Human Aspects of Healthcare*, 665–674. https://doi.org/10.1201/b12318-82

Zhu, B., Kaber, D., Zahabi, M., & Ma, W. (2020). Effects of feedback type and modality on motor skill learning and retention. *Behaviour & Information Technology*, *39*(4), 431–442. https://doi.org/10.1080/0144929x.2019.1599068

APPENDICES

A: APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

DUMLUPINAR BULVARI 06800
ÇANKAYA ANKARA/TURKEY
T: +90 312 210 22 91
F: +90 312 210 79 59
ueam@metu.edu.tr
www.ueam.metu.edu.tr

Sayı: 28620816 /

15 ŞUBAT 2022

Konu : Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi : İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Doç. Dr. Sadettin KİRAZCI

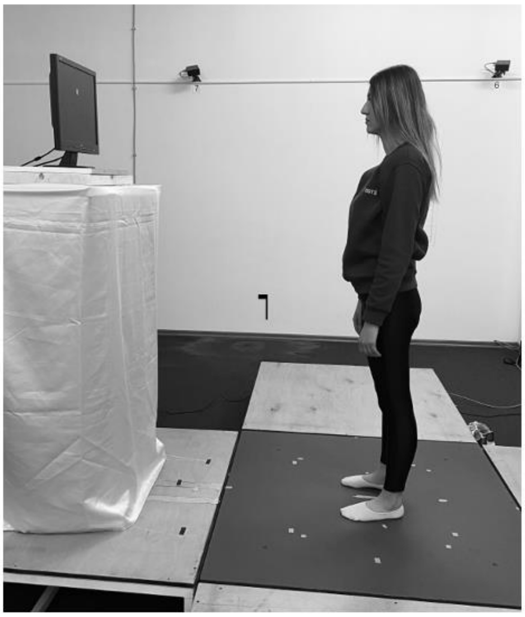
Danışmanlığını yürüttüğünüz Seda TAŞCI'nın "Hareket Sırasında Verilen Geribildirim ve Postüral Görev Karmaşıklığının Postür Kontrolü Üzerindeki Etkisi "başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **0116 ODTUİAEK-2022** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

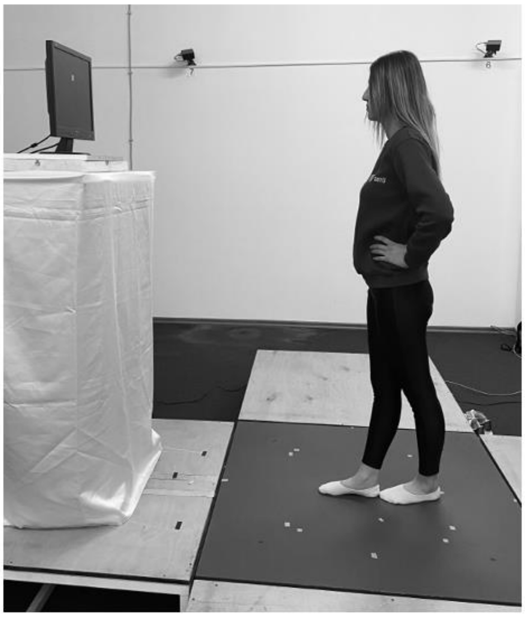
Prof.Dr. Mine MISIRLISOY
İAEK Başkan

B: ILLUSTRATION OF POSTURAL STANCES

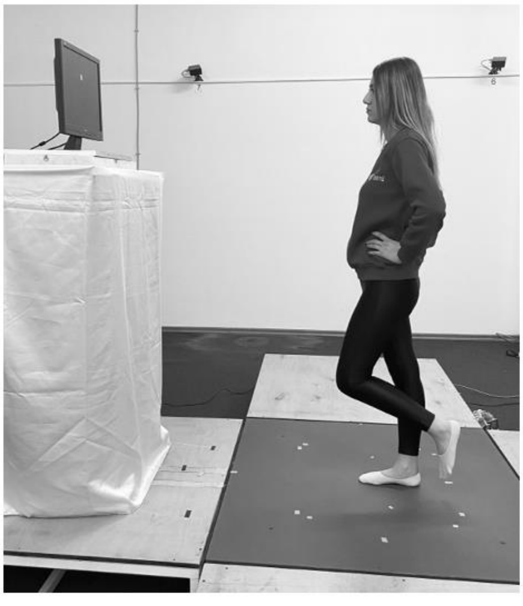
Below is the illustration of postural tasks with six different difficulties.



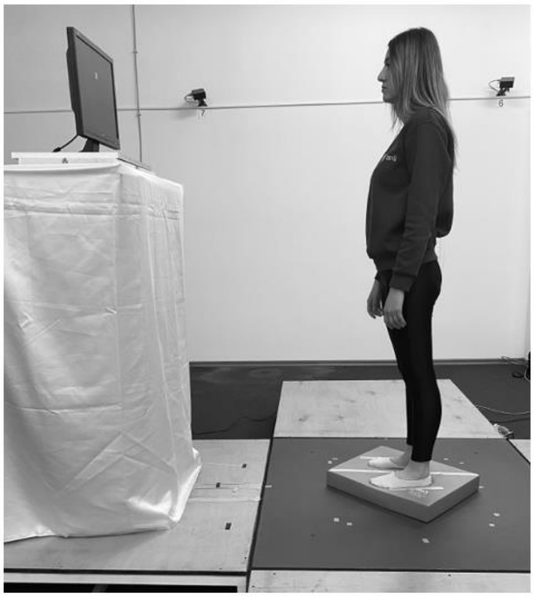
Quiet Stance (QS)



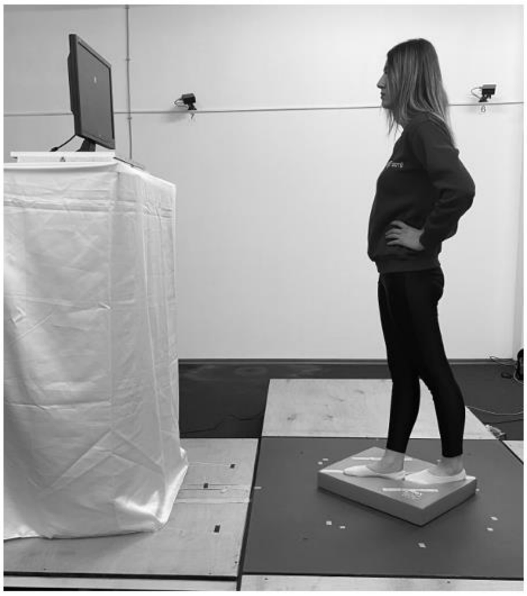
Tandem Stance (TS)



