Palacký University Olomouc
Faculty of Physical Culture

THE INFLUENCE OF VARIOUS SACCADIC EYE MOVEMENTS ON POSTURAL STABILITY DURING MORE DEMANDING POSTURAL TASKS

Doctoral Dissertation

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Název disertační práce: Vliv sakadických pohybů očí na posturální stabilitu v náročnějších posturálních úlohách

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Abstrakt:

Hlavním cílem této disertační práce bylo posoudit vliv různých rychlostí a směrů sakadických pohybů očí na posturální stabilitu v náročnějších balančních úlohách u zdravých mladých dospělých jedinců a seniorů. Výzkum byl rozdělen do tří experimentů, které zahrnovaly odlišné zrakové úlohy (centrální fixace, horizontální a vertikální sakadické pohyby očí) s různou frekvencí jejich provedení (0,5 Hz a 1,1 Hz) při vykonávání balančních úloh. Do těchto tří experimentů bylo zahrnuto 32 zdravých mladých dospělých, 18 seniorů a 21 zdravých mladých dospělých. Poznatky této disertační práce ukazují pozitivní vliv pomalých a horizontálních sakád na posturální stabilitu v porovnání s fixací pohledu u mladých dospělých ve stoji na pohyblivé plošině. V posturálních úlohách se stabilní opěrnou bází byl pozitivní vliv sakád na posturální stabilitu pozorován u mladých dospělých pouze v bipedálních posturálních úlohách. U seniorů nebyly pozorovány žádné statisticky významné změny posturální stability související se zrakovým úkolem. Detailní analýza pohybu očí dále ukázala, že větší amplituda horizontálních sakád byla spojena s většími předozadními posturálními výchylkami během unipedálního postoje u mladých dospělých. Nalezení pozitivního vlivu sakád v tomto výzkumu potvrzuje možnost facilitativní kontroly pohledem, která se projevuje zmenšením posturálních výchylek těla.

Klíčová slova: posturální kontrola, pohyby očí, sakady, amplituda sakád, eye tracker

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Title of the doctoral dissertation: The influence of various saccadic eye movements on postural stability during more demanding postural tasks

Department: Department of Natural Sciences in Kinanthropology

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Abstract:

The main aim of this dissertation was to assess the influence of various speeds and directions of saccadic eye movements on postural stability during more demanding balance tasks in healthy young and elderly adults. The whole research was divided into three studies, in which the experiment design included central, horizontal, and vertical visual tasks of lower (0.5 Hz) and higher (1.1 Hz) frequencies of eye movement while performing balance tasks. The number of participants in these studies was 32 healthy young adults, 18 elderly and 21 healthy young adults, respectively. The overall findings of this dissertation show positive effect of slow and horizontal saccades on body sway compared to fixation condition in healthy young adults while standing on a movable platform. In postural tasks with stable base of support, positive effect of saccades on body sway compared to fixation condition was observed in healthy young adults only in bipedal postural tasks. In elderly, no significant changes of balance performance related to the visual task were observed. Furthermore, detailed analysis of the eye movements showed that higher amplitude of horizontal saccades was associated with higher anterior-posterior body sway while performing unipedal stance in young adults. The positive effect of saccades in this research interprets the possibility of a facilitatory gaze control that is manifested in the attenuation of body sway.

Keywords: postural control, balance, eye movements, saccades, saccadic amplitude, eye tracker

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I declare that I have prepared this dissertation independently under the supervision of prof. RNDr. Miroslav Janura, Dr. I have listed all the literature and professional resources used, and I have adhered to the principles of scientific ethics.

In Olomouc, ... ……………………………

I would like to express my sincere gratitude to my supervisor prof. RNDr. Miroslav Janura, Dr. for his professional guidance, advisory, patience and support during the whole research process. I show my big appreciation to my colleagues and friends from the Faculty of Physical Culture at Palacký University Olomouc, my consultant Mgr. Lucia Bizovská, Ph.D. for her immense help and patience, Reza Abdollahipour, Ph.D., M.Sc., Mgr. Ivana Djordjević, Ph.D., and Mgr. Ludvík Valtr, Ph.D. for their support, scientific assistance and cooperation. Last but not least, this doctoral dissertation would not be possible without the encouragement and motivation of my loving family and friends who were supporting me during my studies.

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1 Introduction

Postural control is strongly correlated with the sensory system integration that is crucial for standing posture (Hatzitaki, Zisi, Kollias, & Kioumourtzoglou, 2002; Sibley, Straus, Inness, Salbach, & Jaglal, 2013). Besides the influence of proprioceptive sensations, the visual system provides the most significant afferent information from the environment on a movement formation (Cerman & Larkin, 2000), and vision is considered to be the important factor in maintaining balance (Hunter & Hoffman, 2001; Paulus, Straube, & Brandt, 1984; Redfern, Yardley, & Bronstein, 2001).

The significance of vision on postural control is well known in the literature. It is evident that a well-functioning visual system complements the vestibular activities during standing posture (Rutkowska et al., 2015) and that a body sway can be reduced by almost 50% if the visual information is available (Turano, Dagnelie, & Herdman, 1996). In the recent time studies have been exploring the impact of vision on postural stability and the effects of various eye movements on balance whilst standing on various surfaces.

Nonetheless, in more than the past decade it has been shown that saccadic eye movements have rather positive influence on postural stability compared to fixation (Aguiar et al., 2015; Legrand et al., 2013; Rey, Lê, Bertin, & Kapoula, 2008; Rodrigues et al., 2013, 2015; Rougier & Garin, 2007; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Bardy, Bonnet, Hove, & Oullier, 2007; Uchida et al., 1979). The majority of these studies justify their outcome on the basis of the functional integration of posture and gaze control (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006), which is also the focus of our study. The functional integration of posture and gaze control paradigm explains underlying mechanism used while a person is simultaneously performing a visual task during postural control task. It was suggested that a body sway might be adjusted during visual search to assist eye movements (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000), meaning that saccadic eye movements may decrease body sway to allow more accurate gaze shifts (Rodrigues et al., 2013, 2015; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). Based on this paradigm we may assume that a functional coupling between postural control and gaze behavior might be moderated by a demand of a visual task, and if a visual task is more difficult, postural stability might improve to support solving a visual task. Still, this raises the question if the effect of saccadic eye movements changes with more demanding levels of postural tasks.

2 Theoretical background

2.1 The basic model of motor control

The central nervous system (CNS) that generates the motor control system uses the information from the visual, vestibular, and proprioceptive (including kinesthetic, auditory, and haptic) sensory systems (Bertenthal, 2009; Teasdale, Lajoie, Bard, Fleury, & Courtemanche, 1992; Vickers, 2007). To execute movements, the information from the environment is obtained from the body itself through the proprioceptors, and the information from the external environment is obtained from the visual and/or auditory systems (what we see and/or hear). Specifically, the utilization of afferent sensory information is necessary to regulate our movements (Latash, 2012; Schmidt & Lee, 2011). That is, it is important of the sensory systems to provide the correct orientation information into the central nervous system (Hammami, Behm, Chtara, Othman, & Chaouachi, 2014; Han, Anson, Waddington, Adams, & Liu, 2015; Redfern & Furman, 1994) so the body can give the proper motor response. The insufficiency or complete absence of a certain sensory modality can in some cases be compensated by another modality in order to maintain postural stability, for instance, a person may use a touch of the surroundings to maintain postural stability in case of insufficiency of the vestibular or visual apparatus (Dickstein, Peterka, & Horak, 2003). In a well-lit environment and on a stable base of support, healthy individuals rely 70% on the somatosensory system, 20% on the vestibular system and 10% on vision (Horak, 2006). Yet, while standing on an unstable surface, there are increased demands on afferent information support from the vestibular and the visual system, while at the same time the dependence on somatosensory afferent decreases (Horak, 2006). However, if the environment moves relative to a standing individual, the use of the visual system in postural control is reduced (Mahboobin, Loughlin, Redfern, & Sparto, 2005). On the other hand, an increase in the use of the visual system occurs when proprioceptive information is violated for various reasons (Latash, 2008).

2.1.1 Proprioceptive system

Proprioception is afferent information appearing from deeply located receptors of the locomotor system, called proprioceptors, and it is a system of deep sensitivity (Purves et al., 2001). Those proprioceptors are found in muscles, joints, and tendons and they provide the information to the CNS about muscle tension, position, and body segment movements. The muscle spindle, Golgi tendon body, and joint receptors are the most significant proprioceptors (Véle, 2006).

The muscle spindle is formed by a bundle of six to eight modified contractile intrafusal muscle fibers and is located at the interface of tendon and muscle. These are parallel to the skeletal muscles' so-called extrafusal fibers. Afferent nerve fibers spirally wrap intrafusal fibers, transferring information via the spinal nerve to the posterior horns of the spinal cord and the spinal cord. They are connected either directly (monosynaptically) to the alpha motoneurons of the anterior horns or via interneurons to the motoneurons of the antagonistic muscles in this region (Purves et al., 2001). The efferent innervation of intrafusal fibers is provided by motor fibers of the gamma system, in contrast to the extrafusal fibers innervated by alpha motoneurons. The spindle irritates the muscle when it is stretched, serving as a comparator that compares the tension of the two types of fibers. Gamma innervation causes the intrafusal fibers to contract, putting the spindle under a certain tension (Purves et al., 2001; Véle, 2006).

The primary proprioceptive organ of the tendon is the Golgi tendon body, which regulates muscle tension and prevents the muscle from overstretching. The stretching and contracting of muscles trigger its activation. However, in order to irritate the receptor, the tendon must be subjected to significantly more tension than the muscle spindle. Along with the muscle axle, the ligament body frames a programmed defensive servomechanism forestalling the event of microtraumas (Véle, 2006). Articular receptors detect changes in joint capsule tension and, as a result, have an indirect impact on muscle function. According to Véle (2006), they record changes in the joint's speed of movement as well as static information about the angle setting of the segments.

2.1.2 Vestibular system

The vestibular system, located in the inner ear, is divided into a central and a peripheral section (Purves et al., 2001). The peripheral section includes a static sensor that is made up of three semicircular canals and a kinetic sensor that contains the sacculus and utriculus (Purves et al., 2001; Trojan, 2003). The head's angular acceleration, or the beginning or end of its rotation, is detected by perpendicular semicircular canals. The linear acceleration of the head in the anterior-posterior, lateral, or vertical direction is recorded by the sacculus and utriculus in relation to the gravitational force vector (Purves et al., 2001). The vestibulocochlearis nerve, which creates synapses with the vestibular nuclei in the brainstem, is the channel through which information from the vestibular apparatus itself is transmitted (Purves et al., 2001). The signal then travels to other parts of the central nervous system, including the thalamus, the motor nuclei of the eye muscles, the spinal cord, the cerebellum, and the cerebral cortex (Purves et al., 2001). Postural and righting reflexes, which keep the body stable and upright, are triggered by afferents from the vestibular system. The vestibulo-oculomotor reflex that is triggered by a sudden shift in head position is also mediated by the statokinetic sensor (Purves et al., 2001). If this situation occurs, both eyes deviate in the opposite direction with the aim of fixing the current image on the retina.

2.1.3 Visual system

Postural stabilization relies on the visual system, and inputs from the visual apparatus are essential for postural control. Vision provides the nervous system the information about the current position and movements of body parts in relation to other body segments and the external environment (Lord & Menz, 2000). According to Véle (2006) fixating our eyes on points in the external environment gives us postural stability. When the individual modalities coming from other systems are in conflict, then the visual system information is prioritized. On the other hand, when standing with eyes closed, all parameters of postural stability deteriorate, that are reflected in increased in the range and frequency of postural deviations, etc. (Horak, 2006; Latash, 2008).

Retina, macula, and fovea are parts of the eye’s anatomy that provide the best central and peripheral vision (Provis, Dubis, Maddess, & Carroll, 2013) (Fig. 1).

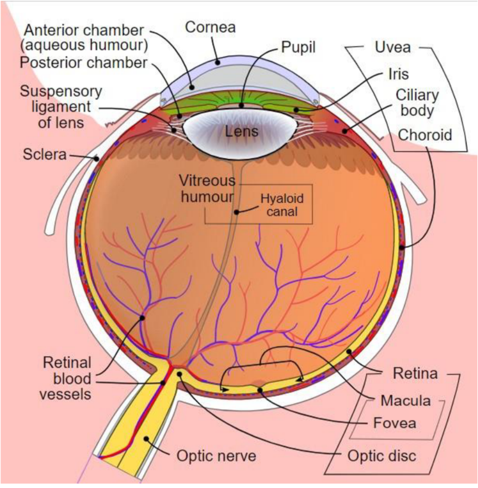

Figure1. Scheme of Fovea centralis. (2022). Retrieved November 29, 2022, from https://en.wikipedia.org/wiki/Fovea_centralis.

Being responsible for the central vision, as a tiny part of the eye, the fovea brings the absolute acuity vision that is crucial for our daily activities (Abrams, 1992; Provis, Dubis, Maddess, & Carroll, 2013). Eye movements can either compensate for disturbances that cause the fovea to be displaced from a target that is already being attended to, or to direct the fovea to new objects of interest, a process known as "foveation". Experiments in which a visual image is stabilized on the retina either by paralyzing the extraocular eye muscles or by moving a scene in exact register with eye movements so that the various features of the image always fall on the same parts of the retina, have also demonstrated the significance of eye movements for visual perception (Purves et al., 2001; Zhaoping, 2019).

There are two distinct issues when moving the eyes to focus on a new target in space, or indeed any other movement: controlling both the movement's amplitude (the distance it travels) and its direction (Leigh & Zee, 2015; Purves et al., 2001). The duration of neuronal activity in the lower motor neurons of the oculomotor nuclei reveals the amplitude of a saccadic eye movement. The direction of a movement is regulated by which eye muscles are engaged (Purves et al., 2001). Although independently adjusting the activity of individual eye muscles could theoretically specify any given movement direction, the task's complexity would be overwhelming. Instead, the local circuit neurons in two gaze centers in the reticular formation, each of which is responsible for generating movements along a particular axis, control the direction of eye movement (Purves et al., 2001). A group of local circuit neurons near the midline of the pons is responsible for generating horizontal eye movements and is known as the paramedian pontine reticular formation (PPRF) or horizontal gaze center. Vertical movements are controlled by the rostral interstitial nucleus, also known as the vertical gaze center, which is situated in the rostral portion of the midbrain reticular formation. The eyes move horizontally or vertically along a single axis when each gaze center is activated separately. Oblique movements whose trajectories are defined by the relative contribution of each center are produced when the gaze centers are simultaneously activated (Leigh & Zee, 2015; Purves et al., 2001).

2.1.3.1 Types of eye movements and their characteristics

A fixation, saccades and smoot-pursuit are the basic eye movements that characterize the oculomotor human behavior (Land & Tatler, 2009; Tatler, Hayhoe, Land, & Ballard, 2011; Thier & Ilg, 2005).

To gather the information from the environment we stabilize our gaze (we fixate a stimulus) (Land & Tatler, 2009). While we fixate, we recognize an object and all its features (for instance a book or a ball) (Rayner, 1992). The visual information is mainly acquired through fixations that are the most commonly used eye movements (Rayner, 1992). During a fixation, the eyes stay still at one spot and hold the foveal area of our visual field. The period of time when our eyes are relatively still is approximately 150 to 350 milliseconds (ms), i.e., the average duration is about 330 ms (Rayner 1998). While moving in our visual field our eyes “jump” from one fixation to another. In other words, we rapidly shift our eyes towards the new information (Wu, Chua, & Yen, 2016). That rapid shift of the eyes between fixations are called saccadic eye movements (Findlay, 1992; Rayner, 1992).

Saccades are ballistic, “pre-programed” eye movements. They are voluntarily (sometimes involuntarily) elicited movements that occur reflexively even when fixating a stimulus (Findlay, 1992). The term “ballistic eye movements” refers to the fact that they are fast movements with the average duration of between 20 ms – 100 ms, depending on the size of a movement. It takes between 50 and 60 milliseconds for visual information to reach higher cortical areas after a fixation begins (McConkie, 1983). A saccade plan is initiated to compute a motor program that specifies the direction and amplitude of the eye movement at some point prior to the end of the fixation—

that is, prior to the upcoming saccade. Based on the minimum amount of time required to make a completely new eye movement, the time required for this has been estimated to be between 175 and 250 ms (Salthouse & Ellis, 1980). In the end, the saccade is carried out after the plan for it has been completed. According to Becker and Jürgens (1979), there is evidence that saccade plans can overlap in time, i.e., a later plan can start while an earlier plan is still being formed (Bhutani, Ray, & Murthy, 2012; Walker & McSorley, 2006). Moreover, involving a head movement while performing saccades would involve an elicited saccade to be initiated above 15° of central vision. That is, to fixate one target and to initially change fixation as fast as possible to another appearing target without a head movement, an orienting target should not be deviating more than (not be greater than) 15° of visual angle (Findlay, 1992).

Saccadic amplitude is considered to be a carried distance between two fixation locations, and the eyes typically land close to the target when a saccade is made in the direction of that target location (Paeye & Madelain, 2011). It has been suggested that fixation duration and saccadic amplitude are similarly controlled by the same mechanism, as both fixation duration and saccadic amplitude change in the first couple of seconds during a visual search (during a visual information processing) (Unema, Pannasch, Joos, & Velichkovsky (2005), which also means that based on the nature of saccades, saccadic amplitude gradually recovers (Optican, Zee, & Chu, 1985).

Last but not least, the smooth-pursuit eye movements are tracking eye movements that help us to follow a stationary stimulus (an object) that moves. In smooth-pursuit system, after the fast saccades capture a stimulus (an object), the eye movements achieve and track the velocity of a moving object (Land & Tatler, 2009). Smooth pursuit eye movements are much slower than saccades which makes them different type of eye movements than fixations and saccades (Orban de Xivry, & Lefѐvre 2007). As they follow a moving object they move in a continuous trend, and once a fixation error accumulates (because of a changing trajectory of an object) they automatically "catch-up" with the new trajectory (e.g., de Brouwer et al. 2002b). Saccades and smooth pursuit eye movements also occur alternatively when the observer switches between tasks. As an example, a person that drives switches their gaze back and forth between looking at the dashboard instrument and following the road. In cases like this, saccades may occur before or after smooth pursuit, and this type of interaction requires less attention (e.g. in Bieg, Bresciani, Bülthoff, & Chuang, 2013).

2.1.3.2 Visual functioning and visual perception

Visuomotor integration is recognized as the linkage between perceptual and motor codes in the brain as the mechanism which underlies the planning and programming of motor action (Prinz, 1990, 1997). In order to carry out a complex motor pattern it is necessary for the central nervous system to be able to process afferent information rapidly and efficiently. Perceptual elaboration of visual information gives rise to a retinotopic representation that needs to be transformed into a stable spatial representation (Bonifacci, 2004). This representation can be obtained through the integration of information from proprioceptors about the relative position of the head and the body, together with information concerning the position of the visual stimulus in the retina (Bonifacci, 2004).

From the neurological perspective of visual functioning, the visual information is processed in two parallel neural pathways. Those neural pathways are complex segregated systems throughout which input signals from the environment travel from retina to the primary visual cortex (Milner & Goodale, 2008). The visual projection from the primary visual cortex in the occipital lobe goes into two streams - dorsal and ventral streams, which have different visual functioning. While dorsal stream conveys the information about the object localization and motion, ventral stream is responsible for providing information about the object identification, so-called "what is it" information (Sigmundsson, Hansen, & Talcott, 2003; Tsai, Wilson, & Wu, 2008). The ventral stream takes the input from the central vision and requires sufficient light, contrast, and focus (Schmidt & Lee, 2011), and this system is specialized for the conscious perception of the environment. That is why it is also called the vision for perception system (Jeannerod, 1997; Milner & Goodale, 2008), and is responsible for what the individual is looking at and/or focusing on. On the other hand, dorsal system's input is peripheral (up to 180º) and does not require focus nor sufficient light, which is why it is also called the vision for action system. Altogether, those processes mutually interact in order to inform the action planning in the environment.

2.2 Motor control principles

In postural control exist mechanisms for mediating movement feedback (feedback) and movement anticipation (feedforward) with subsequent corresponding correction using motor programs coordinating muscle activity (Bizovská, Janura, Míková, & Svoboda, 2017; Shumway-

Cook & Woollacott, 2011). Specifically, motor control relies on the usage of sensory (afferent) information to regulate our movements. The information tells us about the state of environment, about the state of our body, or about the state of our body in the environment. There are two ways how sensory information is used in the action control, the open-loop (feedforward) control, and closed loop (feedback) control (Schmidt, Lee, Winstein, Wulf, & Zelaznik, 2018). That is, a movement coordination may be achieved in a predictive, feedforward manner, or in a feedback manner. Feedforward movements are made without the online use of sensory feedback evolving during the action, and require an internal model for accuracy (Kawato, 1999). Such actions can occur rapidly, as there is no need to account for the delay of feedback loops. For instance, when the duration of a movement exceeds 200 ms, there is enough time for a body to adjust the motor action (e.g., golfers arm movement during the arm swing before hitting the ball, or movements of the arms before catching a ball). Feedforward models capture the forward or causal relationship between inputs to the system (e.g. the arm) and the outputs (hitting or catching the ball). I.e., a forward dynamic model of the arm predicts the next state (e.g. position and velocity) given to the current state and motor command.

The concepts of the closed-loop motor control (Latash, 2012; Posner, 1980; Schmidt & Lee, 2011) is often termed movement-produced feedback (or simply feedback), and it provides the explanation of an organized movements which rely on sensory feedback which controls movements. The closed-loop system is important in many situations, especially those in which the system has to “control itself” for long period of time (for instance, maintaining balance on a stabilometer platform). Specifically, the closed loop control is a mechanism of motor control where any act on the environment creates some sort of change through a feedback that affects future performance (Adams, 1971; Roth, Sponberg, & Cowan, 2014; Schmidt & Lee, 2011). As a conclusion, a combination of both feedforward and feedback processes reflect the optimal movement control (Desmurget & Grafton, 2000). For the closed-loop (feedback) control, the vision provides the richest source of information, as it gives the information about the errors in movements, as well as predictive information, by which the potential errors can be anticipated and avoided (Schmidt & Lee, 2011).

2.2.1 Postural stability

Postural stability is defined as the ability to prevent an accidental or uncontrolled fall by maintaining an upright body posture and responding to changes in both internal and external forces (Vařeka, 2002). It is likewise balanced and coordinated body position and a process of maintaining body parts in the environment (Pastucha, et al., 2012). According to Kolář (2009) postural stability is rather a continuous holding position. That is, this term is related to balance, which maintains posture stability. Stability in posture is made by interactions between the motor, sensory, and central nervous systems. These systems, which transmit data to the vertebral nuclei, spine, and cerebellum of the central nervous system, detect changes in the position of the center of mass. The focal sensory system sends orders to the skeletal muscles and to other body muscles to give postural response. The human body's base of support are the feet. Because of this, the feet play a major role in maintaining balance, and postural stability is significantly influenced by foot size, muscle strength, and feet position (Horak, 2006; Safi et al., 2017).

The following terminology is associated with postural stability (Bizovská et al., 2017; Kolář, 2009):

Area of support – part of the surface that is in a straight-line contact with the body. The area of support is usually smaller than the base of support.

Base of support – part of the surface bounded by all the outer boundaries of the area of support,

COM (center of mass) – a hypothetical point where the weight of the whole body is concentrated,

COG (center of gravity) – projection of the common center of mass of the body onto the plane of the base of support,

COP (center of pressure) – place of action of the reaction force vector from the surface; weighted average of the partial pressures at the contact of the foot with a surface,

Physical factors such as the individual's weight, the size of the base of support, the position and properties of the individual moving segments, the nature of the body's contact with the support surface, and the distance from the center of mass to the base of support all have an impact on postural stability. In addition to the mechanical factors, internal body factors, but also neurophysiological factors like inputs from the visual, vestibular, and proprioceptive systems as well as psychological influences, can affect postural stability (Bizovská et al., 2017; Winter, 1995). Also, many cognitive resources are necessary in postural control (Teasdale & Simoneau, 2001). Increased reaction times when standing compared to sitting with support demonstrate the need for cognitive processing even when standing quietly. As a difficulty of a postural task increases, the more cognitive processing is required. As a result, as a difficulty of the postural task increases, a reaction times and performance in a cognitive task decrease (Teasdale & Simoneau, 2001). Still, some authors suggest that the performance of postural tasks is restricted by a secondary cognitive task because the control of posture and other cognitive processing share cognitive resources (Camicioli, Howieson, Lehman, & Kaye, 1997; Teasdale et al., 1993).

2.2.2 Balance control

From a functional point of view, balance control can be considered as a closed-loop feedback control system in which one component is the integration of various sensory orientation information sources (Peterka, 2018). For standing balance, body sway is detected by sensory systems, corrective motor action is generated as a result of sensory-detected sway, and motor action alters the time course of sway, which is registered by sensory systems (Peterka, 2018). This is what feedback control means for standing balance. In contrast to open-loop motor control (such as the vestibulo-ocular reflex's control of eye movements in the dark), a closed-loop feedback control organization is a continuous loop of "sensing-acting-sensing-acting" (Peterka, 2018). The balance control system's feedback nature restricts how sensory information is combined and converted into corrective motor actions, as well as the dynamic regulation of sensory integration in response to environmental changes that either remove or restore access to accurate sensory information (Peterka, 2018).

To actively maintain balance in a standing position requires a sensorimotor control loop that detects body orientation and motion in the environment (Rasman, Forbes, Tisserand, & Blouin, 2018). The loop generates the forces that stabilize torques that are needed to remain upright, as well as controls the activation of the vestibular system that requires head movements in the environment (Rasman, Forbes, Tisserand, & Blouin, 2018). That being said, we may also mention that proprioceptive, vestibular, and visual sensory systems have different operating frequency ranges, and each of them have a different influence on postural control depending on a situation (Redfern, Yardley, & Bronstein, 2001). During stance, for instance, the vision stabilizes body sway the best if frequency of a sway is low (<0.1 Hz), and the somatosensory senses from feet and ankles provide the best stability for standing posture at frequencies higher than 1 Hz. Last but not least, the semicircular canals of the vestibular system, that respond to rotational movements (angular acceleration), have a sensory threshold above 0.1 Hz, while the otolith organs, that sense gravity and linear acceleration, are used below 0.5 Hz, particularly below 0.1 Hz (Diener, Dichgans, Guschlbauer, & Mau, 1984; Lestienne, Soechting, & Berholz, 1977). These sensory systems have their optimal frequency ranges, but incorrect integration among them may interrupt postural control (Redfern, Yardley, & Bronstein, 2001).

From a body stabilization point of view, balance is a motor (movement) ability that belongs to the group of coordination abilities. The basis of these abilities is neuromuscular coordination that enables the regulation of motor skills so that the movement is performed as close as possible to its ideal structure (Pavlík, Zvonař, & Vespalec, 2014). Postural stabilization is a complex neuromuscular task of stabilizing one's posture necessitates joint coordination across multiple joints. Internal model control, supraspinal processes for anticipatory postural adjustment, and passive viscoelasticity of the muscle-tendon complex are all mechanisms of postural stability and control (Iqbal, 2011). The human body addresses a multisegmented biomechanical chain, as a result of the unique cooperation between body sections. According to Alexandrov and Frolov (2011), in order to move any joint segment, joint torque correction must be produced in all joints.

Understanding postural control requires considering the numerous physiological basics of an individual's capacity to stand, walk, and to safely and efficiently interact with the environment. Biomechanical constrains, movements strategies, sensory strategies, orientation in space, control of dynamics and cognitive processing are required resources for postural stability and orientation (Horak, 2006). We are able to analyze each individual's specific balance disorders in a systematic manner once we have a comprehension of these systems and the various ways in which they contribute to postural control. Thus, assessments additionally allow us to anticipate a specific instability, in which every individual is in risk of falling in various settings (Horak, 2006). The cone of stability (the area in which a person moves their center of mass, or the area of stable swaying; Erdeniz, Selvaraj & Bulut 2019) is internal representation of the CNS, that is used to determine how to move in order to maintain equilibrium (Horak, 2006). For instance, this cone of stability is often small in elderly individuals with balance disorders, or if elderly's central neural representation is deformed, which affect individual's selection of movements strategies in order to maintain balance (Horak, 2006).

The term balance refers to the dynamics of posture as a prevention of falling, i.e., it is a constant adaptation of muscle activity and joint position to the functional requirements for maintaining the body above the base of support (Winter, 1995). Keeping the human body in static and dynamic positions and moving between them is a basic ability that a person uses for their natural movement. Therefore, balance can be divided into two categories: static and dynamic (Alexandrov & Frolov, 2011; Bizovská, et al., 2017; Kalichová, Baláž, Bedřich, & Zvonař, 2011; Winter, Patla, & Frank, 1990).

2.2.2.1 Static balance

To be able to perform a planned movement, it is necessary to create conditions for adequate postural stabilization, therefore it is necessary to set a purpose-oriented posture, i.e., postural attitude (Vařeka, 2002; Véle, 2006). According to Shumway-Cook and Woollacott (2011) the term postural orientation can be defined as the ability to maintain a desired relationship between body segments and space. For that reason, this relationship is essential for performing a purposeful movement in solving a given situation. In regard to static and dynamic postural stability, Nashner and McCollum (1985) introduced the idea of the functional postural stability. Static postural stability, according to these authors, refers to the ability to limit COG movement without any change of base of support, while the capacity to move the COG in a controlled manner within a fixed base of support is related to dynamic stability. Therefore, the functional postural stability is defined as the capacity to control COG movement within a shifting base of support.

In other words, postural stability is described as static when the base of support does not change (Shumway-Cook & Woollacott, 2011). On the other hand, if the body is in motion and the base of support is altered, is described as a dynamic postural stability. Yet, definitions may be different for different authors. For instance, dynamic balance is characterized as the ability to transition from a dynamic state to a static position or as maintaining stability while performing dynamic movements (DiStefano, Clark, & Padua, 2009), but also as the ability to perform a given task while maintaining or restoring a stable position (Winter et al., 1990), as well as the ability to maintain or regain balance on an unstable surface, with minimal movement outside the original base of support (Paillard & Noé, 2006). Static balance is defined as the capacity to keep the center of gravity above a base of support, but also as the ability to maintain an unchanging base of support with minimal body movement (Winter, Patla, & Frank, 1990). According to DiStefano, Clark and Padua (2009) two types of tasks can be used for the assessment of static balance. First, we are able to measure static balance while standing on a firm surface, and second, the measurement of static balance can be conducted while standing on an unstable surface. Considering the fact that static balance is the one where the base of support does not change, for the purpose of this research we included various static balance tasks on more demanding surfaces (such as stabilometer and the foam pad).

In the human body, we are unable to attain a state of absolute equilibrium. This is due to the fact that it constantly restores this equilibrium through corrective movements. Processes within the body, such as breathing, move the body from a static position. Kolář (2009) argues that dynamic phenomena implicitly characterize any static position, i.e., that the body's steady position is actually a process that goes against the locomotor apparatus's natural ability. As a result, it is not a one-time shift toward equilibrium but rather an ongoing shift toward a permanent position. This behavior is referred to as postural stability. As humans, we are constantly affected by the gravity, therefore if we want to maintain a balanced position with a titubation, such as standing, the action of this force pushes us to constantly engage the skeletal muscles, thereby compensating for minor changes (Tresilian, 2012).

The search for the center of gravity becomes more difficult when we have different body segments of different shapes and densities, such as the human body. The human body's proportions and current positions of its segments in relation to one another influence the body's center of mass. Thus, every new position of the body and limbs alters the precise location of the COM. For instance, each time we move our body parts (arms, legs, the head, and various parts of the trunk) our overall form changes. In the standard anatomical standing position, the body's center of gravity is directly in front of the second lumbar vertebra (L2) (Jelacic, Dedic, & Dindo, 2020).

2.2.2.2 Postural movement strategies

The body's vertical position is relatively unstable due to the high position or placement of center of gravity and small base of support (Horak, 2006; Shumway-Cook & Woollacott, 2001). Postural titubation, which is the active oscillation of the body's center of mass around the equilibrium position, is the dynamic event that represents maintaining a stabilized position (Horak, 2006). The ankle and hip mechanisms are mainly used in static strategies, while dynamic strategies mostly use step mechanisms (Vařeka, 2002; Fig. 2). The frontal plane and sagittal plane are where most movement strategies are used to keep the body in a stable position.

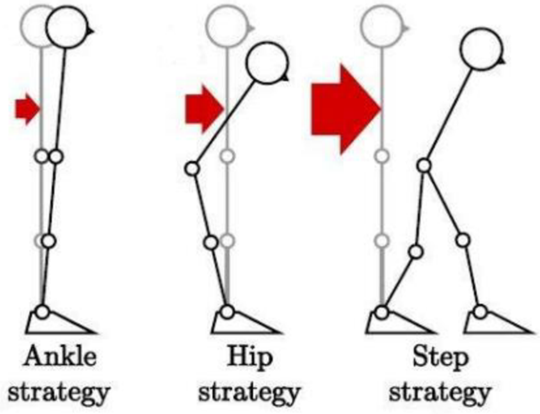

Figure 2. Ankle strategy, hip strategy, and step strategy. From "Gait analysis using optimality criteria imputed from human data" by A. M. Panchea, S. Miossec, O. Buttelli, P. Fraisse, A. Van Hamme, M.L. Welter, & N., Ramdani, 2017, *IFAC-PapersOnLine, 50*(1), 13510-13515. Copyright 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd

Movements in the sagittal plane are realized in three types of postural strategies: ankle strategy, hip strategy, and step motion strategy (Horak, 2006). The ankle strategy is the most effective in implementation of relatively slow postural deviations, in a situation where the vertical projection of the center of mass is within the limits of a fixed base of support, as minor postural deviations are corrected by movement in the ankle (Horak, 2006; Nashner, 1997). The body rotates around the ankle joints in what is known as the "inverted pendulum model" (Horak, 2006) and it results as the contraction of the distal muscles in the lower limbs, which produce torque in the ankle joints. In this case the individual muscles are engaged in a disto-proximal order (Nashner, 1997; Yucesoy, Maas, Koopman, Grootenboer, & Huijing 2006). The knee and hip joints are then stabilized by contracting the thigh and trunk muscles (Nashner, 1997). The use of the ankle strategy requires preserved muscle strength and an intact range of motion in the distal joints of the lower limb (Shumway-Cook & Woollacott, 2001).

The hip strategy is used when the use of the ankle strategy is no longer sufficient and the demands for maintaining stability are higher (for instance, on uneven surface or base support is narrow, or when visual control is disabled). In this situation, creating a rapid movement in the hip joints and counter-rotation in the ankle controls the movement of the body's center of mass (Brauer, Woollacott, & Shumway-Cook, 2001; Horak, 2006). Contrary to the ankle strategy, proximo-distal is the order in which each muscle is engaged to maintain stability. The activation of the anterior thigh muscles and abdominal muscles is necessary for the COG to move backward, which causes the hip joints to flex. On the other hand, the COG moves to the front because of the extension of the hip joints caused by the activity of the back paraspinal muscles and the thighs back muscles (Nashner, 1997).

Last but not least, the step movement strategy is used when the ankle or hip strategy are insufficient to maintain stability because the demands on balance are already too high (Shumway-Cook & Woollacott, 2001). As a consequence, older people and people with stability disorders tend to use the step strategy more frequently.

Movements in the frontal plane also include ankle, hip, and step motion strategy (Horak, 2006), yet the hip strategy is primarily responsible for providing stability in sagittal plane (Horak & Nashner, 1986). By activating the adductors of the contralateral limb and the abductors of the standing lower limb, lateral movement of the pelvis is the primary means of preserving mediolateral stability, and as a result, the muscles around the ankle start to move (Shumway-Cook & Woollacott, 2001). Also, unlike the stability in the hip strategy in the sagittal plane, stability in the frontal plane is provided proximo-distal (Horak & Nashner, 1986).