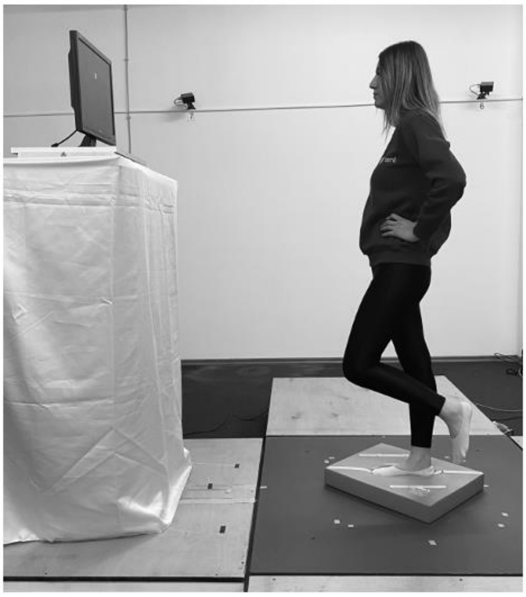
Single Stance (SS)



Quiet Stance on Balance Pad (PQS)



Tandem Stance on Balance Pad (PTS)



Single Stance on Balance Pad (PSS)

C: BODY MASS INDEX OF SUBJECTS

Body mass index of participants were shown in the following table

	Control Group	Experimental Group
Participants	**BMI (kg/m^2)**	**BMI (kg/m^2)**
1	25.8	32.8
2	23.2	24.2
3	18.6	37.5
4	23.4	26.3
5	28.2	22.4
6	18.6	19.8
7	21.7	22.8
8	24.2	19.6
9	23.7	22.6
10	36.2	30.7
11	31.0	22.1
12	26.0	17.8
13	20.6	21.6
14	27.0	21.5
15	18.9	18.0
16	18.5	22.1
17	23.4	25.7
18	25.0	35.0
19	24.9	23.9
20	20.9	18.6
Mean	24.0	24.3
SD	4.44	5.61

D: TURKISH SUMMARY / TÜRKÇE ÖZET

EŞ ZAMANLI GERİBİLDİRİM VE POSTÜRAL GÖREV ZORLUĞUNUN POSTÜR KONTROLÜNE ETKİSİ

GİRİŞ

İnsanlar gelişmiş hareket kabiliyetleri sayesinde yeryüzünde yaşamın var olduğu günden bu yana başarılı bir şekilde varlıklarını sürdürebilmişlerdir. Doğuştan gelen duyusal ve motor süreçler tarafından kontrol edilen bir yetenek olan duruş kontrolü, zaman içinde gelişmiş ve insanların karmaşık hareketler gerçekleştirmelerini sağlamıştır. Bireylerin tüm bu hareketleri gerçekleştirmek ve duruşlarını kontrol etmek için kaynak olarak kullanabilecekleri bazı bilgilere ihtiyaçları vardır. Bu bilgilerden önemli bir tanesi kişilere hareketleriyle ilişkili olarak verilen geribildirimdir. Yeni bir beceri öğrenirken veya öğrenilen bir beceriyi geliştirirken, istenen sonuçların elde edilmesinde geribildirim önemli bir rol oynar. Schmidt ve Lee (2011) geribildirimi "Öğrencinin gelecekteki düzeltmeleri yapmak için kullanabileceği performansı veya hataları hakkında bilgi" olarak tanımlamaktadır (s. 256). Benzer şekilde Magill ve Anderson (2017) geribildirimi bir beceriyi gerçekleştirirken veya tamamlandıktan sonra alınan bilgilerle ilgili genel bir terim olarak tanımlamaktadır. Literatürde geribildirim iki ana türe ayrılır: içsel geribildirim ve dışsal geribildirim. Bireyler her zaman mevcut olan duyu organlarından bilgi edindiğinde buna içsel geribildirim denir. Ayrıca içsel geribildirim beden duyumu (proprioseptif) geribildirim ve dıştan gelen geribildirim olarak iki kategoriye ayrılır. Bireyin kas iğciklerinde, eklem reseptörlerinde, golgi tendon organlarında ve vestibüler aparatta bulunan reseptörler tarafından sağlanan duyusal bilgilere proprioseptif geribildirim denir. Öte yandan, dıştan gelen geribildirim, görsel, işitsel ve dokunsal duyular gibi dış çevreden gelen diğer duyuları içerir. Bireylere öğretmen, koç, terapist veya belirli cihazlar tarafından dışarıdan bilgi verildiğinde ise buna dışsal geribildirim, bazen artırılmış geribildirim adı verilir.

Artırılmış geribildirim bireylerin kendi duyularına ek destek görevi gören ve kendisi tarafından elde edilemeyen dışardan gelen bir kaynaktır ve bu nedenle bir ekran veya bir eğitmen tarafından sağlanabilir (Schmidt & Wrisberg, 2008). Arttırılmış geribildirim, gerçekleştirilen bir görevin amacına ulaşmasını kolaylaştırır ve öğrenenleri buna yönelmeye teşvik eder (Van Dijk & diğerleri, 2005). Motor öğrenme ortamında, artırılmış geribildirim sunmak, öğrenenlerin öğrenmelerini desteklemek için gerekli olan bilgilendirici (Schmidt & Lee, 2014), motivasyonel (Wulf & Lewthwaite, 2016), pekiştirici (Coker, 2017) ve rehberlik edici (Adams, 1987) işlevlerle hizmet eder. Geribildirim, görevlerin motor ve diğer özelliklerine bağlı olarak farklı yöntemlerle çeşitli şekillerde verilebilir (Sigrist & diğerleri, 2012). Görsel sistem, dış dünya ile etkileşim sırasında insan vücudunun en önemli sistemlerinden biri olarak kabul edilebilir ve bu önemi nedeniyle geribildirim çalışmalarında görsel sisteme hitap eden yöntemler yaygın olarak kullanılmaktadır. Geribildirimin göz önünde bulundurulması gereken diğer özelliği ise kişilere ne zaman verildiğidir. Bu bağlamda geribildirim ikiye ayrılır; eş zamanlı geribildirim (motor becerilerin yürütülmesi sırasında verilen bilgi) ve terminal geribildirim (bir motor becerinin tamamlanmasından sonra verilen bilgi). Eş zamanlı ve terminal geribildirimi araştıran çalışmalar, aynı anda eş zamanlı geribildirim ve terminal geribildirim alan katılımcıların, yalnızca terminal geribildirim alan katılımcılara kıyasla daha fazla olumlu etki elde ettiğini bulmuştur (Vander Linden ve diğerleri, 1993; Winstein ve diğerleri, 1996; Schmidt ve Wulf, 1997). Aynı zamanda, eş zamanlı geribildirimin performans sırasında olumlu etkileri olduğu ve daha iyi hata düzeltmesi ile sonuçlandığı gösterilmiştir. Bununla birlikte, bu çalışmalar geribildirim sağlamadan yapılan kalıcılık testlerinde (dışsal geribildirim verilmeden gerçekleştirilen performans) tam tersi sonuçlar vermiştir.