In real life, to keep stability it is necessary to combine all strategies mentioned above. A person’s goal, previous experience, as well as the nature of the external environment play a role in determining the best movement strategy (Shumway-Cook & Woollacott, 2001). Also, individual's physiological state or the quality of the sensory information available to the nervous system determine the selection of an appropriate strategy (Horak, Henry, & Shumway-Cook, 1997). For instance, the hip strategy is ineffective in patients with severe Parkinson's disease or individuals with complete vestibular insufficiency (Colnat-Coulbois, Gauchard, Maillard, Barroche, Vespignani, Auque, & Perrin, 2011), while patients with peripheral neuropathy of the lower limbs use the hip strategy more frequently (Mueller, Minor, Sahrmann, Schaaf, & Strube, 1994).

In elderly, during an increased demand of postural task, seniors use a hip strategy to compensate for stability in response to an external stimulus (for instance balancing on a mat, foam pad, or a platform), whereas young people prefer an ankle strategy in the same situation (Liaw, Chen, Pei, Leong, & Lau, 2009; Toledo & Brela, 2010). Also, the amount of postural response to fast platforms movement is slower in elderly than in young adults (Shumway-Cook & Woollacott, 2001). A possible reason for this could be in a limited range of motion in the ankle joints, muscle weakness, or decreased sensitivity of the receptors in the ankle joint. Thus, automatic postural responses to an external stimulus have longer latencies in older people than in younger individuals due to neurodegenerative changes (Liaw et al., 2009; Shumway-Cook & Woollacott, 2001), therefore the increased latency is also evident in voluntary movements and anticipatory postural strategies (Shumway-Cook & Woollacott, 2001; Sparto et al., 2008).

2.3 The effect of aging in postural control

Aging is associated with the sensory system and neuromuscular deterioration, which is involved in postural control and balance (Horak, 2006; Rees, Murphy, & Watsford, 2009). In the vestibular apparatus, as a result of the loss of neurons and their nuclei, their excitability decreases, therefore, the reactivity of the vestibulo-ocular reflex decreases. In addition to deterioration of visual acuity, accommodation and blurry vision disorders also include deterioration of proprioception on the lower limbs or degenerative changes in the vestibular apparatus (Zavázalová, Holmerová, Weber, Kalvach, Zadák, & Jirák, 2008).

Changes in the locomotor system are closely related to changes in the nervous system. As deterioration of motor control has an effect on the slowing down of movements, therefore, walking and making larger movements become challenging (Mikhael, Orr, Amsen, Greene, & Singh, 2010). A mobility disorders are caused by muscle loss (sarcopenia), muscle weakness, reduced muscle performance, and slower muscle contractions (Mikhael et al., 2010). Specifically, joint stiffness and mobility limitations are caused by degenerative changes in the cartilages, a decrease in their elasticity, and a decrease in the volume of synovial fluid (Kittnar, 2020). Therefore, a significant loss of muscle mass can adversely affect quality of life and reduce functional independence. A decline in skeletal muscle mass as a result of involutional changes is a significant factor in the decline in senior self-sufficiency (Rees, Murphy, & Watsford, 2007). In the skeletal system, there is a violation of the microarchitecture of the bone tissue, a decrease in the density of minerals and thus an increase in the fragility and brittleness of the bones. For instance, osteoporosis is among the most common metabolic diseases of the locomotor system of the elderly (Hála, 2005). Although often considered a typical guide to old age, osteoporosis contributes to a significant reduction in quality and length of life (Hála, 2005).

Elderly people are more likely to fall as their sensory and motor abilities decline with age (Hirjaková, Bizovska, Bzdúšková, Hlavačka, & Janura, 2020), i.e., as their postural deviations increase (Fernie, Gryfe, Holliday, & Llewellyn, 1982). The most common cause of falls in old age is a transient balance disorder, freezing of the lower limb during walking, when the body continues to move forward, and falls due to tripping with the tip of the foot (most often in Parkinson's disease) or other undifferentiated falls, often caused by inattention from on the part of the senior (Roth, Sekyrová, & Růžička, 2009; Topinková, 2005). Furthermore, once brain functions change, brain cells decline and become degenerative changes that affect both the peripheral and central nervous system, therefore physical and psychological resistance, adaptability, and compensatory mechanisms weaken. All these changes affect postural stability and increase the risk of falling (Ambler, 2011; Jančová & Kohlíková, 2007). Despite the fact that elderly individuals perceive harder everyday activities than younger generations, some of the conditions in which a decrease in stability in elderly individuals is expressed is in the condition of impaired visual conditions or in situations that additionally require the involvement of a cognitive task (a dual-task) (Priest, Salamon, & Hollman, 2008). For instance, in situations which somatosensory information is changed, decreased postural control as a result of aging is reflected in increased postural deviations during quiet standing with both opened and closed eyes (Horak, Nutt, & Nashner, 1992; Shumway-Cook & Woollacott, 2001). Nonetheless, the functional and anatomical changes described above do not occur in every senior. For each individual, there are changes in postural stability at different levels, there is also the possibility of partial compensation of some disorders. For example, the afferentation disorder from the area of the foot due to neuropathy in a person with diabetes can be replaced by an increased sensitivity to visual information, therefore disbalance may occur only in dim light environmental conditions (Horak, 2006).

2.4 The eye tracking system principle

Having in mind the significance of vision in daily activities and in maintenance of balance, specifically, some may address the question how vision can be analyzed. The most often used devices in assessing an eye behavior in quantitative research are the eye gaze trackers. The eye tracking system methodology is particularly useful to understand more about what and how a person can see while executing a movement action (Franchak & Adolph, 2010; Vickers, 2007). The system is used for recording and analyzing the visual information seen by a subject. This equipment allows us to detect the precise eye movement, to record the visual field, as well as to synchronize the gaze with recorded movements.

The early generations of the eye tracking measurements were based on the scleral search coils, electro-oculography, infrared-oculography and video-oculography principles, which were developed for clinical observations, researches in laboratories and controlled environment (Morimoto & Mimica, 2005). That equipment required contact lenses, electrodes, or head mounted devices. The modern video-oculography systems are usually digitalized video-based pupil/corneal reflection eye trackers which are the most widely used methods, also called invasive (head-mounted) and non-invasive (remote) eye tracking systems (Duchowsky, 2007; Morimoto & Mimica, 2005). The most popular head-mounted eye tracker glasses equipment exists in a single eye camera or multi eye cameras model (Chennamma & Yuan, 2013).

The eye tracker system methodology allows us to detect and measure the eye movements and its features (e.g. pupil size) shown in video frames and to map the gaze position coordinates (Blignaut, 2014). For eye gaze tracking, the 2D mapping-based approach is the most commonly used (Zhu & Ji, 2007). The system maps the eye by illuminating it with an infrared light which produces the glints around the cornea and this procedure is called “the corneal reflection” (Duchowsky, 2007; Merchant, Morrissette, & Porterfield, 1974). When glints detect the pupil (Fig. 3) it is necessary to fixate to a known point in environment in order to calibrate the eye tracker online. In the end, the system is able to project the point of regards showing us the exact eye position in the video and to provide information about the eye behavior (Duchowsky, 2007).

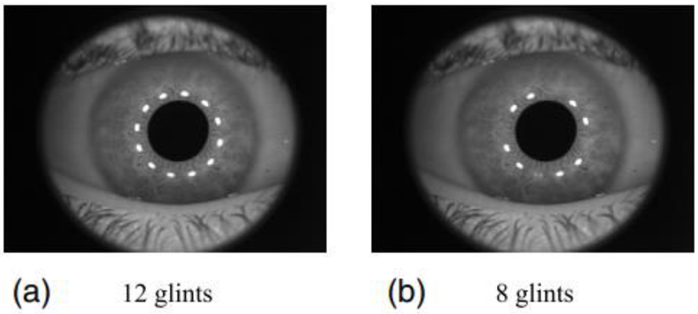

Figure 3. Glints around the pupil. From “Robust eye tracking based on multiple corneal reflections for clinical applications”, by C. Mestre, J. Gautier, & J. Pujol, 2018, *Journal of Biomedical Optics, 23*(3), 035001-035001. Copyright 2018 Society of Photo-Optical Instrumentation Engineers (SPIE)

With the eye tracker system methodology we are able to use the visual feedback of participants, including gaze direction and its distances, position of a fixation point, timing and duration of a fixation and number of fixations, as well as direction, timing, a number of saccades, and more (Hvelplund, 2014).

2.4.1 Eye tracking in science

Eye tracking system has become a popular research tool in a variety of studies in various scientific fields. It has found its wide application in cognitive and social psychology, neuroscience, visual control studies, rehabilitation, etc. (Vagaja, Bizovská, Janura, & Vařeka, 2019). Various measuring methods on eye movements have been used during years to understand more about cognitive processes such as decision making and problem solving, as well as motor and visual behavior. For instance, in the field of the feedforward motor control, studies were exploring a spatio-temporal gaze behavior during locomotion by analyzing a perceptual-motor control in children during obstacles navigation (Franchak & Adolph, 2010) and gaze behavior patterns while stepping over obstacles of different height (Patla & Vickers, 1997). Also, the majority of studies used the Quiet Eye concept to explore the effectiveness of gaze behavior on motor performance and motor learning. As an example, the concept was used to determine gaze and stepping behavior in elite ballet dancers and their gate control (Panchuk & Vickers, 2011), to examine gaze behavior during the execution of aiming task in a state of anxiety (Behan & Wilson, 2008) and to investigate the relation between attentional focus and gaze behavior in golf-putting task (Klostermann, Kredel, & Hossner, 2014) (for more information about motor performance and the Quiet Eye see Vickers, 2007).

Studies focusing on the feedback control system used the eye tracking system methodology to understand the close relationship between eyes behavior and postural control. For instance, Ajrezo, Wiener-Vacher and Bucci (2013) were quantifying the effects of various saccadic visual tasks on postural performance, including the surface area, the length, and the mean speed of the center of pressure (CoP) in their study. While participants were performing Standard Romberg stance on stability platform and maintaining balance, a fixation with a visual angel of 0.5 ° and visually guided horizontal saccades were used to manipulate with centrifugal and centripetal saccades that were randomly presented. The eye tracker system was used to analyze the mean latency of saccades (in milliseconds) and the mean number of saccades during fixation. Saccades with amplitudes less than 2° were counted during the fixation task, and all the eye movements were recorded binocularly with recording frequency set up on 300 Hz. Also, Thomas, Bampouras, Donovan and Dewhurst (2016) used the eye tracker system to assess the effects of fixations, smooth pursuits, and saccadic eye movements to generate different forms of retinal flow on postural control in healthy young and older females. In this study the authors also manipulated with various background conditions. Various visual scenes and different age groups were used as independent variables to measure their effect of postural sway. With the help of the eye tracker system, a gaze error was studied. The eye tracker was used to analyze the RMS of gaze error, which was calculated by subtracting the target position from the RMS of gaze throughout each video sequence, which was then used to measure errors of gaze in relation to the target. In addition, one year later the same authors conducted the experiment in which the effects of smooth pursuit and saccadic eye movements were assessed in young and older healthy females during walking , whilst posture and gaze were measured with motion analysis and the eye tracking equipment (Thomas, Dewhurst, Bampouras, Donovan, Macaluso, & Vannozzi, 2017). A 7 camera Vicon system and the same eye tracker methodology as in the authors' previous study were employed, with the gaze data sample at 50 Hz to analyze gaze errors variables during gait cycles and their relations, including trunk movement analyses, step-width, and a head rotation. Moreover, the application of the same device was seen in the study with the focus of investigating the medial-lateral postural control mechanisms and its' adjustment while performing voluntarily 80° lateral gaze shifts at different frequencies (Bonnet, Morio, Szaffarczyk, & Rougier, 2014).

Interestingly, the question was raised, however, regarding the possibility that wearing an eye tracker might have an effect on the performance of motor actions due to this advanced method of measuring eye movement. For instance, this issue was looked at in various sports performance studies, and they found that using these devices did not affect motor skills in any way (Vickers, 1996; Vickers, Rodrigues, & Edworthy, 2000). But, Gotardi, Rodrigues, Barbieri, Brito, Bonfim and Polastri (2020) conducted the study with the aim to investigate how wearing a head-mounted eye tracker affects upright balance during various visual tasks. While participants were asked to perform all visual conditions in order to compare whether or not the head-mounted eye tracker device had an effect on body sway, the results showed that wearing a head-mounted eye tracker attenuates body sway, i.e., wearing the device did not have any impact on the experiment itself. The authors argue that their significant outcome eliminates any methodological bias that could have been caused by using a head-mounted eye tracker in experiments aimed at determining the effects of eye movements and visual information on posture. The authors also mention their findings indicate that wearing the eye tracker may have an additional sensory information effect rather than just a mechanical one, due to the weight of the equipment because it did not affect the relationship between postural adjustments and eye movements in young adults, and that lighter eye tracker models, particularly those used in sports research, may present a similar effect.

Furthermore, the advantages of the eye tracker system methodology is also visible in the study that was analyzing saccadic reaction times (SRTs) during a task-switching smooth-pursuit eye tracking condition (Bieg, Bresciani, Bülthoff, & Chuang, 2013), in the study that examined the relations between postural sway and cognitive workload during various visual tasks, in which an index of cognitive activity (ICA) was used, as the part of the eye tracking system, which measures cognitive workload through a pupil dilation (Roh, Shin, & Lee, 2021), in the innovative research which implemented two advanced technologies, the infrared-based eye tracking technique together with Virtual Reality (VR) technology, with the aim to measure and analyze the oculometrics of latency, peak velocity, and error rate of pro-saccades and anti-saccades tasks while showing VR animations (Imaoka, Flury, & De Bruin, 2020), and much more.

2.5 The efficacy of saccadic eye movements on postural stability

In more recent time, a large number of studies commonly used fixation (a stable gaze), saccades or smooth-pursuit eye movements to understand the visual control of posture and an impact of various visual conditions on postural stability. For instance, Ajrezo, Wiener-Vacher and Bucci (2013) were assessing an effect of two oculomotor tasks, a fixation, and horizontal saccades, on postural stability in children during Standard Romberg condition. Ninety-five children (aged 5.83 to 17.58 years) were asked to perform the Standard Romberg test while standing on a force platform, with heels four centimeters apart and feet positioned symmetrically to the participant's sagittal axis at the angle of 30°. To assess the effects of visual tasks on postural stability, the surface area, the length, and the mean speed of the center of pressure (CoP) were measured. In addition, Kim, Moon, and Cho (2016) have manipulated with horizontal, vertical, and diagonal smooth-pursuit eye movements visual conditions, with a target speed set on at 10°/s, 20°/s, and 30°/s for all three visual directions. To analyze the influence of those visual tasks on a balance in static posture, forty young adults (23.24 ± 2.58 years) participants were asked to stand on the TETRAX biofeedback system platform. Besides, Thomas, Bampouras, Donovan and Dewhurst (2016) used a force platform analyzes to explore the effect of a fixation, saccadic and smooth-pursuit visual conditions on postural control. Twelve young adult (26.1 ± 4.9 years) and twelve elderly (72.8 ± 6.9 years) females participated in this study. While participants were standing still on a force platform with their feet together, a fixation, saccadic and smooth-pursuit eye movements conditions with a combination of fixed, absent, and oscillating visual background were presented. Also, Legrand et al. (2013) manipulated with two fixation conditions (with and without distractors), two pro-saccade conditions (towards a target) and one anti-saccade condition (in the opposite direction of a target), while performing Standard Romberg test and tandem test, for which participants were instructed to place their feet in a semi-tandem position with the dominant foot in front of the non-dominant. Furthermore, three more studies conducted similar experiments to analyze the influence of saccadic eye movements on body sway magnitude while standing upright. In Rodrigues et al. (2013) twelve young adults (21.9 ± 3.6 years) stood in wide stance (in align with shoulders) and narrow stance (feet together) and were instructed to follow three conditions: fixation condition and saccadic conditions with low and high frequencies, at 0.5 and 1.1 Hz, respectively. Similarly, the same experimental protocol with similar trial repetitions was used in the study with twelve elderly (73.6 ± 6.4 years) participants (Aguiar et al., 2015). Whereas, in Rodrigues et al. (2015) ten young adults (19.5 ± 1.91 years) stood in wide stance (in align with hips) while being instructed to follow saccadic and smooth pursuit eye movements conditions during low and high frequencies, at 0.5 and 1.1 Hz, respectively. In all three studies, the body sway was measured by using reflecting markers that were attached to participants' head, above the occipital bone, and on the back, between the scapulae at the level of the 8th thoracic vertebra. Moreover, similarly to the previous studies mentioned, Dault, Geurts, Mulder and Duysens (2001) conducted the experiment with the aim to assess postural control modifications during various levels of balance tasks difficulties when a cognitive task was added. In their experiment three different levels of balance task were included, shoulder width normal stance, shoulder width stance while standing on two individual seesaws (shoulder–seesaw), and tandem stance while standing on the seesaws (tandem–seesaw), all placed on one of the force plates. The authors have manipulated with a shorten version of the Stroop task, for which three tasks were used, the word card, the color card, and the color-word card, considered as the cognitive task. While performing randomized order of balance tasks, participants were asked to complete various cognitive tasks by reading the cards, such as to read the color name on the word card and name the color of the block, from right to the left and from up to down.