Davranışta kalıcı bir değişiklik elde etmek açısından, geribildirim sıklığını değiştirmenin öğrenme üzerinde çeşitli etkileri olduğu düşünülmektedir. Bu konuyu açıklığa kavuşturmak için Bilodeau ve ark. (1959), geribildirim sağlanmadığında herhangi bir gelişme veya azalma gözlemlenmezken, geribildirim sağlanmasıyla aşamalı bir gelişme olduğunu bulmuştur. Öğrenmenin gerçekleşip gerçekleşmediğini belirlemek için öğrenciler, kalıcılık testlerinde herhangi bir geribildirim almadan performanslarını gerçekleştirirler. Bazı testlerin sonuçları, geribildirimin bilgisel özelliğinin, çok fazla verildiğinde motor beceri öğrenimi üzerinde zararlı olabileceğini göstermektedir. Salmoni ve ark. (1984) ve Schmith (1991) bu durumu bir rehberlik hipotezine atıfta bulunarak açıklamaktadır. Bu hipotez, beceri öğreniminin kazanım aşamasında sıklıkla geribildirim almanın bu bilgiye bağımlılık yarattığını ve sonuç olarak geribildirim verilmediğinde performansın düştüğünü belirtmektedir. Öğrenenlerin yaşına (Liu vd., 2013), öğrenenlerin beceri düzeyine (Guadagnoli & Lee, 2004) ve görevin özelliklerine (Guadagnoli & Lee, 2004) göre farklı geribildirim koşullarının kullanılması öğrenme için esastır. Özellikle, eş zamanlı geribildirimin etkinliği, artıları/eksileri ve geribildirim frekansları çeşitli zorluklara sahip görevlerle test edilmiştir. Basit motor görevlerin kullanıldığı bazı araştırmalar, farklı geribildirim frekanslarının sonuçlarının genellikle benzer olduğunu göstermiştir (Dunham & Mueller, 1993; Lai & Shea, 1998). Diğer bazı çalışmalar, deneme sayısını değiştirmeden göreceli frekansı değiştirerek geribildirim sıklığını azaltmanın, %100 geribildirim sıklığı sağlamaktan daha uygun olduğunu göstermiştir (Winstein & Schmidt, 1990; Sparrow & Summers, 1992). Ayrıca bir beceriyi öğrenirken sık dönüt verilmesinin zararlı etkileri de bazı araştırmalarla desteklenmektedir (Weeks & Kordus, 1998; Winstein ve Schmidt, 1990). Bu çalışmaların sonuçlarının aksine, Shea & Wulf (1999) karmaşık postüral kontrol görevlerini öğrenirken eş zamanlı geribildirim sağlamanın faydalı bir yöntem olduğunu bulmuşlardır. Geribildirimle ilgili daha sonraki çalışmalardan bazıları, basit motor becerilere geribildirim sağlama ilkelerinin karmaşık motor becerilere genelleştirilemeyeceğini de göstermiştir (Wulf & Shea, 2002; Guadagnoli & Lee, 2004). Bu nedenle, motor beceri kazanımını geliştirmek için uygun geribildirim sıklığının seçilmesi tartışmalıdır ve özellikle postür kontrolüne odaklanan motor görevlerin farklı zorluklarında daha fazla çalışmaya ihtiyaç duyulmaktadır.

Postüral kontrol, bir insanın günlük yaşam aktivitelerinin normal işleyişini sürdürmesi için en önemli belirleyicilerden biridir. Postür kontrolü sadece günlük yaşam aktiviteleri için değil, bu yeteneklerini üst düzeyde kullanan profesyonel sporcular veya yaşa bağlı problemler, fiziksel ve duyusal sistem eksiklikleri gibi sebeplerle postür kontrolünü tam sağlayamayan kişiler için de bir o kadar önemli olduğunu söyleyebiliriz. Postüral kontrolü netleştirebilmemiz için tanımını, etkileyen faktörleri, çalışma mekanizmasını ve ölçüm yöntemlerini anlamamız gerekmektedir. Postüral kontrol, merkezi sinir sisteminin (MSS), kasların aktivasyonu ile uygun motor çıktı ve kontrollü dik duruş üretmek için vücudumuzun pozisyonu hakkında somatosensoriyel, vestibüler ve görsel girdilerden gelen duyusal bilgileri düzenleme şekli olarak tanımlanabilir. Postüral oryantasyon ve postüral denge, insan postür kontrolünün iki ana işlevsel amacıdır (Horak, 2006). Vücudun kütle merkezi (CoM) destek tabanı (BoS) içinde korunduğunda denge sağlanır. Diğer yandan, insan duruş kontrol ve hareketini ölçmek için kullanılan vücudun atalet fonksiyonlarına herhangi bir dış etki olmadığında toplam vücut kütlesinin toplandığı bir nokta (CoG) (Benda & ark., 1994) ve vücut üzerindeki dikey kuvvet dağılımının merkezinin yerdeki izdüşümünü gösteren CoP (Benda ve diğerleri, 1994) önemli parametrelerdendir.

Statik denge görevleri, uygun eğitim programları ile postüral kontrolün değerlendirilmesi ve iyileştirilmesi için iyi bir belirleyici olabilir (Donath & ark., 2016). Ancak postüral kontrolün belirlenmesi için statik denge görevleri (sakin duruş) kullanılsa bile (Clifford ve Holder-Powell, 2010), insan postüral kontrol sistemi için tek başına büyük bir zorluk oluşturmayabileceği belirtilmektedir. Bu nedenle, Amerikan Spor Hekimliği Koleji statik denge görevlerini daha zorlu görevlere dönüştürmek için bazı varyasyonlar önermektedir; bunlar destek tabanını değiştirmek (çift bacak duruşu, tandem duruşu, tek bacak duruşu vb.) ve duyusal girdiyi değiştirmek için çevresel bilgileri manipüle etmektir (sert veya köpük yüzeyde ayakta durma, gözler açık veya kapalı ayakta durma ve baş pozisyonunu değiştirme vb.) (Chodzko-Zajko ve ark., 2009). Genel olarak, postüral kontrol çalışmalarında görev zorluğu geribildirim, dikkat veya ikili görev gibi diğer bazı faktörlerle birleştirilir. Bu çalışmaların bazılarında görsel geribildirim gibi bazı yöntemlerin postüral kontrolü iyileştirdiği bildirilmiştir (Cawsey ve diğerleri, 2009; Rougier ve diğerleri, 2004). Geribildirim sıklığı, motor öğrenme ve kontrol çalışmaları özelde postür kontrolü açısından da önemli bir değişkendir. Basit motor görevler üzerinde sık geribildirim kullanan bazı araştırmalar, sık geribildirimin kalıcılık testleriyle değerlendirildiğinde öğrenme için yararlı olmadığı sonucuna varmıştır (Winstein ve Schmidt, 1990). Öte yandan, Shea ve Wulf (1999), karmaşık postüral kontrol görevlerini öğrenirken eş zamanlı geribildirim sağlamanın faydalı bir yöntem olduğunu iddia etti. Ancak, geribildirim sıklığı ve postüral kontrol görevi zorluğu ile ilgili araştırmalar nispeten sınırlı kalmıştır bu nedenle kişilere etkili geribildirim sağlamak amacıyla bu iki faktör dikkatli bir şekilde araştırılmalı ve düzenlenmelidir. Bu nedenlerle bu çalışmanın önemi, eş zamanlı görsel geribildirimin çeşitli zorluklara sahip postür görevleri üzerindeki etkisini anlamaktır.

LİTERATÜR TARAMASI

Geribildirim

Geribildirim, insanlar için günlük yaşamın normal operasyonel faaliyetlerini sürdürmesi ve geliştirmesi için gerekli olan bilgi olarak tanımlanabilir. Motor öğrenme ve kontrol alanında, geribildirim çalışmaları büyük bir yer tutar, çünkü öğrencilerin performans ve öğrenme sonuçlarını iyileştirmek amacıyla hata düzeltmesi yapmak için bu bilgileri almaları önemlidir. Bu bağlamda artırılmış geribildirim bireylerin normalde mevcut olan duyusal bilgilerini geliştirmek için ek bir bilgi olarak çalışır. Görsel artırılmış geribildirim bu bağlamda en çok faydalanılan duyusal bilgilerden birisidir. Motor becerilerin öğrenilmesi açısından geribildirimin dört önemli işlevi tanımlanmıştır; bilgilendirici, motivasyonel, pekiştirici ve rehberlik edici işlevleri (Adams, 1987; Salmoni ve diğerleri, 1984).

Kişiler duyusal sistemlerinden gelen bilgileri yorumlamak için yeterli deneyime sahip olmayabileceklerinden, geribildirimin bilgilendirici özelliği onları beceri geliştirme için gerekli düzeltmeleri yapmaya yönlendirir. Bu sayede bir sonraki performansları aynı hatalardan arındırılacak ve istenilen performansa daha yakın olacaktır. Geribildirimin motive edici rolü, bireyleri uyanık tutar, ilgilerini sürdürür, enerjilerini yükseltir ve onları daha yüksek performans hedeflerine ulaşmaya teşvik eder (Schmidt ve Lee, 2011). Pekiştirme işlevi ise arzu edilen davranışın sürdürülmesi ve istenmeyen davranışın azaltılması/ortadan kaldırılması olarak performansa yansır. 1927'de Thorndike bu kavramı "etki yasası" ile belirtti ve bir eylemin ardından hoş veya ödüllendirici sonuçlar geliyorsa, uyaran tekrar ortaya çıktığında tekrarlanma eğiliminde olduğunu, ancak sonuçlar nahoş veya cezalandırıcıysa bunun olmama eğiliminde olduğunu belirtti. Son olarak, artırılmış geribildirim, öğrencilere eylemlerini düzeltmeleri ve performansın doğru sınırları içinde kalmaları için rehberlik eder. Ancak öğrenenler geribildirime bağımlılık oluşturabilir ve geribildirim kaldırıldığında, “rehberlik hipotezi” olarak adlandırılan durum meydana gelebilir ve kalıcılık testlerinde performansları önemli ölçüde bozulur (Salmoni ve diğerleri, 1984). Bu hipotezin arkasındaki mantık, kendi içsel geribildirimini kullanarak bağımsız hareket üretme yeteneği geliştiremeyen kişiler yalnızca dış bilgileri kullanır ve bu dışsal bilgi ortadan kaldırıldığında performans önemli ölçüde düşer.

Geribildirim Sıklığı

Motor öğrenme ve geribildirim çalışmalarında, öğrenme ve performans etkilerinin doğru yorumlanması ve geribildirimin hangi sıklıkla verilmesi gerektiğine karar vermek için bu iki terim birbirinden ayrılmalıdır. Performans etkileri geçicidir, öğrenme etkileri ise bir veya daha fazla gün sonra bile devam eder. Bireyler, görevin yürütülmesi sırasında (eşzamanlı geribildirim) veya görevin tamamlanmasından hemen sonra (terminal geribildirim) artırılmış geribildirim alabilirler. Ek olarak, geribildirim sıklığını azaltmak için bazı yöntemler önerilmiştir (Schmidt ve diğerleri, 1989; Lee ve Carnahan, 1990; Janelle ve diğerleri, 1997; Winstein ve Schmidt, 1990).

Öğrencilerin daha fazla öğrenme kazanımı elde etmeleri için sıklıkla dönüt verilmesi gerektiği düşünülmüştür (Thorndike, 1931). Ancak eş zamanlı geribildirim almak, olumsuz öğrenme etkisine neden olabilir (Magill ve Anderson, 2017). Bu olumsuz öğrenme etkisi, sürekli bimanuel koordinasyon görevleri (Verschueren ve diğerleri, 1997), izometrik dirsek ekstansiyon kuvveti üretme görevi (Vander Linden ve diğerleri, 1993), klinik ortamda kısmi ağırlık taşıma görevi (Winstein ve diğerleri, 1996) gibi farklı görevlerde belirtilmiştir. Eşzamanlı geribildirimin bu olumsuz öğrenme etkisinin nedeninin geribildirimin bağımlılık yaratan özelliğinden kaynaklandığı düşünülmektedir (Salmoni vd., 1984; Winstein ve Schmidt, 1990). Öte yandan, eş zamanlı geribildirimin rehberlik etkisi, uygun bir şekilde sağlanırsa performansı kolaylaştırmak ve beceri öğrenmeyi geliştirmek için kullanılabilir (Magill ve Anderson, 2017). Buchanan ve Wang'ın (2012) çalışmasında, katılımcıların Lissajous şablonu biçiminde görsel artırılmış geribildirim sağlanmasıyla iki el arasındaki karmaşık bir koordinasyon modelini öğrenmeleri istendi. Bir grup imleç üst üste gelecek şekilde (yan grup) eğitilirken, diğer grup imleç ayrı bir pencerede (arka grup) sunularak eğitildi. 5 dakikalık performans sergilediler ve 15 dakika sonra geribildirim almadan kalıcılık testi yaptılar. Geribildirim çekildiğinde arka grubun performansında dramatik bir düşüş gözlenirken, yan grup görsel geribildirim eksikliğinde performansını sürdürebildi. Çalışmanın sonucu, rehberliğin frekansa değil görsel geribildirim sağlayan gösterimin formatına bağlı olduğunu göstermiştir (Buchanan ve Wang, 2012).