Ambiguous results are suggesting that fixating a stable cue facilitates balance performance (Paulus, Straube, & Brandt, 1984; Schulmann, Godfrey, & Fisher, 1987), but also increases the excursion of center of pressure (Ajrezo, Wiener-Vacher, & Bucci, 2013). It was also found that a postural sway is attenuated by a stationary fixation on a fixed background, in contrast to smooth pursuit eye movements and oscillating background that increases it (Thomas, Bampouras, Donovan, & Dewhurst, 2016). In addition, a static visual background has a stabilizing effect on posture, apart from a fixation or a moving visual condition (Laurens et al., 2010). Furthermore, saccadic eye movements were shown to improve postural stability (Aguiar et al., 2015; Legrand et al., 2013; Rey, Lê, Bertin, & Kapoula, 2008; Rodrigues et al., 2013, 2015; Rougier & Garin, 2007; Stoffregen, Bardy, Bonnet, Hove, & Oullier, 2007; Uchida et al., 1979) comparing to fixation task, while other researchers found no effects on posture while performing saccadic eye movements (Glasauer et al., 2005; White, Post, & Leibowitz, 1980). Moreover, it was found that saccadic eye movements reduce postural sway while performed in the dark (Uchida et al., 1979), and that a postural instability is higher during smooth pursuit eye condition with respect to a fixation condition (Glasauer et al., 2005). Furthermore, in regard to the cognitive dual-task manipulation on postural control during more difficult levels of balance tasks (Dault, Geurts, Mulder, & Duysens, 2001), several significant outcomes are to be mentioned. First, changes in balance have occurred independently from the cognitive tasks, showing tandem–seesaw stance as the most difficult stance to maintain in lateral direction, and showing larger amplitude, frequency and velocity of the COP in shoulder width and tandem- seesaw stance compared to the shoulder width stance condition in AP postural direction. Second, the shoulder–seesaw stance was affected by a Stroop tasks showing decrease in amplitude, yet independently from a Stroop task difficulty. Third, the authors found that postural frequency in tandem–seesaw stance was more affected by the addition of a Stroop task than the other stances in the lateral direction, and fourth, the increase in velocity of postural sway was significant in tandem–seesaw stance during a Stroop task, regardless of Stroop task difficulty. Yet, no influence of the level of difficulty of the Stroop task on the degree of dual-task interference during any of the postural stance was found in this study. However, controversial results in earlier studies might be due to the fact that various methodology protocols and variables were used, such as different postural tasks (narrow or wide bipedal positions), different gaze tasks (directions, frequencies, amplitudes), different backgrounds, tasks performed in the dark, eyes opened/closed, or different age groups.

2.6 The functionality of attention in postural control

Several previous studies have been focusing on the fact that performing a suprapostural (dual) task, like auditory reaction time (see Lajoie, Teasdale, Bard, & Fleury, 1993), visual matching (Dault, Geurts, Mulder, & Duygens, 2001), or mental arithmetic (Yardley, Gardner, Leadbetter, & Lavie, 1999) increase body sway. These outcomes were often described in terms of the competitive allocation of central processing resources in dual-task activities, i.e., between two tasks being simultaneously performed (Abernethy, 1988; Lajoie et al., 1993; Teasdale et al., 1993. The idea behind is that postural and suprapostural activities are separate tasks that use a different set of the same central pool of cognitive processing resources. As a result, it is generally predicted that the performance of either postural control, a suprapostural task, or both, should suffer (will reduce in performance) when postural control is combined with a suprapostural activity (for the review, see Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Woollacott & Shumway-Cook, 2002).

For instance, Schmidt and Lee (2011) argue that the attention is viewed as limited as the humans have limited capacity to focus on several different things at the same time. Specifically, attention's limited capacity has been illustrated in the ability to perform two tasks simultaneously, since both tasks/activities require attention in order to be well performed. But, if two tasks are performed simultaneously, at least one of them will be performed automatically, as the other task obtains "full" attention. Still, this automatization will occur if motor skills in both tasks are very well developed (Schmidt & Lee, 2011). The explanation for this lies in the interfering pattern model (Schmidt & Lee, 2011). In a dual-task situation, both actions (A) and (B) require a certain amount of attention. Since the amount of attentional capacity is thought to be limited, it means one action/performance will interfere with performance of another. This interference could result in: 1) performance of action (B) could suffer in quality while action's (A) performance stays unaffected; 2) the vice versa - action (A) can suffer while action (B) is unaffected; 3) both performances are affected; or 4) one action is prevented from occurring while the other one is in progress (Schmidt & Lee, 2011). As a result, in a dual-task situation, directing/shifting attention to activity (A) from the other activity (B) puts deficit in the performance of a secondary (B) task.

Within its limited capacity, attention can be distinguished as overt and covert (Hoffman, 1998; Posner, 1980). According to Posner (1980), the overt attention can be measured by the head and/or eye movement, while on the other hand, the covert attention cannot be observed, and it goes under mental (cognitive) process. Still, both systems are able to be controlled and shifted separately from each other (Posner, 1980, Posner & Raichle, 1994). In order to do that, it is possible to direct eye movements (overt attention) to one specific stimulus, while focusing on something very differently (covert attention) in response to cueing. More specifically, the covert attention means that we may recognize something (a sudden stimulation) in our peripheral environment but not to gaze towards it. In other words, during overt attention a person is clearly paying attention and looking at the object when they move their head and eyes in that direction. But, allowing the brain to focus on another object (i.e., to shift the attention) without moving the eyes in that exact direction is known as the covert attention (Hoffman, 1998; Posner, 1980). For instance, while catching a ball during a basketball game, we are looking in front of us in the direction of the ball, but we are aware of other players approaching us, without looking straight at them. Overall, the visual attention and cognitive attention are important for motor performance, as an individual needs to be able to perceive and assess the visual information from the environment, so that motor response can be appropriate to the changing situation. As an interesting aspect to analyze, the over attention is easy to record with eye tracker devices, which explains why it has been extensively studied in modern time.

Regarding attentional demands of various postural tasks within dual-task paradigms, one may ask the question: which task will receive a higher priority in terms of the attentional resources' allocation in a dual-task situation in which maintaining postural stability is performed simultaneously with another task? It was reported that, while performing a postural stability task (a quiet stance), a focal (main) voluntary movement is delayed long enough to trigger anticipatory postural adjustments, that ensure stability is maintained (Cordo & Nashner, 1982; Horak, Esselman, Anderson, & Lynch, 1984). If there is a secondary task included during a postural task, the reaction time for the secondary task is reduced which lowers the stability demand of the (main) postural task (Cordo & Nashner, 1982). That is, if one of two motor tasks that are "competing" during maintaining stability is postural control, the postural stability control is a priority (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Based on this, it is reasonable to assume that the "posture first" principle applies to all dual-task situations. As a result, when a person is working on both postural and cognitive tasks at the same time, their focus would be on postural control, which ensures stability and may have an impact on how well they do on the cognitive task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). As an example, it was found that, compared to elderly, young adults successfully used an arm swing to keep their balance, without being affected by a secondary task, in a postural dual-task in which a secondary mental arithmetic task was included (Stelmach, Zelaznik, & Lowe, 1990). This means that the "posture first" hypothesis could be supported for young adults, yet it is possible the attentional allocation priorities while performing dual-tasks may change with age (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997).

Another example of a dual-task paradigm is the Adaptive resource-sharing model (Mitra, 2004). The model was introduced as an answer to contradictory results of previous studies in which it was shown that cognitive suprapostural task have either stabilizing or destabilizing effect on postural sway, as well as the fact that those outcomes are the result of differences in prioritizing the instructions during which participants were introduced in dual-tasks experiments. For example, while one number of studies asked their participants to minimize their sway while performing suprapostural task (Dault et al., 2003; Hunter & Hoffman, 2001; Redfern, Jennings, Martin, & Furman, 2001; Redfern, Talkowski, Jennings, & Furman, 2004; Vuillerme, Nougier, & Teasdale, 2000), the others asked participants to perform a suprapostural task without giving any instruction to postural control (Dault, Geurts, Mulder, & Duysens, 2001; Mitra, 2003; Yardley, Gardner, Bronstein, Davies, Buckwell, & Luxon, 2001). Thus, the same author (Mitra, 2004) was focusing on the novel approach by Stoffregen, Smart, Bardy and Pagulayan (1999) who combined an upright stance (as a postural task) with a visual fixation (as a suprapostural task) to demonstrate that a body sway variability was not controlled by optic flow in a task-independent manner (autonomous control) but rather regulated by the demands of the suprapostural (visual) task (facilitatory control). Mitra (2004) found the opposite results showing evidences of autonomous control and no indication of facilitatory control in their study, which means that a posture control and some cognitive tasks have concurrent demands on the same capacity-limited resources. That is, the Adaptive resource-sharing model (Mitra, 2004) argues that participants' increase and decrease in sway across experimental conditions may originate from either stabilization or facilitation actions, or partially from both, depending on a number of factors. More specifically, Mitra and Fraizer (2004) further explain, that performance may originate from the system's inability to maintain the same level of either type of action due to capacity constraints or structural interference. The precise pattern of postural sway that is observed may depend on, for example, on how precise the postural and suprapostural components (activity) need to be, on how well the perceptual information that is available supports each component, on how difficult it is to acquire all of the necessary information, and on how much attention is being paid to each component (Mitra & Fraizer, 2004). Therefore, the faciliatory control can be detected when the suprapostural task precision is high (e.g., precise eye fixation or aiming actions) while the balancing component is relatively easy (e.g., support surface area is large and rigid, and there are no perturbations), in which case a performance can be aided by postural adjustments (Mitra & Fraizer, 2004). This could be the case, for instance, when a person needs to read something from a distance while maintaining a stable stance in a comfortable position. Or, posture control can help with a reading by either supporting a lean in the direction of the stimulus or reducing head movements to help with accurate fixation (Mitra & Fraizer, 2004). Then, there are two examples in which an autonomous sway minimization control can be detected. For instance, if balancing task becomes difficult (e.g., higher stance perturbations), all available resources will become dedicated to it, and performance in the suprapostural task may suffer (Mitra & Fraizer, 2004). This could happen, for instance, when standing in a crowded public transportation, and in this case, the previously mentioned "posture first" principle is recognized in the adaptive resource-sharing. In the end, the last pattern is explained in the Adaptive resource-sharing pattern in which postural sway is partly facilitatory, and partly autonomous, also known as the "hybrid" pattern. This means, when a suprapostural task's demand and cognitive load are high while the postural task is also demanding (without threatening imminent loss of balance), the adaptive resource-sharing takes the place of resource competition. As a conclusion, the performance "trade-off" results are typically explained by resource competition because the system cannot reserve its capacity for facilitatory actions and must share or prioritize between postural and suprapostural performance (Mitra, 2004; Mitra & Fraizer, 2004).

On the other hand, another concepts of attentional demand in postural control existing in the literature which argues the opposite from the authors mentioned in previous paragraph, is the "U-shaped nonlinear interaction model" (Lacour, Bernard-Demanze, & Dumitrescu, 2008) which says that suprapostural (dual-task) activities can support the adjustment of postural control. It describes the condition in which a secondary task (cognitive or motor) during postural task leads to a better postural stability, because the execution of a secondary task allows attention to focus on a secondary task rather than on a postural performance. This means that shifting attentional focus away from postural control makes a postural performance more automatic (automatic attentional system) (Vuillerme & Nafati, 2007). Following this model, one may assume that horizontal or vertical saccades (as a secondary task) may help with a body movements automatization, as they may prevent someone's attention to focus on a postural task but rather on a visual task.

2.6.1 The visual stabilization of posture and the functional integration of posture and gaze control paradigm

In addition to the previous chapter, this new chapter will introduce the paradigm that is the focus of our study. Stoffregen, Bardy, Bonnet and Pagulayan (2006) established a general opinion that could possibly explain underlying mechanisms used while performing suprapostural (dual) task (such as visual task, reaction time task, cognitive task, or generally any other task that is being performed simultaneously) during standing. The authors argue that a postural control can be accommodated to support the realization of suprapostural activity (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, et al., 2007). In this manner, regards to suprapostural visual task, it was suggested that a body sway might be adjusted during visual search to facilitate eye movements (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). In other words, saccadic eye movements lead to a decreased body sway to allow more accurate gaze shifts (Rodrigues et al., 2013, 2015; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). This opinion is explained as the "functional relationship between eye movements and a body sway", as a very little change in a body sway may influence the accuracy of the eye movements (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). More specifically, Stoffregen et al. (2000) conducted a study to measure postural sway during standing while participants performed two visual tasks. While one group of participants had to look at a blank target (as an inspection task rather than a fixation task because participants were not required to maintain focus on a specific point), a second group of participants were looking at a target covered in text and were asked to search the text for instances of a specified target letter and count them. The visual angle of the targets remained constant across distance variations. The standard deviation (SD) of the head and torso displacements, analyzed separately for the AP and ML axes was used to operationalize the amplitude of postural sway. As a result, the sway variability was primarily influenced by the suprapostural task, with target distance also having a significant impact (cf. Stoffregen et al., 1999). As anticipated, sway variability in AP postural direction was significantly lower in the visual search than in the inspection of blank targets. The extended experiment by Stoffregen et al. (2000) used prolonged sequence of coordinated gaze shifts, also known as visually guided eye movements, in addition to brief periods of fixed gaze (fixation). The purpose of the functional changes in sway might have been to make it easier to control either the shifting or stationary gaze, or both. The hypothesis that body sway can be manipulated to support changes in gaze direction was tested in this study. The authors hypothesized that body sway and visually guided eye movements would have a functional relationship. This is due to the fact that even minor shifts in body sway can affect the precision of such eye movements. In contrast, small changes in body sway do not facilitate or disrupt eye movements that are not visually guided, such as those made in the dark or with the eyes closed (Stoffregen et al., 2000).

Moreover, while performing a dual-task, rather than using a competitive processing activity of central cognitive resources (for a review, see Woollacott & Shumway-Cook, 2002) that may reduce postural control, a posture, and a certain type of suprapostural activity can be integrated, and therefore, to improve performance. The explanation is based on the idea that two different mechanisms promote a visual stabilization of posture that relates to afferent and efferent motion perception (Guerraz & Bronstein, 2008). The afferent mechanism tries to stabilize a visual flow (retinal slip) of an image projected on retina, and to minimize changes between a body sway and a stable gaze, whereas the efferent mechanism (efference copy) activates to reduce a body sway to stabilize pre-saccades and post-saccades and therefore to form a spatial accuracy of the saccades (Guerraz & Bronstein, 2008; Rodrigues et al., 2013).

Analogically to the preceded paragraphs, we can expect that a functional coupling between postural control and a gaze behavior might be moderated by a demand of a visual task. Based on this general prediction, we can presume if a visual task is more challenging a postural stability might increase in order to support solving a visual task. Yet, that raises the question of how a more challenging visual task affects postural control while performing more challenging balance task?

The aging process includes several performance diminutions that increases the risks of falls (Muir, Kiel, Hannan, Magaziner, & Rubin, 2013). Limited attentional capabilities and deficit in sensory and motor control in elderly is reflected in a reduction of a functional integration of visual cues into the postural control (Massion, 1994), and those decrements in performances have been evident during more difficult postural conditions (Toledo & Barela, 2014). Also, impaired performance in eye-movement tasks is manifested in elderly compared with young adults (Aguiar et al., 2015). In general, reduced accuracy of saccadic eye movements (Warren, Thurtell, Carroll, & Wall, 2013) and slower saccadic reaction time (SRTs) (Moschner & Baloh, 1994) are demonstrated in elderly. Due to these facts, elderly participants were also included in the research.

3 Aim and hypotheses of the research

3.1 The main aim

The main aim of the research is to analyze the effect of saccadic eye movements on postural stability during different levels of demands of balance tasks in healthy young adults and in healthy elderly.

3.2 The sub-aims and hypotheses

The sub-aim 1: To investigate the effect of various frequencies and directions of saccadic eye movements on postural stability in healthy young adults. The following hypotheses for study 1 are proposed:

H1: Various speeds of saccadic eye movements influence postural stability in more demanding balance task in healthy young adults.

H2: Various directions of saccadic eye movements influence postural stability in more demanding balance task in healthy young adults.

The sub-aim 2: To investigate the effect of various directions of saccadic eye movements on postural stability in more demanding balance task in healthy elderly. The following hypothesis for study 2 is proposed:

H3: Various directions of saccadic eye movements influence postural stability in more demanding balance task in healthy elderly.

The sub-aim 3: To investigate the effect of saccadic eye movements on postural stability in various levels of difficulty of balance task in healthy young adults. The following hypothesis and research question for study 3 are proposed:

H4: The influence of saccadic eye movements on postural stability differs with various levels of difficulty of balance tasks in healthy young adults.

Research question: Is there a relationship between selected eye movements' parameters and the level of postural stability?

4 Methods

4.1 Basic research design

The design of the research is based on experimentation. Within this experiment, the effect of various saccadic eye movements on postural stability was analyzed. The experiment design includes central, horizontal, and vertical visual tasks as independent variables in all three studies, and balance performance (in study 1) and postural sway (in all three studies) as dependent variables. In addition, in study 3, the horizontal saccades' amplitude is considered to be a moderator between independent variables (visual conditions) and dependent variables (postural sway). All experiments are based on the within-subject design and were carried out in a laboratory setting that was the same for all three studies.

In all three studies, participants with medical conditions, such as visual impairment (including eyes abnormalities), neurological impairment, musculoskeletal disorders, with complaints of dizziness or vertigo, or with similar comorbid conditions were not included in the study. Participation in the study was voluntary and without any incentives. Information about the purpose of the study was given to all participants before the experiment. The study was conducted after the approval by the Ethical Committee of the Faculty of Physical Culture, Palacky University in Olomouc and participants signed written informed consent before testing.

4.2 Study 1

4.2.1 Participants

A total number of thirty-two (32) healthy young adults (15 males, 17 females, age 22.8 ± 2.7 years, height 170.6 ± 7.9 cm, body mass 68.8 ± 10.6 kg) participated in this study. A priori power analysis showed that a sample size of 15 participants would be sufficient to identify a significant effect of the five independent variables with 12 trials of repeated measurements within-subject design with a power ($1 - \beta$) of 0.80, effect size f of 0.26, and an α of 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007).

4.2.2 Apparatus

Stabilometer

The main task was to maintain balance on stabilometer (model 16030, Lafayette Instrument, Indiana, IN, USA; sampling frequency 25 Hz) positioned in a distance of 1.5 m from a screen (Hunter & Hoffman, 2001). The stabilometer platform tilts to the left and the right with a maximum deviation of 15° on both sides and is used for maintaining balance, i.e., to be kept in a horizontal plane during standing position (Fig. 4).

Figure 4. Stabilometer (model 16030, Lafayette Instrument, Indiana, IN, USA)

Accelerometer

In this study, one 3D accelerometer (Trigno wireless system, Delsys Inc., Natick, MA, USA, sampling rate 148 Hz) (Fig. 5) was securely attached to participants' lower back at the level of the fifth lumbar vertebra (L5) (Fig. 6). The acceleration signal was recorded for each trial in medial-lateral (ML) and anterior-posterior (AP) directions.