2007'de Marschall ve arkadaşlarının bir meta-analizi, eşzamanlı ve çok sık geribildirim sağlamanın basit görevleri öğrenmede zararlı olduğunu, ancak bu kavramın karmaşık, sporla ilgili görevleri öğrenmek için doğru olmayabileceğini belirtti. Ayrıca, görevin zorluğu arttıkça bireylerin eş zamanlı geribildirimden daha fazla yararlanabilecekleri görüşü ortaya atıldı (Sigrist vd., 2012). Eşzamanlı geribildirimin bu sonucu için bazı olası açıklamalar yapıldı. İlk olarak, eşzamanlı geribildirim, harici bir dikkat odağını (dışsal odak) çekebilir (Shea ve Wulf, 1999) ve otomatik davranışı geliştirebilir. Eşzamanlı geribildirim, bilişsel aşırı yüklenmeyi önleyebilir (Wulf ve Shea, 2002) ve bu sayede bireylerin karmaşık görevleri öğrenmek için spesifik bilgilere ulaşmasına izin verebilir. Son olarak, geribildirimin yol gösterici işlevi, öğrencilerin karmaşık motor görevin bileşenlerini anlamalarına yardımcı olabilir (Huegel & O'Malley, 2010).

Postür Kontrolü

Postüral kontrol sisteminin karmaşık yapısını ve gerçekte nasıl işlediğini anlamak için bazı kavramsal teorilere ve ardından farklı sistemlerin birlikte nasıl çalıştığına bakmamız gerekir. Bunun için farklı biyomekanik ve nörofizyolojik yaklaşımlardan yararlanılmıştır (Horak ve Macpherson, 1995). Ivanenko ve Gurfinkel (2018), insan postüral kontrolünün özel sinir döngülerine ihtiyaç duyduğunu belirtmişler ve basit biyomekanik yaklaşımların postüral kontrol mekanizmalarını tam olarak açıklayamadığını eklemişlerdir. Bu teoriler, refleks teorisi, hiyerarşik teori, motor programlama teorileri, sistem teorisi ve ekolojik teori olarak sıralanabilir. Postür kontrolü çoklu duyusal ve motor süreçlerin etkileşimi ile oluşan karmaşık bir motor beceri olarak kabul edilir. Bu açıdan bakıldığında tüm bu teoriler içinde sistem yaklaşımı, postüral kontrolü karmaşık bir beceri olarak açıklar ve kas-iskelet sistemi ile sinir sistemleri arasında sürekli etkileşim gerektirdiğini belirtir (Horak, 2006). Sistem yaklaşımı, hareketleri gerçekleştirme ve postürü kontrol etme yetenekleri sınırlı olan bireylerin değerlendirilmesi ve rehabilitasyonu ihtiyacından gelir, ayrıca insanların hangi bağlamlarda düşme riski altında olduğunu anlamak için bağlama özgü sorunları da tespit eder (Horak, 2006). Horak'a (2006) göre postürün kontrolü için gerekli olan altı sistem vardır: biyomekanik kısıtlamalar, hareket ve duyusal stratejiler, uzayda oryantasyon, dinamiklerin kontrolü ve son olarak bilişsel işleme.

Postüral Kontrolü Etkileyen Faktörler

Postür kontrolü üzerine çalışmalar yaparken bireysel, çevresel ve diğer koşulları göz önünde bulundurmak gerekir. Bu bağlamda dikkate alınması gereken bazı faktörler vardır; örneğin yaş, cinsiyet, vücut faktörleri, deneyim, postüral görev özellikleri bunlardan bazılarıdır. 65 yaş ve üzeri nüfusun üçte biri her yıl düştüğü için yaşa bağlı değişiklikler yaşlıların postüral kontrol sistemleri üzerinde oldukça etkilidir (MacRae ve diğerleri, 1992). Öte yandan, sakin duruş aktiviteleri sırasında cinsiyet farklılıkları etkili bir faktör olarak bildirilmemiştir (Maki ve diğerleri, 1990). Araştırmalara göre, vücut ağırlığı ile postüral stabilite arasında güçlü bir ilişki vardır ki bu vücut ağırlığındaki artışın postüral stabilitenin azalmasına neden olur (Hue ve ark., 2007). Jimnastik ve dans gibi sporlarda uzman olmak, iyi bir duruş kontrolü ve denge gerektirir (Asseman ve diğerleri, 2008; Bruyneel ve diğerleri, 2010). Profesyonel bir spor olmasa bile, bazı fiziksel aktivitelerin belirli popülasyonlar ve yaşlılar için duruş kontrolünü arttırdığı ve düşmeleri azalttığı gösterilmiştir (Gregg ve ark., 2000; Gardner, 2000). Gerçekleştirilen postür görevinin zorluğu da postüral kontrolü etkilemektedir fakat sakin duruş gibi statik denge görevi tek başına postüral kontrol sistemi üzerinde yeterince zorluk oluşturamayacağından, bazı bireysel ve çevresel faktörler değiştirilerek postüral görevlerde istenen zorluklar oluşturulabilir. Somatosensoriyel, vestibüler ve görsel sistemlerden elde edilen bazı bilgilerin kısıtlanması ve değiştirilmesi, postürü kontrol etmek için gerekli motor cevapların üretilmesinde zorluklara neden olacak ve görevi daha zor hale getirecektir. Diğer yandan, proprioseptif duyuları ve destek yüzeyini manipüle etmek de postüral kontrol sistemini etkiler. Örnek vermek gerekirse, sert zemine karşı köpük zemin üzerinde durarak duyusal girdiyi manipüle etmek, gözler açık veya kapalı olarak ayakta durmak veya destek yüzeyi boyutunu iki ayak üzerinde duruş, tandem duruş ve tek ayak üzerinde duruş şeklinde manipüle ederek BoS'u değiştirmek, postür üzerinde büyük bir etkiye sahiptir (Muehlbauer ve ark., 2012).

Geribildirim ve Postüral Kontrol

Eş zamanlı olarak ve farklı frekanslarda geribildirim sağlamanın etkisini araştıran pek çok postüral kontrol çalışması bulunmaktadır. Geribildirim frekansını %100 ve %67 frekans olarak ayarlayan bir çalışma, yüzey desteğinin kararsızlık oluşturduğu statik denge görevlerinde (tahterevalli üzerinde iki ayaklı durma) %67 geribildirim frekansının önerildiğini bulmuştur (Marco-Ahulló ve diğerleri, 2018). Ayrıca, D'Anna ve ark. (2015), kuvvet plakası ile değerlendirilen sakin duruşta hem eş zamanlı geribildirimin hem de kesikli geribildirimin hiç geribildirim verilmeyen koşula göre daha üstün olduğu, ancak kesikli verilen geribildirimin daha doğal postüral davranışı desteklediğini belirtmiştir (D'Anna ve ark., 2015).

Öte yandan, eş zamanlı geribildirimin rolüne ilişkin bu son bulgulara rağmen, Shea ve Wulf'un (1999) çalışmasında 32 öğrenci stabilometre üzerinde test edilmiştir. Toplam dört grup, (1) yalnızca içsel odaklanma talimatları, (2) yalnızca dışsal odaklanma talimatları, (3) geri bildirimli içsel odak talimatları ve (4) geri bildirimli dışsal odak talimatları ile denge görevini yürütmüştür. İki günün her birinde yapılan 7 uygulama denemesinden sonra, katılımcılar herhangi bir geribildirim veya talimat olmadan kalıcılık testi yaptılar. Sonuçlar, geribildirimin uygulama sırasında performansı arttırdığını, ayrıca geribildirim geri alındığında herhangi bir performans düşüşü gözlemlenmediğini göstermiştir (Shea ve Wulf, 1999). Sonuç olarak, özellikle kalıcılık testlerinde, eşzamanlı geribildirimin çeşitli motor görevlere etkisi birbirinden farklıdır. Bu sonuçlar, eşzamanlı geribildirimin, özellikle değişen zorluktaki postüral görevler üzerindeki etkilerini anlamak için daha fazla çalışmaya ihtiyaç olduğunu göstermektedir.

YÖNTEM

Çalışmaya 18-30 yaş aralığında profesyonel sporcu olmayan 40 üniversite öğrencisi dahil edilmiştir. Her grupta eşit cinsiyet dağılımı olacak şekilde katılımcılar kontrol ve deney gruplarına rastgele seçildi.

Bu çalışmada farklı zorluklara sahip olan postüral görevler; sert zeminde sakin duruş (QS), sert zeminde tandem duruş (TS), sert zeminde tek ayak duruş (SS), köpük zeminde sakin duruş (PQS), köpük zeminde tandem duruş (PTS) ve köpük zeminde tek ayak üzerinde duruş (PSS) olarak dahil edilmiştir. Kuvvet plakasına Airex denge pedi yerleştirilerek köpük zemin yapılmıştır. Bu görevler, katılımcıların deney veya kontrol grubunda olmalarına bağlı olarak, CoP lokasyonunun eş zamanlı geribildirimi alınarak veya alınmadan ayrı ayrı gerçekleştirilmiştir. Altı farklı görevin sırası hem performans hem de kalıcılık testi günleri için rastgele sıralarla gerçekleştirilmiştir. Her görev, gözler açık şekilde ve denekler her görev için üç denemeyi başarıyla tamamlayana kadar tekrarlanmıştır. Her tekrar için 60 saniye verilmiştir. Sonraki analizler için üç denemenin ortalaması kullanıldı. Üç deneme arasında, deneklerin oturmasına izin verilen 60 saniyelik dinlenme süreleri sağlandı. Katılımcılar görevleri yerine getirirken "olabildiğince hareketsiz dur" yönergesi verilmiştir.

Protokol 1: Deney Grubu

Eş zamanlı geribildirim, katılımcılara göz hizasında ve 1 m uzaklıkta bulunan monitör tarafından sağlanmıştır. Ekrandaki imleç, CoP'lerinin konumundaki anlık değişiklikleri temsil ediyordu. Katılımcılara, görevler sırasında imleci monitörün ortasındaki belirlenen noktada tutmaları talimatı verilmiştir.

Protokol 2: Kontrol Grubu

Kontrol grubundaki katılımcılar için protokol ve görevler aynıydı. Ancak, CoP konumu hakkında herhangi bir geribildirim almadılar. Postüral görevler sırasında göz hizasında ve 1 m uzaklıkta bulunan siyah ekranda işaretlenmiş olan sabit noktaya bakmaları istenmiştir.

Protocol 3: Kalıcılık Testi

Hem deney hem de kontrol grubundaki katılımcılar, yaklaşık 24 saat sonra kalıcılık testi yaptılar ve CoP konumlarına ilişkin herhangi bir geribildirim almadan postüral görevleri gerçekleştirdiler. Her bir postüral görevi rastgele sırayla üç kez tekrarlarken göz hizasında ve 1 m uzaklıkta bulunan siyah ekran monitörde bulunan sabit noktaya bakmaları istenmiştir.

Verilerin Toplanması ve İstatistiksel Analizi

Veriler Orta Doğu Teknik Üniversitesi Modelleme ve Simülasyon Ar-Ge Merkezi'nde bulunan Hareket Yakalama Laboratuvarında toplanmıştır. Postüral salınım verileri kuvvet platformu (Bertec Corporation, Columbus, OH, ABD) ile ölçülmüştür. Veri toplama algoritmaları ve verilerin sonradan işlenmesi için sırasıyla Bertec Digital Acquire 4.1.20 yazılımı ve MATLAB R2021b (The Mathworks, Inc., Natick, MA, USA) kullanılmıştır. Kuvvet plakası sinyallerini elde etmek ve COP konumu hakkında geribildirim sağlamak için Bertec Digital Acquire 4.1.20 yazılımının orijinal uzantısı kullanıldı.

Araştırma sorularıyla ilişkili olarak basınç merkezi değişimlerinin (CoP) çeşitli parametreleri (hız, menzil, değişkenlik, elips alanı, entropi) anterio-posterior, medio-lateral ve bileşke yönlerinde edinim ve kalıcılık testi için ayrı ayrı analiz edildi. Her deneme için tüm CoP değerleri hesaplandı. İstatistiksel analiz için 3 denemenin ortalaması kullanıldı. Varyans modellerinin iki yönlü karma tasarım analizi (ANOVA), her bir postüral salınım (CoP) parametresi için ayrı ayrı hesaplandı.

SONUÇLAR

Performans Bulguları

ANOVA sonuçlarına göre, basınç merkezi değişimlerinden RMS parametresinin AP yönü için eş zamanlı görsel geribildirim ve postüral görev zorluğu arasında etkileşim bulunmuştur. Basınç merkezi değişimlerinden RMS parametresinin AP ve RD yönleri için, elips alanı ve entropi parametreleri için eş zamanlı görsel geribildirim anlamlı farklılık ortaya çıkarmıştır. Basınç merkezi değişimleri için ölçülen tüm parametreler için postüral görev zorluğu anlamlı farklılık ortaya çıkarmıştır.

Tablo 1. Performans için özet ANOVA sonuçları

Salınım Parametreleri	EGG x PGZ Etkileşim	EGG Ana Etkisi	PGZ Ana Etkisi
VEL-AP	AD	AD	*
VEL-ML	AD	AD	*
VEL-RD	AD	AD	*
RANGE-AP	AD	AD	*
RANGE-ML	AD	AD	*
RANGE-RD	AD	AD	*
RMS-AP	*	*	*
RMS-ML	AD	AD	*
RMS-RD	AD	*	*
EA	AD	*	*
ApEn	AD	*	*

Not. EGG: Eş zamanlı Görsel Geribildirim; PGZ: Postüral Görev Zorluğu; AD: Anlamlı Değil, *: Anlamlı.

Kalıcılık Testi Bulguları

ANOVA sonuçlarına göre, basınç merkezi değişimlerinin hiçbirinde eş zamanlı görsel geribildirim ve postüral görev zorluğu arasında etkileşim bulunamadı. Aynı şekilde, eş zamanlı görsel geribildirim de tek başına anlamlı bir farklılık yaratmadı. Diğer taraftan, postüral görev zorluğu tüm parametreler için anlamlı farklılık ortaya çıkardı.

Tablo 2. Kalıcılık Testi için özet ANOVA sonuçları

Salınım Parametreleri	**EGG x PGZ Etkileşim**	**EGG Ana Etkisi**	**PGZ Ana Etkisi**
VEL-AP	AD	AD	*
VEL-ML	AD	AD	*
VEL-RD	AD	AD	*
RANGE-AP	AD	AD	*
RANGE-ML	AD	AD	*
RANGE-RD	AD	AD	*
RMS-AP	AD	AD	*
RMS-ML	AD	AD	*
RMS-RD	AD	AD	*
EA	AD	AD	*
ApEn	AD	AD	*

Not. EGG: Eş zamanlı Görsel Geribildirim; PGZ: Postüral Görev Zorluğu; AD: Anlamlı Değil, *: Anlamlı.

TARTIŞMA

Bu çalışma, eşzamanlı görsel geribildirim ve postüral görev zorluğunun postüral kontrolü nasıl etkilediğini belirlemek için tasarlanmıştır. Bu iki faktörün performans ve öğrenme üzerine etkileri ayrı analiz edilmiştir.

Performans Etkisi

Bu çalışmanın sonuçları, EGG ve PGZ arasındaki etkileşimin CoP salınım değişkenliği üzerinde sadece AP yönünde olduğunu ve ayrıca AP ve RD yönünde bir grup farkı olduğunu bulmuştur. Bu sonuçlar diğer çalışmalar tarafından desteklenmiştir (Lakhani & Mansfield, 2015; Dault ve diğerleri, 2003). Bu sonuç için kabul edilen gerekçe, sinir sisteminin adaptif kontrol mekanizmalarının, özellikle zorlu postüral görevlerde CoP değişkenliğini en aza indirmek ve vücudu stabilize etmek için çalıştığıdır (Van Wegen ve diğerleri, 2002). Ayrıca, zorlu postüral görevler sırasında ileri-geri salınımları azaltmak için ayak bileği stratejisi ile CoP değişkenliği arasında bir ilişki bulundu (Shafizadeh ve ark., 2020). Bizim de aynı şekilde bulduğumuz bu sonuçların adaptif kontrol mekanizmalarına ve ayak bileği stratejisine atfedilmesi mümkün görünmektedir. Ayrıca, elips alanı ve CoP zaman serilerinin düzenliliği açısından grup farkı bulundu. Bulguların diğer çalışmaların sonuçlarıyla karşılaştırılması, eşzamanlı görsel geribildirimin, zor postüral görevlerde bile sallanma alanının azalmasına neden olduğunu doğrulamaktadır ve bu ilişki, geribildirimin kısmen dış dikkat odağını harekete geçirebilen özelliği ile açıklanabilir (Dos Anjos ve ark., 2016; D'Anna ve diğerleri, 2015). Mevcut sonuçlar, eşzamanlı geribildirimin bilişsel aşırı yüklenmeyi önleyebileceği (Wulf & Shea, 2002) ve bu sayede bireylerin karmaşık görevleri yerine getirmek için gerekli bilgilere kolay ulaşmasına izin verme olasılığını artırmaktadır. Ek olarak, geribildirimin yol gösterici işlevi, katılımcıların karmaşık motor görevin bileşenlerini daha iyi anlamalarına yardımcı olmuş olabilir (Huegel & O'Malley, 2010).

Bu çalışmadaki entropi ölçümlerinin sonuçları, deney grubundaki katılımcıların kontrole kıyasla daha fazla karmaşıklık gösterdiğini ve bunun yanı sıra artan görev zorluğu ile entropinin de arttığını gösterdi. Bu sonuçlar Vaillancourt ve Newell, (2002) tarafından ifade edilen görüşlerle uyumluydu. Araştırmacılar yüksek düzeyde karmaşıklığı, sistemlerin daha az sürdürülebilir olma özelliği ve düzensizlik için bir ölçütle ilişkilendirdiler. Bizim bakış açımıza göre ve diğer araştırmacıların görüşleri doğrultusunda (Shafizadeh ve diğerleri, 2020; Lipsitz, 1992b; Baltich ve diğerleri, 2014), eşzamanlı geribildirim ve görev zorluğunun artması, motor sistem düzenlemelerini ve dinamik, yüksek uyum sağlayabilme özelliğine sahip nöromusküler bağlantıların da artmasına neden olarak daha karmaşık sinyallerin elde edilmesi ile sonuçlanmış olabilir.

Postüral görev zorluğu bu çalışmada değerlendirilen tüm CoP parametreleri için etkili bulundu. Bu sonuç için bazı olası açıklamalar var. İlk olarak, rijitlik veya eklem katılığı ile sönüm mekanizması arasındaki ters ilişki, artan CoP değerlerine neden olabilir (Maurer ve Peterka, 2005). Çünkü sessiz duruş sırasında BoS ve zemin özelliklerinin değiştirilmesi, nöromusküler sistemde sertliğin artmasına ve sönümlemenin azalmasına neden olmuş olabilir. İkinci olarak, Riccio'nun (1993) önerdiği gibi salınım, dikey pozisyonda dengeyi korumak için stabilite sınırlarını test eden bir arama mekanizmasıdır. Ayrıca hem psikolojik hem de nöromekanik faktörlerin katkısıyla salınım meydana gelebilir, bu nedenle birey rahatsız edici ve güvensiz pozisyonlarda durmaya çalıştığında sistemin arama fonksiyonu en üst düzeye çıkmış ve CoP parametrelerinin değerlerinin yükselmesine neden olabilir.

Bu çalışmada bazı parametreler için bulunan sonuçların aksine, görsel olarak sağlanan geribildirim mevcut doğal görsel, proprioseptif ve vestibüler bilgilerin işini kolaylaştırıcı etki gösterdiğinde postüral kontrolün geliştirilebileceği gösterilmiştir (Cawsey ve diğerleri, 2009; Rougier ve diğerleri, 2004; Giansanti ve diğerleri, 2009). Geri bildirimden istenen sonuçların elde edilmesi, geri bildirimin sıklığı (Shea ve Wulf., 1999), geri bildirimin ekrandaki büyüklüğü (Cawsey vd., 2009; Jehu vd., 2015) ve duyusal geri bildirimin türü (Sienko vd., 2018) gibi bazı faktörlere bağlıdır. Bu faktörler, dışardan verilen duyusal bilgiler ile duyusal sistemin kendi denge sağlama mekanizması arasındaki negatif etkileşimi önlemek için dikkatlice ayarlanmalıdır. Çalışmalar, vestibüler sistem rahatsızlığı olan bireyler (Bechly ve ark. (2012) ve inme hastaları (Chen ve ark., 2015) gibi bazı sağlıklı olmayan sistemlere sahip bireylerin dışarıdan sağlanan bilgilerden daha fazla fayda sağladığını göstermiş ve bunun için potansiyel bir neden olarak ‘ceiling’ etkisini öne sürmüşlerdir. Bu bilgiler ışığında, bu çalışmada kullanılan eşzamanlı geribildirimin gereksiz olabileceğini ve bu olasılığın üstesinden gelmek için farklı zorluklara sahip bazı postüral görevler belirlememize rağmen, katılımcılar sağlıklı bir sisteme sahip oldukları için verilen geribildirim kendi duyu sistemleri üzerinde herhangi bir etkiye sebep olmamış olabilir.