Figure 5. 3D accelerometer (Trigno wireless system, Delsys Inc., Natick, MA, USA)

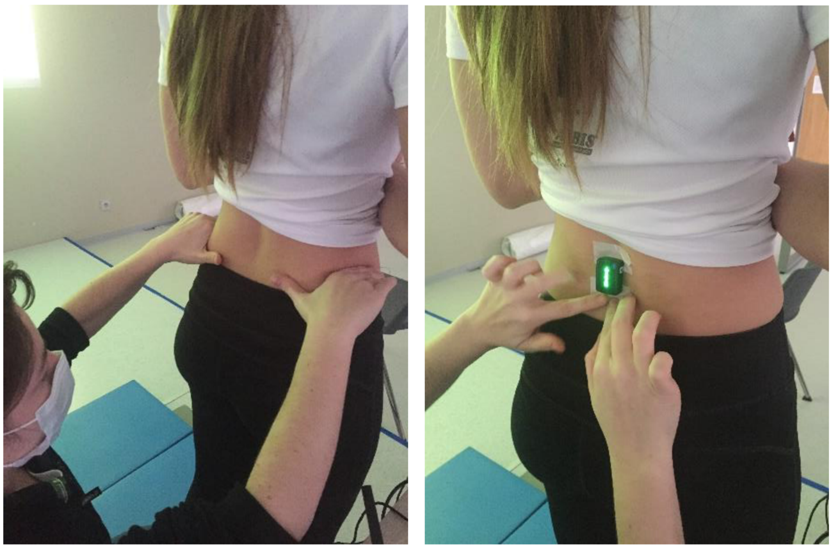

Figure 6. Accelerometer attached at participant's lower back at the level of L5

Eye tracker

A head mounted eye tracker (SMI ETG 2W, SensoMotoric Instruments GmbH, Teltow, Germany) has been used. In study 1, the eye tracking system was used only for the online visual manipulation check. The eye tracking system is consisted of a head gear (eyeglasses) and a battery pack. SMI glasses (SMI ETG 2W, SensoMotoric Instruments GmbH, Teltow, Germany) contain two eye cameras focused on participant's eyes, built-in on the inner frame of the glasses, and a field camera installed on the external part of the frame above the nose (in the middle of the glasses) which records the visual field seen from participant's perspective (Fig. 7). The head gear (glasses) were attached to the laptop and the examiner was able to follow participant's eye movements online through the iView ETG eye tracker software (SensoMotoric Instruments GmbH, Teltow, Germany). The same software was used for recording the gaze. The eye movements were recorded binocularly with the gaze tracking accuracy of 0.5° and gaze tracking range of 80° horizontal and 60° vertical. The recording resolution of the scene camera was set to 960 × 720 pixels and the sampling rate for both scene camera and eye cameras was set at 30 Hz.

Figure 7. SMI eye tracker glasses.

4.2.3 Procedures

Visual stimuli

Visual cues were projected on the screen from the video projector Epson EB-96W (Seiko Epson Corporation, Suwa, Japan) installed on the ceiling. During maintaining balance, participants were asked to follow five visual conditions: a) fixation condition, b) horizontal slow saccadic eye movements at the frequency of 0.5 Hz, c) horizontal fast saccadic eye movements at the frequency of 1.1 Hz, d) vertical slow saccadic eye movements at the frequency of 0.5 Hz, and e) vertical fast saccadic eye movements at the frequency of 1.1 Hz (Aguiar et al., 2015; Rodrigues et al., 2015).

Stimulus was a black dot (cue), in a diameter of 2 cm presented on the white screen in front of participants at the level of their eyes, which was adopted by the height of participants. The height adaptation was divided into four categories (150-160 cm, 160-170cm, 170-180 cm, 180-190 cm) so that all visual stimuli would fit each participant's height and appear in front of a participant in the exact same visual angle. Shifts in gaze without head rotation are achieved in cases when the angular change in a direction of gaze is less than 15° (Hallet, 1986), therefore, both horizontal and vertical conditions were visually designed within the visual angle of 11° (Aguiar et al., 2015; Rodrigues et al., 2015) in order to minimize head movement. Still, there were no restrictions to participants about their head movement during trials (Aguiar et al., 2015).

In the fixation condition, the black dot appeared in the center of the screen. During the entire trial, the dot was on the screen and participants were asked to fixate it. During horizontal slow and horizontal fast saccadic conditions, participants were asked to follow the dots that were appearing and disappearing in horizontal direction during the entire trial at the frequencies 0.5 Hz and 1.1 Hz, respectively. Saccadic distance between left and right dots was 29 cm, i.e., 14.5 cm from the center on the left and the right side. The same procedure was followed for the vertical direction.

The entire experiment consisted 36 trials that were divided into 6 blocks. Each trial lasted 30 seconds. The rest interval between each trial was 30 s and between each block 1 min. Before the beginning of the experiment, each participant was required to wear sports shoes and to perform one practice trial in a duration of 15 s to become familiar with a task. The order of visual tasks was randomized. I.e., the first block started with two central conditions, followed by two vertical conditions (slow then fast) and horizontal conditions (slow then fast), etc. Participants were asked to stand on the stabilometer platform in a comfortable position with eyes open and arms alongside the body. They were instructed to stand as still as possible and to follow a visual pattern as trial begins. The measurement started when participant stabilized horizontal position on the platform, a few seconds after the change of position from stable to unstable.

The eye tracker calibration procedures (Fig. 8) was done with a three-point calibration while participant was instructed to randomly fixate gaze at the central, horizontal, and vertical dots presented in front of them on the screen. Calibration was done at the beginning of each block and after the third trial in each block. The system was re-calibrated if the points of regard deviation was more than 0.5° of visual angle from the calibration points. The examiner followed the iView ETG eye tracker online system to control the calibration, and to confirm on the spot if all participants were following the given instructions in all trials during experiments. A battery pack from the eye tracker glasses was put into a bum bag so that each participant carried the bum bag around their waist in order to move freely.

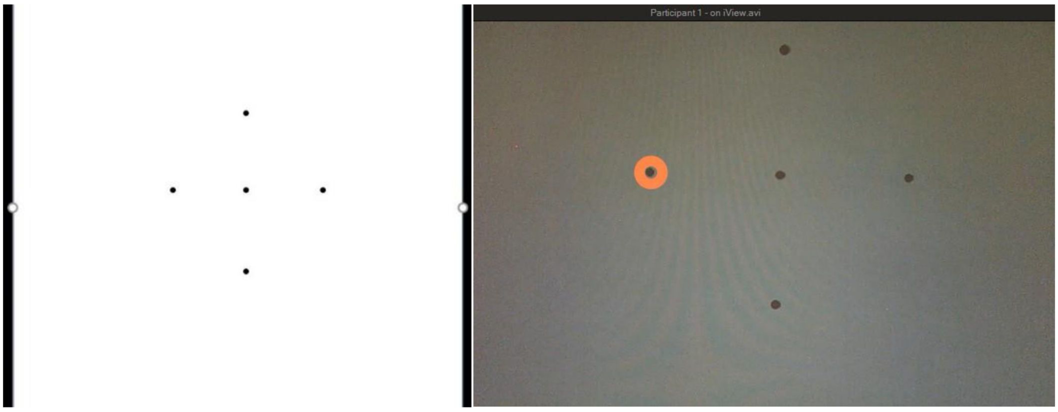

Figure 8. Calibration points and the eye cursor focused on the left horizontal point

In addition, stabilometer and the eye tracker were synchronized with a sound signalization to control the trials. The synchronization between stabilometer laptop and eye tracker SMI-ETG laptop was done with the parallel port interfacing through the peripheral component interconnect express card and line print terminal connector. A transistor-transistor logic signals from the stabilometer software were received in the iView ETG eye tracker software at the beginning and the end of each trial. Using the "event log" in the iView software, each trigger line was controlled during each trial. The beginning of each trial was defined in the recording with the trigger line, which synchronized the eye movement recording with the recording of the acceleration of the lower torso.

4.2.4 Data processing and data analysis

For the stabilometer data analysis, the procedure described by Shea and Wulf (1999) was followed to compute root mean square error (RMSE). RMSE describes the deviation of the contact surface from the horizontal position identified as 0°. The higher the RMSE the less stable posture during the task indicating that RMSE is a measure of postural sway in medial-lateral direction if used for assessment of postural stability during standing on stabilometer.

For the accelerometers data analyses, the acceleration signals were filtered using the 4th order low-pass bidirectional Butterworth filter with a cut-off frequency of 10 Hz. From acceleration signals, root-mean-square (RMS) as a characteristic of variability was computed for each direction and each speed. The computed variables of acceleration signals from the lower back at the level of (L5) (RMS in ML and AP directions) were averaged for trials with the same visual conditions. Data analysis was performed in the software MatLab (R2017b, MathWorks, Inc., Natick, MA, USA).

4.2.5 Statistical analysis

Kolmogorov-Smirnov test was used for analysis of distribution confirming normal distribution for all variables. Repeated measures analysis of variance (ANOVA) followed by Bonferroni post-hoc test was performed for the effect of conditions. For investigation of effect of speed of saccades, results obtained from horizontal slow and vertical slow trials were averaged to obtain the Slow saccades condition, and horizontal fast and vertical fast trials were averaged to obtain the Fast condition. Similarly, for investigation of direction of saccades, horizontal slow and horizontal fast trials results were averaged to obtain the Horizontal condition, and vertical slow and vertical fast trials were averaged to obtain Vertical condition. Analyses were performed at significance level $p = 0.05$. Analyzes are done in software Statistica (v. 12, StatSoft, Inc., Tulsa, OK, USA).

4.3 Study 2

4.3.1 Participants

A total number of eighteen (18) elderly subjects (3 males, 15 females, age 70.3 ± 7.7 years, height 164.4 ± 6.0 cm, body mass 74.7 ± 9.5 kg) participated in this study. A priori power analysis showed that 18 participants would be sufficient to identify a significant effect of the three independent variables with three blocks of repeated measurements within-subject design with a power (1 - β) of 0.80, effect size f of 0.26, and an α of 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007).

4.3.2 Apparatus

The main task was to maintain balance while standing barefoot on the foam pad (Airex Balance Pad, Airex AG, Sins, Switzerland). The same as in the previous study, one 3D accelerometer (Trigno wireless system, Delsys Inc., Natick, MA, USA, sampling rate 148 Hz) was securely attached to the participants' lower back at the level of (L5), and the acceleration signal in ML and AP directions was recorded in each trial. Also, participants wore a head mounted eye tracker (SMI ETG 2W, SensoMotoric Instruments GmbH, Teltow, Germany; sampling frequency 30 Hz) (see above in study 1) in order to check if participants were following a given instructions (manipulation check purpose only).

4.3.3 Procedures

Visual stimuli

During maintaining balance, participants were asked to follow three visual conditions: a) fixation condition, b) horizontal saccadic eye movements at the frequency of 1.1 Hz, and c) vertical saccadic eye movements at the frequency of 1.1 Hz (Aguiar et al., 2015; Rodrigues et al., 2015).

The entire experiment consisted 18 trials that were divided into 3 blocks, and each trial lasted 30 seconds. A sound signalization between gaze recording and a balance task was used to control the beginning and the end of each trial. After a practice trial at the beginning of the experiment, participants were asked to stand on the foam pad in a comfortable position with eyes open and arms alongside with the instructions to stand as still as possible and to follow a visual task as it starts. Each trial started a few seconds after participants were positioned into the stabilized final position.

4.3.4 Data processing and data analysis

The same procedure was followed as in the previous study. Acceleration signals were filtered using the 4th order low-pass bidirectional Butterworth filter with a cut-off frequency of 10 Hz. From acceleration signals, (RMS) was computed in each direction.

4.3.5 Statistical analysis

Shapiro-Wilk test confirmed normal distribution for all variables. Repeated measures analysis of variance (ANOVA) followed by Bonferroni post-hoc test was performed for the effect of conditions. The significance level was set at $p = 0.05$. Statistical analysis was performed in the software Statistica (v. 12, StatSoft, Inc., Tulsa, OK, USA).

4.4 Study 3

4.4.1 Participants

A total number of twenty-one (21) healthy young adults (21 females, age 21.8 ± 1.1 years, height 167.5 ± 6.9 cm, body mass 60.3 ±7.8 kg) participated in this study. G-power analysis was unable to calculate a priori sample size for three-way Anova.

4.4.2 Apparatus

The foam pad (Airex Balance Pad, Airex AG, Sins, Switzerland) and one 3D accelerometer (Trigno wireless system, Delsys Inc., Natick, MA, USA, sampling rate 370 Hz) were used as in the previous studies (see above).

Eye tracker

The same head mounted eye tracker glasses were used (SMI ETG 2W, SensoMotoric Instruments GmbH, Teltow, Germany; sampling frequency 30 Hz) as in previous two studies (see above). Yet, in this study the system was used to record and analyze participants' eye behavior.

4.4.3 Procedures

Visual stimuli

The same visual stimuli were presented as in the second study (see above). I.e., participants were asked to follow three visual conditions: a) fixation condition, b) horizontal saccadic eye movements at the frequency of 1.1 Hz, and c) vertical saccadic eye movements at the frequency of 1.1 Hz (Aguiar et al., 2015; Rodrigues et al., 2015).

While standing on the foam pad, participants were asked to maintain balance in four different stance positions: a) normal stance, b) feet together stance, c) stance on a dominant leg and d) tandem stance (Fig. 9).

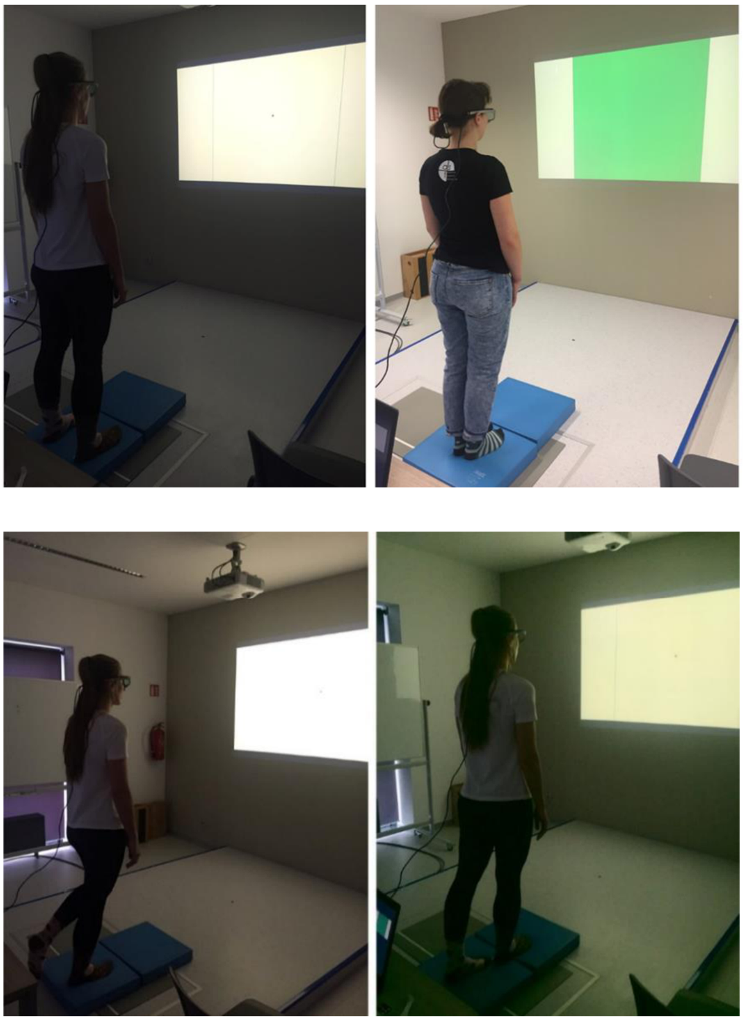

Figure 9. Normal stance (top left), feet together stance (top right), dominant leg stance (down left) and tandem stance (down right)

Study 3 consisted 36 trials divided into 3 groups. Participants were instructed to stand in the defined position with eyes open and arms alongside with the instructions to stand as still as possible and to follow a visual task as it starts. As in the previous study, a sound signalization between gaze recording and a balance task was used to control the beginning and the end of each trial and each trial started a few seconds after participants were positioned into the stabilized final position.

4.4.4 Data processing and data analysis

From acceleration signals, (RMS) was computed in each direction – see Study 2 for detailed description.

4.4.5 The eye tracker data analysis

The calculation of the eye movements' characteristics is consisted of a multi-step process. In the first step, saccadic eye movements and eye fixations were identified within the entire recording by the software supplied by the manufacturer of the Eye tracker system, based on the software's internal criteria. Considering the technical parameters of the measurement, all performed trials of participants, including break time between trials, were exported in one-eye movement recording. In the second step of the analysis, it was necessary to manually demarcate the end of each individual trial (i.e. to distinguish them from a break time) and to identify trials which defined horizontal or vertical saccadic eye movements (i.e. to remove break time slots and trials in which gaze fixation occurred). The next step involved identifying the "correct" saccades, i.e. saccadic movements in the area of our interest. Regarding the complexity of eye movements, it was necessary to define the boundary size of the saccade amplitude in order to be able to exclude possible refocusing. Only saccades with an angular amplitude $\geq 7°$ were included in the analysis. The last step was the calculation of the average value of individual characteristics of saccadic eye movements. The mean value entering the statistical analysis was determined from 20 saccades defined according to the above procedure within each trial. The resulting characteristics of eye movements include saccade duration, horizontal, vertical, and angular amplitude, average and maximum acceleration, average and maximum speed, and maximum deceleration of saccades. For the purpose of study 3, the horizontal saccades' amplitude was used for the analyses. The horizontal saccades' amplitude was pre-defined in the eye tracker system as a distance from start to end point of the saccade (calculated as average velocity times saccade duration), exported as length of saccade in degrees (°). Due to the technical limitation of vertical eye movements recordings and issue with data analyses, some participants needed to be excluded from the analyses.