Kalıcılık Etkisi

Performans sürecinden bir gün sonra yapılan kalıcılık testinin amacı eşzamanlı görsel geribildirimin farklı zorluklardaki postüral görevler üzerinde herhangi bir öğrenme veya kalıcı bir etkisinin olup olmadığını ortaya çıkarmaktı. Genel sonuçlara bakıldığında bazı parametrelerin ortalama değerleri farklılık gösterse de hiçbirinde anlamlı bir farklılık ortaya çıkmamış ve etkiler kalıcılık ölçümlerine taşınmamıştır. Bu sonucun en olası nedeni, deneme sayısı ve bu denemelerin sadece bir gün ile sınırlı olması olabilir. Uzun zaman boyunca sağlanan geribildirim eğitiminin, en iyi duyusal adaptasyonu oluşturmak için sinir sistemine daha fazla zaman sağlayabileceği ve daha iyi duyusal entegrasyon ve belirli bağlamlara adaptasyon ile sonuçlanacağı tahmin edilmektedir (Sienko ve diğerleri, 2018).

Ayrıca Sienko ve ark. (2018), uzun süreli geribildirim eğitiminin neden olduğu duyusal entegrasyondaki olumlu değişikliklerin, geribildirim olmayan koşullarda bile korunabileceğini vurguladı. Görsel geribildirim ve eğitim seanslarının sayısı ile kalıcı ve/veya devam eden etkiler arasındaki ilişki kesin olarak belirlenmemiştir, ancak Sienko ve ark.'nın incelemesi. (2017), 10'dan fazla seanstan oluşan birkaç çalışmanın, herhangi bir duyusal bilgi eklenmeden verilen eğitime göre avantajlar gösterdiğini belirtmiştir. Ancak, bildiğimiz kadarıyla, postüral görev zorluğu ile ilgili olarak eşzamanlı görsel geribildirimin performansa olan etkilerini ve sonrasındaki etkilerini izlemek için önceden belirlenmiş bir deneme sayısı veya bir eğitim süresi yoktur.

SONUÇ VE ÖNERİLER

Performans sırasında, AP yönündeki değişkenlik parametresi, altı farklı postüral kontrol görevinde kontrol grubu ve eşzamanlı görsel geribildirim grubu arasında önemli ölçüde farklılık göstermiştir. Ek olarak, postüral görev zorluğunun ana etkisi göz ardı edildiğinde AP ve RD yönlerindeki salınım değişkenliği, elips alanı ve entropi parametreleri, kontrol grubu ile eşzamanlı görsel geri bildirim grubu arasında anlamlı farklılık göstermiştir. Öte yandan hem performans hem de kalıcılık ölçümlerinin sonuçları, postüral görev zorluğunun tüm postüral salınım parametreleri üzerinde anlamlı bir etkiye sahip olduğunu göstermiştir.

İleride yapılacak çalışmalar, eşzamanlı geribildirim ve postüral görev zorluğu arasındaki bağlantılarla ilgili kesin sonuçlar elde edebilmek için bazı düzenlemeleri ve metodolojik değişiklikleri dikkate almalıdır. İlk olarak geribildirimin varlığında kalıcı öğrenmeyi veya geribildirimin postüral kontrol üzerindeki faydalı etkilerini ortaya çıkarmak için eğitim verilecek gün sayısı ve görev tekrar sayıları dikkatli bir şekilde planlanmalıdır. İkinci olarak, bu çalışmada kullanılan altı farklı postüral görev, genç ve sağlıklı yetişkinler için gerekli zorluğu yaratmaya yeterli olmamış olabilir. Bu nedenle, yapılacak çalışmalar her katılımcı için kişiselleştirilmiş zorluk seviyesinin belirlenmesine odaklanabilir. Diğer taraftan, vestibüler defisiti veya postüral kontrolü etkileyebilecek diğer sorunları olan katılımcıları dahil etmek gibi katılımcı profilinin tamamen değiştirildiği çalışmalar da yürütülebilir. Son olarak, daha sağlam sonuçlar elde etmek için eşlik eden elektromiyografi (EMG) kayıtları dahil edilebilir. Ayak bileği ve kalça stratejileri vücut bölümlerinin farklı duruş pozisyonlarına ve görme fonksiyonlarına göre değişiklik gösterir, çünkü görme ile ayak bileğinin dengeyi korumaya yönelik stratejisinin bağlantılı olduğu ifade edilmiştir (Singh ve ark., 2012). Bu sayede postüral kontrolü sürdürürken geri bildirimin etkisi, motor kontrol sistemleri ve diğer vücut stratejileri hakkında daha fazla bilgi edinilerek daha kesin yargılarda bulunulabilir.

E: THESIS PERMISSION FORM / TEZ İZİN FORMU

ENSTİTÜ / INSTITUTE

Fen Bilimleri Enstitüsü / Graduate School of Natural and Applied Sciences	☐
Sosyal Bilimler Enstitüsü / Graduate School of Social Sciences	☒
Uygulamalı Matematik Enstitüsü / Graduate School of Applied Mathematics	☐
Enformatik Enstitüsü / Graduate School of Informatics	☐
Deniz Bilimleri Enstitüsü / Graduate School of Marine Sciences	☐

YAZARIN / AUTHOR

Soyadı / Surname : TAŞCI
Adı / Name : SEDA
Bölümü / Department : Beden Eğitimi ve Spor / Physical Education & Sports

TEZİN ADI / THESIS TITLE (İngilizce / English):
Effect of concurrent feedback and postural task difficulty on postural control

TEZİN TÜRÜ / DEGREE: Yüksek Lisans /Master ☒ Doktora / PhD ☐

1. **Tezin tamamı dünya çapında erişime açılacaktır.** Release the entire work immediately for access worldwide. ☒
2. **Tez iki yıl süreyle erişime kapalı olacaktır.** Secure the entire work for patent and/or proprietary purposes for a period of **two years**.* ☐
3. **Tez altı ay süreyle erişime kapalı olacaktır.** Secure the entire work for period of **six months**.* ☐

***** *Enstitü Yönetim Kurulu kararının basılı kopyası tezle birlikte kütüphaneye teslim edilecektir. / A copy of the decision of the Institute Administrative Committee will be delivered to the library together with the printed thesis.*

Yazarın imzası / Signature ____________________ **Tarih** / Date ___ / ___ / ______
(Kütüphaneye teslim ettiğiniz tarih. Elle doldurulacaktır.)
(Library submission date. Please fill out by hand.)

Tezin son sayfasıdır. / This is the last page of the thesis/dissertation.