All data analyses were performed in the software MatLab (R2017b, MathWorks, Inc., Natick, MA, USA).

4.4.6 Statistical analysis

In study 3, Shapiro-Wilk test did not confirm normality of all the variables. Therefore, Friedman Analysis of Variance was implemented for assessment of the effect of visual conditions in each stance separately. It was followed by post-hoc analysis by Wilcoxon test. The significance level was set to 0.05. In addition, Spearman's rank correlation was computed to assess the correlation between horizontal saccades' amplitude and all four stance condition.

In addition, for the ANOVA measures the effect size was quantified using partial eta squared (η_ρ^2), corresponding to $\eta_\rho^2 = 0.01$ (as a small effect), 0.06 (moderate effect), and 0.14 (large effect), respectively (Lakens, 2013). For the Friedman Analysis of Variance, the effect size was estimated with Kendall's coefficient of concordance (W) that ranges from 0 to 1, where a higher value corresponds to a stronger association (Legendre, 2005). That is, Kendall's uses the Cohen's interpretation guidelines of $0.1 \leq 0.3$ (as a small effect), ≥ 0.3 and < 0.5 (a moderate effect) and ≥ 0.5 (a large effect) (Tomczak & Tomczak, 2014). As for the Spearman's correlation coefficient values are defined as low ≤ 0.30, moderate 0.31–0.69 and high 0.70–1.00 (Morrow, Mood, Disch, & Kang, 2015).

5 Results

5.1 Study 1

H1: Various speeds of saccadic eye movements influence postural stability in more demanding balance task in healthy young adults.

H2: Various directions of saccadic eye movements influence postural stability in more demanding balance task in healthy young adults.

5.1.1 Analysis of data from stabilometer

Descriptive results for all conditions are shown in Table 1. No significant effect of speed of saccadic eye movement on balance performance was found (F(2, 62)=1.414, $p = 0.251$, partial $\eta^2 = 0.044$) with similar results obtained for the effect of directions of saccades (F(2, 62)=1.274, $p = 0.287$, partial $\eta^2 = 0.039$), showing small effect size in both results.

Table 1

Descriptive results for all visual conditions, two different speeds and two different directions of saccades (stated as mean ± standard deviation)

Visual stimuli	RMSE (deg)
Fixation	3.37 ± 1.11
Slow saccades	3.39 ± 1.18
Fast saccades	3.46 ± 1.20
Horizontal saccades	3.39 ± 1.18
Vertical saccades	3.46 ± 1.20

Note. RMSE – root mean square error

5.1.2 Analysis of data from accelerometer

Descriptive results for all visual conditions is shown in Table 2, as well as, schematic presentation of results is shown in Figure 10. A significant statistical difference was found in comparison between RMS of acceleration of postural sway for speed of saccades in AP postural direction (F(2, 60)=3.444, p = 0.038, partial $\eta^2 = 0.103$, small effect size) with the post-hoc results showing significantly lower values for slow saccadic condition compared to fixation condition (p = 0.039). No significant difference of postural sway was found in ML postural direction (F(2, 60)=0.075, p = 0.928, partial $\eta^2 = 0.002$, small effect size). Also, a significant statistical difference was found in comparison between RMS of acceleration of postural sway for direction of saccades in AP direction (F(2, 60)=3.914, p = 0.025, partial $\eta^2 = 0.115$, small effect size) with the post-hoc test results showing statistically lower values for horizontal saccadic condition comparing to fixation condition (p = 0.021). No significant differences in ML postural direction was found (F(2, 60)=1.835, p = 0.168, partial $\eta^2 = 0.058$, small effect size). The hypotheses H1 and H2 cannot be rejected.

Table 2

Means and standard deviations of the root mean square (expressed in g) of postural sway in the medial-lateral and anterior-posterior directions of two different speeds and two different directions of saccades

Visual stimuli	Direction	
	Medial-lateral	Anterior-posterior
Fixation	0.107 ± 0.043	0.486 ± 0.141
Slow saccades	0.107 ± 0.042	0.482 ± 0.144
Fast saccades	0.107 ± 0.042	0.483 ± 0.143
Horizontal saccades	0.105 ± 0.040	0.481 ± 0.143
Vertical saccades	0.109 ± 0.043	0.484 ± 0.144

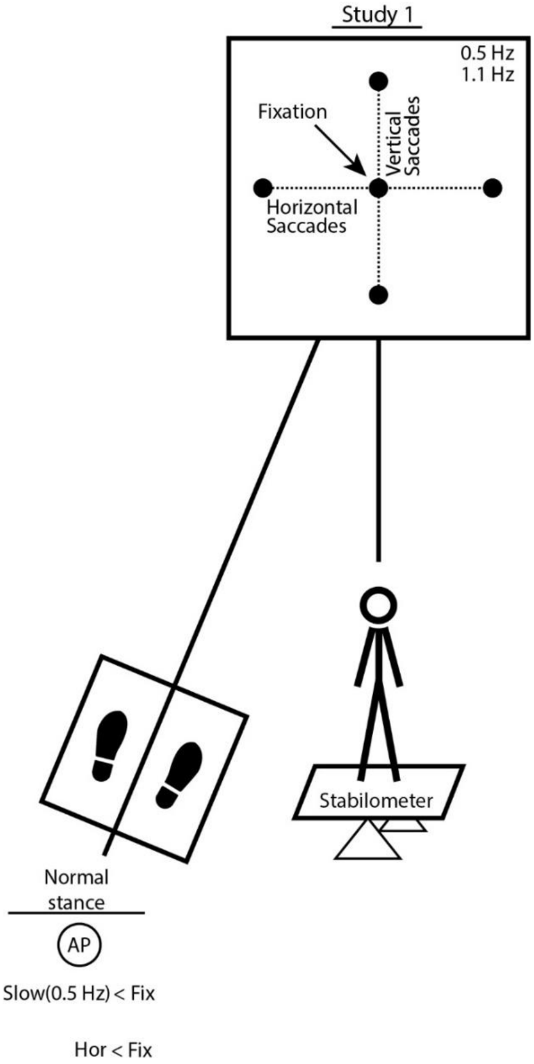

Figure 10. Scheme of significant differences in postural sway in anterior-posterior postural direction in normal stance while maintaining balance on stabilometer during five visual conditions (the “<” sign shows lower values, i.e., better balance performance)

5.2 Study 2

H3: Various directions of saccadic eye movements influence postural stability in more demanding balance task in healthy elderly.

The descriptive results are summarised in Table 3. No significant statistical difference was found in comparison between RMS of acceleration of postural sway for direction of saccades in AP postural direction (F(2, 34)=0.610, p = 0.549, partial $\eta^2 = 0.035$, small effect size) nor in ML postural direction (F(2, 34)=0.921, p = 0.408, partial $\eta^2 = 0.051$, small effect size). We have hypothesised that different directions of saccadic eye movements influence postural stability in more demanding balance task in healthy elderly (H3). The hypothesis H3 has been rejected.

Table 3

Means and standard deviations of the root mean square (expressed in g) of postural sway in the medial-lateral and anterior-posterior directions of two different directions of saccades

Visual stimuli	Direction	
	Medial-lateral	Anterior-posterior
Fixation	0.062 ± 0.036	0.458 ± 0.202
Horizontal saccades	0.064 ± 0.039	0.453 ± 0.205
Vertical saccades	0.062 ± 0.039	0.458 ± 0.208

5.3 Study 3

H4: The influence of saccadic eye movements on postural stability differs with various levels of difficulty of balance tasks in healthy young adults.

Research question: Is there a relationship between selected eye movements' parameters and the level of postural stability?

The descriptive results are summarised in Table 4, and schematic presentation of results is shown in Figure 11. The non-parametric Friedmann ANOVA for each type of stance and each direction of saccades shows statistically significant effects of horizontal saccades and vertical saccades on postural stability in: AP postural direction during normal stance (p = 0.009, W=0.220, small effect size), with the post-hoc results showing lower values for horizontal saccades compared to fixation condition (p = 0.023), in AP postural direction during feet together stance (p = 0.047, W=0.145, small effect size), with the post-hoc results showing two effects, lower values for horizontal saccades compared to fixation condition (p = 0.042), and lower values for vertical saccades compared to fixation condition, (p = 0.039), and in ML postural direction during tandem stance (p = 0.027, W=0.172, small effect size), with the post-hoc results showing lower values for vertical saccades compared to horizontal saccades condition, (p = 0.017). The results do not show that the effect of saccadic eye movements on postural stability differs with various levels of difficulty of balance tasks. Thus, no significant differences were found in dominant leg stance condition. Therefore, the hypothesis H4 has been rejected.

Table 4

Descriptive results for all visual conditions and all types of stance, in ML and AP directions (stated as median, lower quartile and upper quartile of the root mean square of acceleration expressed in g).

	Fixation			Horizontal saccades			Vertical saccades		
	Median	LQ	UQ	Median	LQ	UQ	Median	LQ	UQ
Normal stance ML	0.0060	0.0050	0.0072	0.0057	0.0050	0.0064	0.0057	0.0051	0.0064
Normal stance AP	0.0114	0.0099	0.0154	0.0094	0.0067	0.0114	0.0105	0.0079	0.0153
Feet together ML	0.0127	0.0110	0.0134	0.0113	0.0094	0.0128	0.0121	0.0101	0.0131
Feet together AP	0.0140	0.0096	0.0180	0.0103	0.0084	0.0130	0.0106	0.0081	0.0145
Dominant leg ML	0.0385	0.0342	0.0454	0.0351	0.0267	0.0399	0.0338	0.0290	0.0377
Dominant leg AP	0.0218	0.0180	0.0253	0.0220	0.0181	0.0286	0.0217	0.0169	0.0244
Tandem stance ML	0.0203	0.0172	0.0240	0.0215	0.0170	0.0237	0.0207	0.0166	0.0224
Tandem stance AP	0.0173	0.0141	0.0257	0.0169	0.0146	0.0207	0.0146	0.0114	0.0193

Note. ML – medial-lateral, AP – anterior-posterior, LQ – lower quartile, UQ – upper quartile

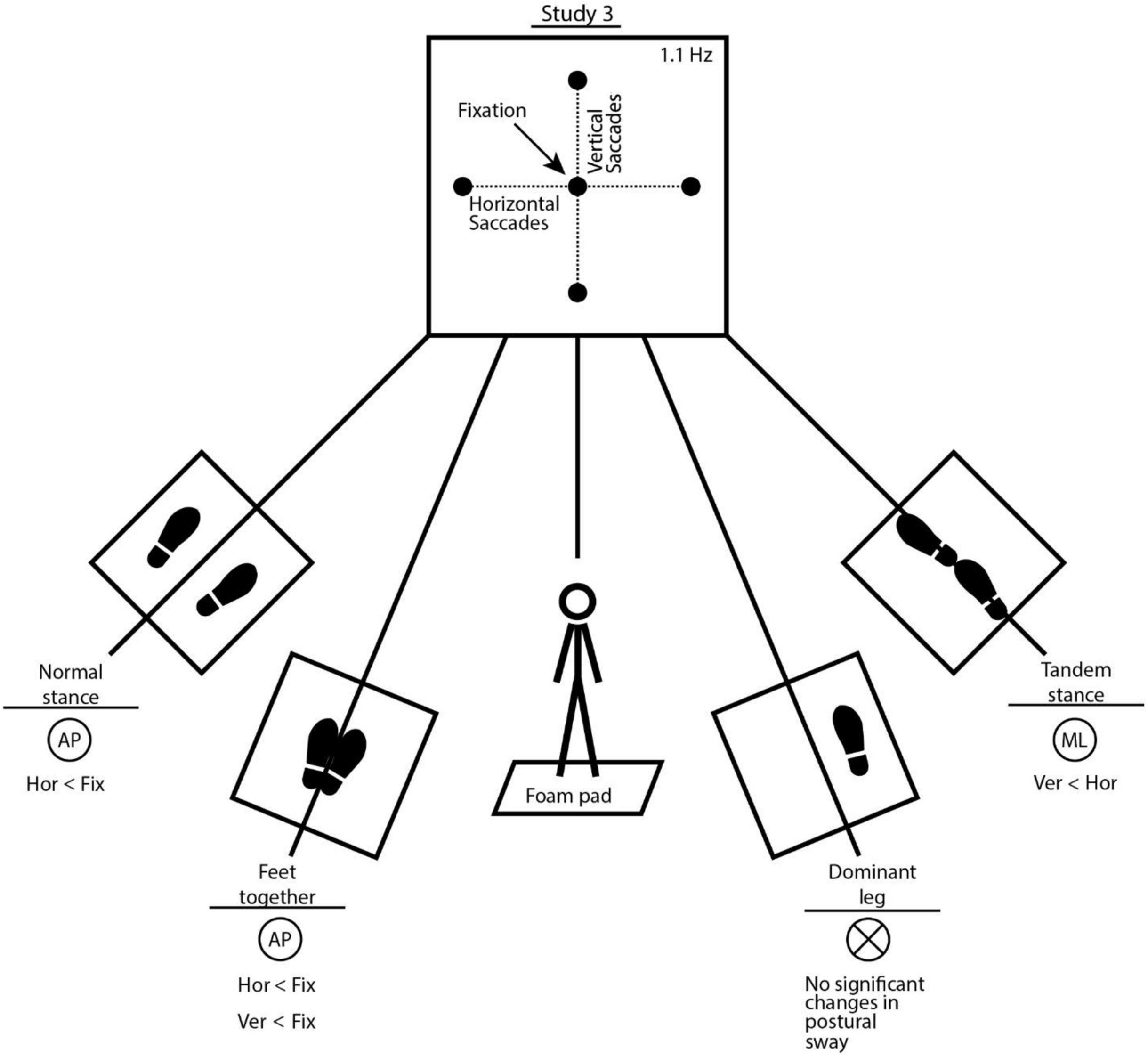

Figure 11. Scheme of significant differences in postural sway in four different stances while maintaining balance on foam pad during three visual condition (the "<" sign shows lower values, i.e., better balance performance)

The positive linear correlation is presented in Figure 12. The Spearman's rank correlation found the significant positive correlation between the horizontal saccades' amplitude and acceleration variability in AP postural direction on dominant leg stance under the horizontal saccadic visual condition, r = 0.66, p = (0.020). The results indicate that the higher the amplitude of horizontal saccades the higher the variability of body acceleration in AP postural direction on dominant leg stance during horizontal saccades condition.

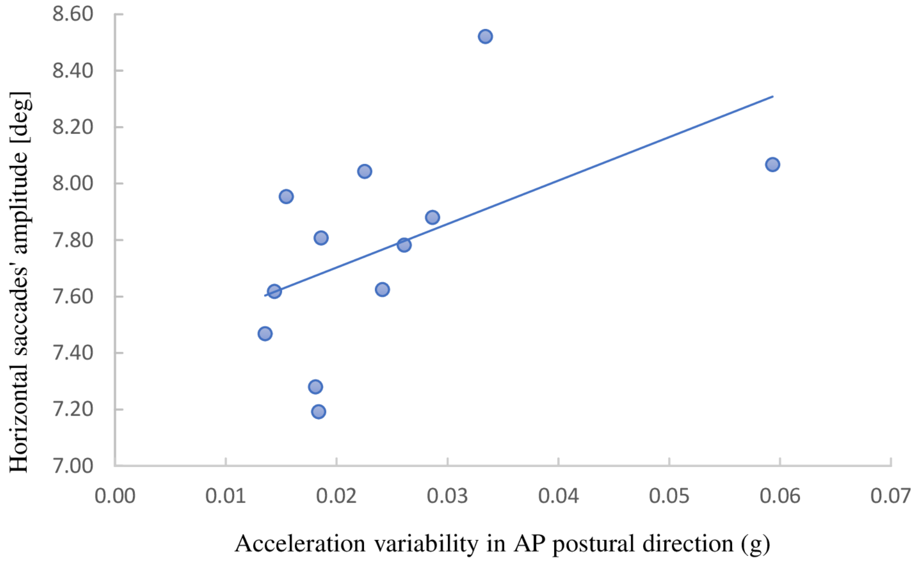

Figure 12. Significant positive linear correlation - the higher the amplitude of horizontal saccades the higher the variability of acceleration in AP postural direction on dominant leg stance during horizontal saccades condition

6 Discussion

The results of earlier studies focused on the effect of eye movement on postural control vary. Those finding concern not only young adults but also elderly population. Some studies which found that body sway was attenuated by various saccadic eye movements support the idea of the functional integration of posture and gaze control paradigm which explains underlying mechanisms used while a person is simultaneously performing a visual task during postural control task. This paradigm further suggests that a body sway might be adjusted during visual search to assist eye movements (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). This further means that saccadic eye movements may decrease body sway to allow more accurate gaze shifts (Rodrigues et al., 2013, 2015; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). Following this paradigm, we wanted to explore if a higher demand of postural task influences an impact of saccadic eye movements on postural control. Therefore, the focus of this research was to analyze the influence of various frequencies and directions of saccadic eye movements on postural stability during more demanding postural tasks in healthy young adults and in healthy elderly. To our knowledge, there are not many studies which examined the influence of saccadic eye movements on postural stability during more demanding postural tasks. For that reason, we conducted three studies in which we gathered a larger group of participants, as well as used a larger number of various challenging balance tasks than in previous studies, while manipulating with the same suprapostural (visual) tasks. More specifically, study 1 examined the influence of slower and faster saccades, as well as horizontal and vertical saccades while healthy young adults' participants were maintaining balance on stabilometer platform in normal stance. The second study was conducted to analyze the influence of horizontal and vertical saccades in healthy elderly individuals while standing on the foam pad in normal stance, while the influence of horizontal and vertical saccades on postural sway was analyzed in study 3, while healthy young participants were balancing on the foam pad in normal stance, feet together stance, stance on a dominant leg and tandem stance. Thus, study 3 examined horizontal saccades' amplitude parameter and its association with body sway acceleration in more demanding postural tasks.

6.1 Study 1

The present study assessed the influence of two different speeds of saccades (0.5 Hz and 1.1 Hz) and two different directions of saccades (horizontal and vertical) on standing balance performance and postural sway in healthy young adults while maintaining balance on stabilometer, that is considered as challenging balance task. Stabilometer platform analyses show no significant effect of visual tasks on balance performance. Yet, accelerometer results show significant changes in postural sway in AP postural direction while standing on stabilometer, indicating lower variability of postural sway during slow saccades (0.5 Hz) compared to fixation condition, and lower variability of postural sway during horizontal saccades compared to fixation condition, meaning slower saccades (at 0.5 Hz) and horizontal saccades have a positive impact on postural sway compared to fixation. No significant changes of postural sway in ML postural direction have occurred.

6.1.1 Stabilometer outcome

We wondered if a more challenging balance task could disrupt the functional relationship between a body sway and a visual search (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006), and how. Considering the fact that no influence of visual tasks have occurred on balance performance, we may assume that, if a physical demand of a balance task increases, then participants adopt a rigid postural control with the main aim to stay on the platform with both legs on and not to fall down (as a safety mechanism). In this case, the rigid posture is reflected in stiffness in joints caused by extra muscles contractions, which did not allow larger sway, therefore this postural strategy does not let visual tasks to be effective (this was suggested for older adults in Aguiar et al., 2015). However, it is very questionable how in the task, such as balancing on stabilometer (keeping balance on a translational platform), any change in postural control did not occur, since in rigid postural strategy (yet, in no cognitive conditions) the increased concentration on balance task may result in an increase in muscle tension, which may have increased body rigidity, which may have increased movement variability of COP (Hunter & Hoffman, 2001). We may therefore suggest that saccadic eye movements did have a stabilizing effect on postural control, yet not significantly enough due to the balance task constrains, and that rigid postural strategy was adopted by participants but resulting in a small body sway (Aguiar et al., 2015). Nonetheless, the explanation for our result could be found in the Adaptive resource-sharing model (Mitra, 2004), because, although participants did look at the exact visual tasks during maintaining balance, their attention might be focused on their body rather than on a visual task (leading to the autonomous control) (Mitra, 2004), in which case balance performance outcome was not affected by a visual manipulation. That is, an autonomous sway minimization control could be activated while balancing on stabilometer, because balancing task was difficult, therefore, all available resources are focused on solving postural control, so an effect of the suprapostural visual task stays ineffective (Mitra & Fraizer, 2004).

6.1.2 Accelerometer outcome

Previous findings show a body sway is attenuated during saccades compared to fixation (Aguiar et al., 2015; Legrand et al., 2013; Rodrigues et al., 2013, 2015). It was argued that a higher frequency of saccades plays an important role in a body sway decrease (Aguiar et al., 2015; Rodrigues et al., 2013, 2015; Thomas, Bampouras, Donovan, & Dewhurst, 2016). Following the previous hypothesis that a postural control might be modulated in order to facilitate gaze changes (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006), authors explain that saccades execution involves a feed-forward motor strategy (Aguiar et al., 2015; Thomas, Bampouras, Donovan, & Dewhurst, 2016) that increases a task complexity and, therefore, may explain a body sway decrease. That is, while following saccadic eye movements a feed-forward modulation of a body sway is activated and the amount of time available for planning the next saccadic movement is reduced, therefore a body does not have enough time to adjust to changes that occur during a visual task. As already mentioned above, a body sway might be adjusted during a visual search to help facilitate eye movements while performing a dual-task, and therefore to lead to a decreased body sway to allow more accurate gaze shifts (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). Analogically, performing saccades at a higher frequency (for instance 1.1 Hz) can further attenuate a body sway because of a higher demand of visual task. It means that in this situation, the feed-forward motor strategy provides less time to a body to react and adjust to changes that occur, which leads to movements automatization.

On the contrary, the accelerometer results in our study indicate lower postural sway variability while participants were following slower saccades at 0.5 Hz compared to fixation, meaning that slower saccades at 0.5 Hz have positive effect on postural sway compared to fixation task, and no significant changes occurred while following faster saccades at 1.1 Hz. Such an outcome could again be possibly explained in the high demand of balance task in the present study. Showing the opposite trend from the previous argument in previous studies mentioned above, in which faster saccades increased postural stability during wide stance compared to a narrow stance (Rodrigues et al., 2013), we may suggest that in this study the high demand of balance task plays an important role and that slow saccades (at 0.5 Hz) compensated the functional integration of posture and gaze control during more challenging balance task. As explained above, a higher frequency of a visual task can attenuate body sway because it leads to a feed-forward motor strategy (in a dual-task situation) that provides less time to a body to react and adjust to changes that occur, which leads to movements automatization (Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). But our results may clarify the reason why slower saccadic frequency leads to a better postural stability rather than faster eye movements. We think that a higher demand of balance task during faster saccadic task (at 1.1 Hz) does not allow higher accuracy of eye movements due to the fact that a person focuses on solving challenging balance task, therefore slower gaze shifts may somehow compensate the functional integration between gaze and postural stability. As a conclusion, following slower saccades could provide better postural control during more challenging balance task, rather than faster saccades.

Our study also reveals that horizontal saccades have positive impact on postural sway compared to fixation condition in AP postural direction, that go in line with previous researches' findings, in which horizontal eye movements were proven to reduce head and trunk sway amplitude in AP postural direction compared to fixation in young adults (Rodrigues et al., 2013) and elderly (Aguiar et al., 2015), but contrary to Stoffregen et al. (2007) in which reduced variability of postural sway was shown in ML postural direction. Nonetheless, some basis of support changes could be the limitations in the postural control as it needs to modify a particular perceptual manipulation, such as, horizontal saccades might cause lateral body sway if eye movements interfered with vestibular and retinal sources of information (Rodrigues et al., 2013). Changes in AP postural direction in our study could be explained in the segmental changes that occurred primarily on the ankles due to the way of standing on the stabilometer platform. Since legs are limited in lateral movements, therefore a change in the movements of the feet in the AP direction, i.e., frontal plane, is expected. As a conclusion, maintaining balance on the stabilometer requires lateral movements of the body, therefore, horizontal saccades helped attenuating balance control as lateral saccadic eye movements were in the same direction as lateral movements of the body while balancing, that was compensated with ankle movements in AP postural direction, which improved balance control.

6.2 Study 2

Considering some previous studies emphasizing that saccadic eye movements have a positive impact on postural stability, we ask whether various directions of saccadic eye movements influence body sway in healthy elderly while balancing on more challenging surface.

Using dual-task paradigms the efficiency of postural control has been used to examine the effects of a secondary task, and it was shown that the simultaneous performance of a secondary task has an impact on healthy elderly in terms of their capacity to regain stability in an external perturbation, i.e. the ability to recover is affected by a secondary task performance (Brauer, Woollacott, & Shumway-Cook, 2001). Thus, it was suggested that the competition for attentional resources between the postural system and the cognitive task causes an inability to produce an appropriate postural response that contributes to falls in elderly with poor balance (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Besides, due to the fact that decreased balance control occurs with ageing and that a sensory system degenerates with ageing (Borel & Alescio-Lautier, 2014; Massion, 1994), we expected that involving a visual (dual) task during maintaining balance on more difficult surface could be more challenging for elderly. In addition, it has been shown that elderly rely mainly on somatosensory information to control their posture (Faraldo-García et al., 2012). So, a task in which the somatosensory system is negatively affected would imply difficult postural conditions for elderly, where mainly the vestibular and visual systems are used to adjust posture.

Whereas previous studies used bipedal stance with varying widths of support on a firm ground, the present study included more challenging balance task. Despite the fact that the attentional demand of postural tasks increases with ageing, and the ability to quickly adopt to external perturbation (to make a quick move) is reduced in elderly individuals (Borel & Alescio-

Lautier, 2014; Massion, 1994), and therefore a disbalance is expected, surprisingly, our results from the accelerometer show no significant effects of horizontal nor vertical saccadic eye movements on a body sway in healthy elderly participants during maintaining balance on foam pad. Our results show the opposite from Bizovska, Vagaja, Mihalova and Janura (2019), who found that saccadic eye movements while standing on the foam pad have positive effect on different body segments, more specifically on the shanks movement variability in AP and vertical (V) postural direction, and on the lower trunk variability in V direction in elderly population. Contrary to the current study, the study of Bizovska, Vagaja, Mihalova and Janura (2019) also revealed the general positive influence of horizontal saccades on shanks and lower trunk movement variability while standing, compared to fixation visual condition. Furthermore, this study’s results do not go in line with Aguiar et al. (2015) who found that elderly did reduce body sway under saccades condition compared to fixation condition, but only in wide stance while no changes occurred in a narrow stance condition, which was explained in a rigid postural control. The authors explain that elderly’s postural performance may have been affected by attentional factors related to the performance of the eye movements task. Particularly, elderly are more likely to experience difficulty with the attentional demands that are involved in performing saccadic eye movements while following shifts in target position compared to young adults. As a result, there may be fewer attentional resources available for the postural control task, which could hinder postural performance in elderly. In the end, since elderly individuals have fewer attentional capabilities than younger adults (Shumway-Cook et al., 1997), as a result, elderly's postural control system may have been overloaded, their balance may have been disrupted, and their control strategy may have been more rigid. To justify our results, we may agree with the explanation of Aguiar et al. (2015) that in elderly, a rigid postural strategy was reflected in a small body sway in scenario in which a high attentional demand is needed in order to perform dual-task and to simultaneously follow saccadic visual task while maintaining balance, including the autonomous control pattern (Mitra, 2004; Mitra & Fraizer, 2004) which was activated in elderly individuals while balancing on the foam pad.

6.3 Study 3

We expected that the effect of saccadic eye movements will differ between less demanding and more demanding postural tasks. That is, it was expected that the more demanding postural task might interfere the positive effect of saccades on postural stability. For instance, the facilitatory control of saccadic eye movements is expected to appear during less demanding postural tasks (normal stance and feet together stance), while the autonomous sway minimization control was expected to happen in more challenging postural tasks (stance on a dominant leg and tandem stance). The expectation was formed based on the few previous statements in previous studies, as well as the Adaptive resource-sharing model (see Mitra, 2004). As the facilitatory control of saccades has already been shown (Aguiar et al., 2015; Rodrigues et al., 2013, 2015; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Bardy, Bonnet, Hove, & Oullier, 2007), but also a few studies have already started to interpret the possibility of facilitatory action in their conclusions (Andersson et al., 2002; Dault, Yardley, & Frank, 2003), instead, an autonomous-control interpretation of postural sway (Mitra, 2003, 2004; Riley, Stoffregen, Grocki, & Turvey, 1999) focuses on the resource-competition framework, which takes an autonomous approach to posture control, in which postural control is unable to assist for task-facilitation effects like decreased sway when suprapostural task load increases (Riley, Baker, & Schmit, 2003), or to enhance suprapostural task effect in a situation when postural task difficulty increases (Mitra, 2003).

In addition, we expected that the effect of saccadic eye movements will differ with increasing levels of difficulty of balance tasks in healthy young adults based on the differences of the findings in previous studies. Such as, the global positive effect of saccades on postural stability compared to fixation condition was found in young adults in Standard Romberg and Tandem Romberg stances while standing on the dynamometric clogs' platform (Legrand et al., 2013). Specifically, the surface of COP was positively affected by saccades tasks compared to fixation in Tandem Romberg condition, while no impact was found in Standard Romberg stance, as well as the global positive effect of saccades compared to fixation tasks was found on the length of CoP and the mean speed of CoP in both Standard Romberg and Tandem Romberg stances. Further, the reduced body sway in wide stance compared to narrow stance during high frequency saccades was found (Rodrigues et al., 2013), while Rodrigues et al. (2015) found that the body sway was reduced by saccades compared to fixation condition in young adults while balancing on a flat surface in normal stance. In addition, in Dault, Geurts, Mulder and Duysens (2001) shown that the shoulder–seesaw stance was affected by a secondary cognitive task showing decrease in amplitude, yet independently from a cognitive task difficulty (see in the introduction). But also, the same authors found that postural frequency in tandem–seesaw stance was more affected by the secondary cognitive task than the other stances (shoulder width normal stance, shoulder width stance while standing on two individual seesaws, i.e., the shoulder–seesaw, and tandem stance while standing on the seesaws, i.e., tandem–seesaw) in the lateral direction, and that the increase in velocity of postural sway was significant in tandem–seesaw stance during a secondary cognitive task, regardless of its' difficulty. On the other hand, destabilizing effect of saccades was found in Hunter and Hoffman (2001) showing reduces sway variability in ML COP during fixation condition while young adults' participants were standing on a force plates platform in tandem stance.

It has been previously demonstrated that a body sway was reduced by horizontal saccades at the frequency at 1.1 Hz while standing in wide stance, compared to narrow stance (Rodrigues et al., 2013). Rodrigues et al. (2013) indicate that a total trunk and head displacement were significantly affected by a gaze, showing changes in both AP and ML postural directions. As already mentioned, similar observation has been seen in Aguiar et al. (2015) indicating that in elderly individuals, head and trunk sway amplitude was higher in narrow stance compared to a wide stance in ML postural direction, but the mean head sway frequency seems to be higher in the wide stance condition compared with the narrow stance condition in ML direction. The study of Ajrezo, Wiener-Vacher and Bucci (2013) also found a significant positive effect of saccadic eye condition on a body sway, indicating a decreased mean value of the surface area of the center of pressure compared to fixation condition in Standard Romberg condition. Also, the important global positive effect of saccadic eye movements compared to fixation on various body sways has been found in Legrand et al. (2013), as well as the effect of postural positions expressing greater body sway in Tandem stance compared to Standard Romberg stance, and postural frequency in tandem stance while balancing on a seesaw (tandem-seesaw stance) was more affected by cognitive manipulation than the shoulder width normal stance and shoulder width stance while standing on a seesaws (shoulder–seesaw) in the lateral direction (Dault, Geurts, Mulder, & Duysens, 2001). The outcome of this study shows several significant visual effects in normal stance, feet together stance and tandem stance condition, that is discussed in the next chapters.

In the normal stance condition, the analyses show lower values for horizontal saccades compared to fixation condition in AP postural direction, i.e., the results found the positive effect of horizontal saccades on body sway compared to fixation. Even though levels of balance difficulties were not the same in studies 1 and 3, we have found the same outcome. As already described above, as a consequence of standing requirements in normal stance, we may conclude that the reason why body sway changes occurred in the AP postural direction in both studied is because of the anatomical degree of freedom in the frontal plane, as in the normal stance condition the feet are placed in the shoulder width having more control in lateral direction (Bizovska, Vagaja, Mihalova, & Janura, 2019; Collins & De Luca, 1993). Regarding the positive effect of the horizontal saccades task on postural stability, we address the same conclusion as in the study 1 (see above).

In the feet together stance condition, two significant changes have occurred in AP postural direction, the positive effect of horizontal saccades compared to fixation, and positive effect of vertical saccadic compared to fixation condition on body sway. First, in stabilizing body motion process, the roles of somatosensory and visual inputs depend on the stance width, so with a larger base support, the role of vision decreases in favor of somatosensory inputs in the frontal plane (Day, Steiger, Thompson, & Marsden, 1993). A narrow stance leads to a reduction in a base of support in ML postural direction as a result of a mechanical constraint that limits the efficacy of postural corrections in ML postural direction (Aguiar et al., 2015), which may explain the postural changes in AP postural directions as the outcome for a better postural control. Second, contrary to the previously demonstrated that the presence of visual target reduces the body sway (Riach & Starkes, 1989), that visual fixation on a stationary object helps to stabilize the static posture (Paulus, Straube, & Brandt, 1984), and that eye movement condition revealed significantly greater COP variability in ML postural direction than no eye movement condition (Hunter & Hoffman (2001), our results show that both horizontal and vertical saccades attenuate body sway compared to fixation condition. As opposed to reasoning of Oblak, Gregoric and Gyergyek (1985) that the oculomotor system requires a posture stabilization to focus on a target, and opposed to Hunter and Hoffman (2001), that eye movements may lead to closing eyes or eliminated vision that increases balance demands, we argue that saccadic eye movements did have a stabilizing effect (the faciliatory control) (Mitra, 2004; Mitra & Fraizer, 2004) which is activated when a suprapostural task is high while the balancing component is relatively easy, in which case a visual performance will be attenuated by postural adjustments (Mitra & Fraizer, 2004). That is, in study 3, maintaining balance in tandem stance on the foam pad is considered as a mild to moderate difficulty of the balance task, therefore, the positive influence of horizontal and vertical saccades justifies the faciliatory control pattern.

The findings in the tandem stance condition show decreased body sway during vertical saccades compared to horizontal saccades in ML postural direction, contradictory to the study of Hunter and Hoffman (2001) in which it was found that the variability of the center of pressure movements area in ML direction increased during saccadic eye movements task compared to fixation condition during tandem stance in healthy young adults. We may suggest that, in our scenario, in which vertical saccades have a positive impact on body sway compared to horizontal saccades, changes possibly occurred because vertical saccades go in the direction of the feet stance, as the tandem stance (i.e., heel-to-toe) is in the frontal plane position, facing forward, that helped them control body sway. That is, participants might be focusing on vertical saccadic movement rather than on horizontal, which is similar to the position of their legs, that might help them attenuate postural sway, and prevented them from falling. On the other hand, following horizontal saccades might "forced" participants to make lateral movements, and since the base of support in sagittal plane is small in tandem stance, that might explain the higher sway variability values in ML postural direction.

No influence of horizontal or vertical saccades has been found on postural sway while participants were maintaining balance in dominant leg stance. Yet, we have found the interesting positive correlation between the amplitude of horizontal saccades and body acceleration variability while participants were standing on a dominant leg. More specifically, we have found that the higher the amplitude of horizontal eye movement the higher the variability of body acceleration in AP postural direction on dominant leg stance while participants were following horizontal saccades condition.

Under the horizontal visual condition in which participants are asked to follow horizontal saccades at the frequency at 1.1 Hz, the task was to maintain balance on a dominant leg while standing on the foam pad. As balancing on dominant leg on a foam pad is considered to have the higher level of balance difficulty than normal or feet together stance for instance, specifically while standing on unstable surface, then postural stability is expected to be disrupted. The assumption behind the result is that, if a body acceleration while maintaining balance occurs, then a visual search may become inaccurate. In this situation participants might not be able to follow the exact frequency of stimuli or to land their eyes at the right location of stimuli of horizontal movements as defined. This further means, if the amplitude of saccades is higher (greater) during this specific task, then a person tries to correct ("restore") the eye movements to the original speed and trajectory of horizontal stimuli simultaneously while balancing, which automatically accelerates eye movement, that may lead to a greater body acceleration. Furthermore, the inability to correctly follow given visual task may also be seen in the fact that sometimes large saccades miss their targets location, in which case a short corrective saccade appear after eyes preliminary stopping for a moment (Pannasch & Velichkovsky, 2009). In addition, a "large-scale" saccade may lead to the saccadic suppression (Lee et al., 2007) that may further lead to an inaccurate eye tracking (Pannasch & Velichkovsky, 2009). For that reason, if postural stability increases with improved visual accuracy and acuity (Paulus, Straube, & Brandt, 1984), then the inaccuracy of visual search decreased postural stability.

Besides, despite the fact that in our third experiment tandem stance and stance on a dominant leg were considered as the most challenging balance tasks (yet, balance difficulties are very individual), according to this correlation results, we may assume that maintaining balance on a dominant leg is the most challenging balance task for our heathy young participants, as the correlation between horizontal saccades' amplitude did not occur during other stance conditions. In the basic research question, we asked what is the influence of different saccadic eye movements on postural stability in balance tasks with different levels of demands. Therefore, this correlation analyze may indicate that the higher level of demands of balance task truly influences an impact of saccadic eye movements on postural control.

Study 3 results show that the effect of saccadic eye movements does not differ between lower and higher demand of postural task as it was expected. The results show that participants' body sway was affected by saccades in less demanding postural tasks (during normal stance and feet together stance) but also during postural task of a higher demand (tandem stance). On the other hand, no effect of various saccadic eye movements was found while participants were maintaining balance on a dominant leg, which is considered to be the challenging postural task in our third experiment. As mentioned in previous paragraph, we may conclude that autonomous sway minimization control (Mitra, 2004; Mitra & Fraizer, 2004) was activated during difficult balance task, in which case saccadic eye movements did not have any effect on postural stability.

6.4 Research limitations

There might be few limitations of the research. We want to mention the duration of the entire experiment as a possible limitation. Although our procedure was time consuming, several measures were employed to avoid fatigue of our participants. That is, we have adopted to the circumstances and were giving more additional time to rest between trials and/or blocks, which was the same for all participants. In addition, in order to have the same issue under control, the number of trials and visual conditions was reduced for elderly participants in study 2. Also, in order to prevent possible pain in the eyes of our participants we have put a green background color on the screen to be seen between every trial so that participants' eyes will rest. All experiments were conducted in a laboratory setting, in which the light was dim due to three reasons, so that the eyes will rest and all visual tasks on the screen would be more visible, so that peripheral vision will be minimized, since the peripheral vision is known to have a stabilizing effect on postural control (Berencsi, Ishihara, & Imanaka 2005), and to minimize an effect of a background as a display conditions in an experiment may affect saccade latencies (Wu, Chua, & Yen, 2016).

6.5 Future recommendation

This research contributes to the current knowledge in this field and highlights the impact of more demanding postural tasks on postural stability in dual-task activities in which participants simultaneously follow various visual stimuli during standing on various surfaces. One part of our analyses support the notion of previous studies and the functional relationship between eye movements and a body sway, indicating the positive saccadic influence on body sway. Yet, the second part of the analyses indicate the opposite trend, suggesting that a higher postural stance difficulty interrupts an impact of saccadic eye movements on postural control, showing no influence of saccadic eye movements on body sway.

Furthermore, we suggest the future examination of a relationship between eye movements and higher difficulty of a postural stance in elderly individuals in more natural environment to assess the influence of saccades on postural stability. Also, future studies should point out an effect of basis of support on the gaze control and posture in a more natural environment.

Nonetheless, this research results provide a potential understanding that could be used as a foundation for the creation of new balance training programs that place an emphasis on training stability in the context of dual tasking. The results may also be beneficial in the field of rehabilitation, such as developing balance improvement.

Finally, a future research should investigate an influence of various saccadic amplitudes and frequencies on postural stability, and their potential underlying mechanisms in dual-task activities.

7 Conclusion

The findings of the whole research provide empirical evidence that the influence of saccadic eye movements on postural stability does not have a linear trend in less demanding and more demanding postural tasks. The overall results show that saccadic eye movements have a positive effect on postural stability compared to fixation condition. More specifically, the facilitating gaze control manifested in attenuation of body sway was shown during balancing on stabilometer in normal stance in AP postural direction, showing positive influence of horizontal saccades compared to fixation condition, as well as positive influence of slow saccades (0.5 Hz) compared to fixation condition in healthy young adults. Furthermore, while maintaining balance on the foam pad, the positive effect of saccades was found in three different stance conditions in healthy young participants. First, the influence of saccades was found in normal stance condition in AP postural direction, showing positive effect of horizontal saccades compared to fixation condition. Second, the positive effect of horizontal saccades compared to fixation condition, and positive effect of vertical saccades compared to fixation condition was found in feet together stance in AP postural direction. And third, the positive effect of vertical saccades compared to horizontal saccades was shown in tandem stance condition in ML postural direction.

Besides, in dominant leg stance condition, this research found the positive association between horizontal saccades' amplitude with body acceleration in AP postural direction, which means that the higher the amplitude of horizontal saccades the higher the variability of body acceleration in AP postural direction on dominant leg stance when performing horizontal saccades. This further means, that inaccurate eye tracking may automatically accelerate eye movement, that may further lead to a greater body acceleration. Therefore, we suggest that inaccuracy of visual search decreased postural stability. Last but not least, no significant effect of saccades on postural sway occurred in elderly participants, which may be due to the autonomous-control of postural stability, as in this experiment balance task had a high demand on our participants.

Overall, this dissertation reveals that body sway was attenuated during saccades, but also shows destabilizing effect of fixation condition on postural stability, that have appeared in all the results that occurred in the AP postural direction.

8 Summary

The main goal of this dissertation was to analyze the influence of various saccadic eye movements on postural stability during different levels of demands of balance tasks in healthy young adults and in healthy elderly. Additional goals were to investigate the effect of various frequencies and directions of saccadic eye movements on postural stability in healthy young adults, as well as to investigate the effect of various directions of saccadic eye movements on postural stability in more demanding balance task in healthy elderly, thus to investigate if the effect of various directions of saccadic eye movements on postural stability differ in various levels of difficulty of balance task in healthy young adults. This research also includes the research question in which we ask if there is a relationship between selected eye movements' parameters and the level of postural stability.

This whole research was divided into three studies, and it includes 71 participants (53 young adults and 18 elderly) in total. More specifically, a total number of thirty-two young adults (15 males, 17 females, age 22.8 ± 2.7 years, height 170.6 ± 7.9 cm, body mass 68.8 ± 10.6 kg) have participated in study 1, a total number of eighteen elderly subjects (3 males, 15 females, age 70.3 ± 7.7 years, height 164.4 ± 6.0 cm, body mass 74.7 ± 9.5 kg) have participated in the second study, and a total number of twenty-one young adults (21 females, age 21.8 ± 1.1 years, height 167.5 ± 6.9 cm, body mass 60.3 ±7.8 kg) have participated in study 3.

The first study revealed the positive effect of saccadic eye movements on postural stability in healthy young adults. We found the reduction of body sway when performing slow saccades (0.5 Hz) compared to fixation condition, as well as the reduction of body sway when performing horizontal saccades compared to fixation in AP postural direction. These results were found while participants were maintaining balance on stabilometer platform while standing in normal stance.

The second study revealed no significant effects of horizontal nor vertical saccadic eye movements on a body sway in healthy elderly participants during maintaining balance on foam pad while standing in normal stance.

The third study revealed several positive effects of saccadic eye movements on postural stability in healthy young adults during different levels of demands of balance tasks while participants were maintaining balance on the foam pad. In normal stance condition, we found the reduction of body sway when performing horizontal saccades compared to fixation in AP postural direction. In feet together stance, we found the reduction of body sway when performing horizontal saccades compared to fixation, as well as the reduction of body sway when performing vertical saccades compared to fixation in AP postural direction. Also, in tandem stance, we found the reduction of body sway when performing vertical saccades compared to horizontal saccades in ML postural direction. Moreover, study 3 results indicate that the higher the amplitude of horizontal saccades the higher the variability of body acceleration in AP postural direction on dominant leg stance when performing horizontal saccades.

9 Souhrn

Hlavním cílem této disertační práce bylo posoudit vliv různých rychlostí a směrů sakadických pohybů očí na posturální stabilitu v náročnějších balančních úlohách u zdravých mladých dospělých a seniorů. Dílčími cíli bylo prozkoumat vliv různých frekvencí a směrů sakadických pohybů očí na posturální stabilitu u zdravých mladých dospělých, stejně jako prozkoumat vliv různých směrů sakadických pohybů očí na posturální stabilitu v náročnějších balančních úlohách u seniorů a dále posoudit odlišnosti mezi výše uvedenými skupinami.

Celý výzkum byl rozdělen do tří experimentů a zahrnoval celkem 71 účastníků (53 mladých dospělých a 18 seniorů). Experimentu 1 se zúčastnilo 32 mladých dospělí (15 mužů, 17 žen) ve věku 22,8 ± 2,7 let, s průměrnou výškou 170,6 ± 7,9 cm a tělesnou hmotností 68,8 ± 10,6 kg. Experimentu 2 se zúčastnilo 18 seniorů (3 muži, 15 žen) ve věku 70,3 ± 7,7 let s průměrnou výškou 164,4 ± 6,0 cm a tělesnou hmotností 74,7 ± 9,5 kg. Do třetího experimentu bylo zahrnuto 21 žen ve věku 21,8 ± 1,1 let s průměrnou výškou 167,5 ± 6,9 cm a tělesná hmotností 60,3 ± 7,8 kg.

Z výsledků prvního experimentu vyplývá, že existuje pozitivní vliv sakadických pohybů očí na posturální stabilitu u mladých dospělých. Bylo zjištěno, že při pomalých sakadických pohybech očí (0,5 Hz) došlo v porovnání s fixovaným zrakem ke snížení posturálních výchylek v předozadním směru ve stoji na stabilometrické plošině.

Druhý experiment neprokázal významný vliv sakadických pohybů očí na posturální výchylky u seniorů při udržování rovnováhy ve ztížených podmínkách (stoj na pěnové podložce).

Ve třetím experimentu jsme nalezli několik pozitivních účinků sakadických pohybů očí na posturální stabilitu u mladých dospělých během různých úrovní rovnovážných úkolů. Ve stoji spatném došlo ke snížení posturálních výchylek v předozadním směru při provádění horizontálních sakadických očních pohybů ve srovnání s fixovaným zrakem. V tandemovém stoji došlo ke snížení posturálních výchylek v pravolevém směru při provádění vertikálních sakadických očních pohybů ve srovnání s fixovaným zrakem. Detailní analýza pohybu očí dále ukázala, že větší amplituda horizontálních sakád byla spojena s většími předozadními posturálními výchylkami během unipedálního postoje u mladých dospělých. Výsledky třetího experimentu naznačují, že s vyšší amplitudou horizontálních sakád se zvyšují předozadní posturální výchylky ve stoji na dominantní noze.

10 References

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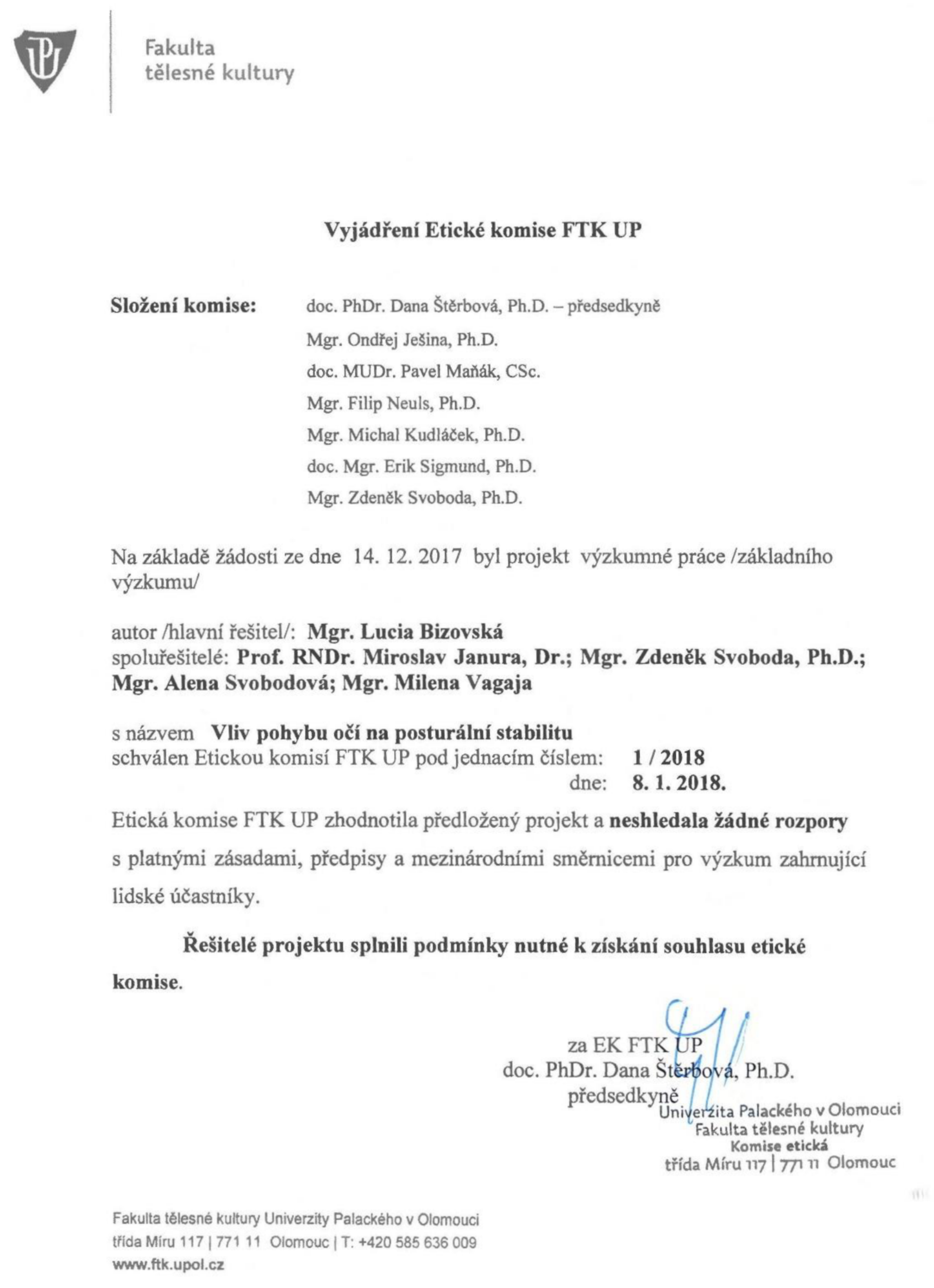
11 Appendices

Appendix 1. The Statement of the Ethics Committee



Fakulta
tělesné kultury

Vyjádření Etické komise FTK UP

Složení komise: doc. PhDr. Dana Štěrbová, Ph.D. – předsedkyně
Mgr. Ondřej Ješina, Ph.D.
doc. MUDr. Pavel Maňák, CSc.
Mgr. Filip Neuls, Ph.D.
Mgr. Michal Kudláček, Ph.D.
doc. Mgr. Erik Sigmund, Ph.D.
Mgr. Zdeněk Svoboda, Ph.D.

Na základě žádosti ze dne 14. 12. 2017 byl projekt výzkumné práce /základního výzkumu/

autor /hlavní řešitel/: **Mgr. Lucia Bizovská**
spoluřešitelé: **Prof. RNDr. Miroslav Janura, Dr.; Mgr. Zdeněk Svoboda, Ph.D.; Mgr. Alena Svobodová; Mgr. Milena Vagaja**

s názvem **Vliv pohybu očí na posturální stabilitu**
schválen Etickou komisí FTK UP pod jednacím číslem: **1 / 2018**
dne: **8. 1. 2018.**

Etická komise FTK UP zhodnotila předložený projekt a **neshledala žádné rozpory** s platnými zásadami, předpisy a mezinárodními směrnicemi pro výzkum zahrnující lidské účastníky.

Řešitelé projektu splnili podmínky nutné k získání souhlasu etické komise.

za EK FTK UP
doc. PhDr. Dana Štěrbová, Ph.D.
předsedkyně

Univerzita Palackého v Olomouci
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Appendix 2. Informed consent

Informovaný souhlas

Název studie (projektu): **Vliv pohybu očí na posturální stabilitu**

Jméno:

Datum narození:

Účastník byl do studie zařazen pod číslem:

1. Já, níže podepsaný(á) souhlasím s mou účastí ve studii. Je mi více než 18 let.
2. Byl(a) jsem podrobně informován(a) o cíli studie, o jejích postupech, a o tom, co se ode mě očekává. Beru na vědomí, že prováděná studie je výzkumnou činností.
3. Porozuměl(a) jsem tomu, že svou účast ve studii mohu kdykoliv přerušit či odstoupit. Moje účast ve studii je dobrovolná.
4. Při zařazení do studie budou moje osobní data uchována s plnou ochranou důvěrnosti dle platných zákonů ČR. Při vlastním provádění studie mohou být osobní údaje poskytnuty jiným než výše uvedeným subjektům pouze bez identifikačních údajů, tzn. anonymní data pod číselným kódem. Rovněž pro výzkumné a vědecké účely mohou být moje osobní údaje poskytnuty pouze bez identifikačních údajů nebo s mým výslovným souhlasem.
5. Porozuměl jsem tomu, že mé jméno se nebude nikdy vyskytovat v referátech o této studii. Já naopak nebudu proti použití výsledků z této studie.

Podpis účastníka: Podpis osoby pověřené touto studií:

Datum: Datum: