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DEVELOPMENTAL CHANGES AND MODULATION OF STATIC POSTURAL CONTROL IN CHILDREN THROUGH ELEMENTARY EDUCATION

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PRESENTADA POR:

D. Roberto Izquierdo-Herrera

DIRIGIDA POR:

Dr. D. Luis Millán González Moreno

Dr. D. Xavier García Massó

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Dr. D. Luis Millán González Moreno, Profesor Titular de la Universidad de Valencia, adscrito al Departamento de Educación Física y Deportiva.

Dr. D. Xavier García Massó, Profesor Ayudante Doctor de la Universidad de Valencia, adscrito al Departamento de Didáctica de la Expresión Musical, Plástica y Corporal.

CERTIFICAN:

Que el presente trabajo, titulado "Developmental changes and modulation of static postural control in children through elementary education", ha sido realizado bajo su dirección, por D. Roberto Izquierdo Herrera, para optar al grado de Doctor por la Universidad de Valencia. Habiéndose concluido, y reuniendo a su juicio las condiciones de originalidad y rigor científico necesarias, autoriza su presentación a fin de que pueda ser defendido ante el tribunal correspondiente.

Y para que así conste expide y firma la presente certificación en Valencia a 2 de abril de 2019.

Fdo: Luis Millán González Moreno

Fdo: Xavier García Massó

Strength does not come from physical capacity.
It comes from an indomitable will.
Mahatma Gandhi

Gracias Luis por tu cercanía a pesar de la distancia, por tu apoyo desinteresado y por ayudarme a pensar en positivo cada verano. Gracias Xavi por tus soluciones instantáneas, tu ayuda siempre que te la he pedido y por contestar presto a todos los emails y WhatsApps. Gracias a los dos por el clima cercano y amistoso que habéis creado en la unidad, una razón más para seguir adelante. Igual que en el SOM, no es un único factor sino vuestro cuidado de todos los factores que afectan al doctorando lo que ablanda el camino.

Thank you Tom and Michael for your support and supervision along this journey. Your detailed comments and suggestions prior to data acquisition helped smooth and standardize the process. Thank you for your abundant and elaborate additions to our common article. It has been a pleasure working with you. I hope we collaborate again in the future.

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Abbreviations

ADHD: Attention-Deficit/Hyperactivity Disorder

AP: Anterio-Posterior

APA: Anticipatory Postural Adjustments

BOS: Base of Support

BS: Eyes Open Feet Separated Condition

BT: Eyes Open Feet Together Condition

CNS: Central Nervous System

COM: Center of Mass

COP: Center of Pressures

DCD: Developmental Coordination Disorder

DFA: Detrended Fluctuation Analysis

EA: Area of the Ellipse Reflecting the Movement of the COP

EC: Eyes Closed Feet Separated Condition

HF: High Frequencies

LF: Low Frequencies

LS: Letter Search Feet Separated Condition

LT: Letter Search Feet Together Condition

MF: Medium Frequencies

ML: Medial-Lateral

MVAP: Mean Velocity of the COP in the AP Direction

MVML: Mean Velocity of the COP in the ML Direction

PAQ-C: Physical Activity Questionnaire for Children

SOM: Self-Organized Maps

VOR: Vestibulo-Ocular Reflex

WBB: Nintendo WII Plus Balance Board

1. Preamble

A successful postural control development relies on controlling movements in relation to ongoing real time perceptual information. A complete development of the central nervous system (CNS), the three subsystems (vestibular, visual and somatosensory) and developments in muscle and motor skills are necessary. Before full performance is reached, individuals undergo different developmental stages that denote specific characteristics. Therefore, a deeper understanding of the characteristics of healthy developmental stages in postural control will have an impact in different research areas. It may assist to identify children at risk for underdevelopment and provide identification of specific deficits. The purpose of this thesis is to provide the reader with a better understanding of some factors affecting different stages in the development of postural control.

Factors such as executing a visual task, position of the feet, the presence or occlusion of vision and the level of physical activity are believed to have a simultaneous or lasting effect on body sway. First, execution of a visual task while maintaining static postural control has a stabilizing effect in adults (1). Second, the visual system has been claimed to play an important role in body sway in children. Third, since physical activity involves the use of body balance, children moving more are supposed to develop better body sway. In this study we examined body sway of elementary aged children when subjected to the previously mentioned factors.

The research methodology used was observational and cross-sectional with 6 to 12 year old children recruited from a school in Forest Lake, Minnesota. These ages were chosen because of the critical period frequently reported around the age of 7-8 in various studies investigating both postural and motor development in children.

Major successes were the formation of differentiated clusters according to the use of vision or not in static balance. Furthermore, performance of a visual task yielded similar changes in body sway when compared to adults. However, our prediction that physical activity levels would correlate to body sway could not be proved by the use of the Physical Activity Questionnaire for Children (PAQ-C).

2. Introduction

The human body is subjected to different forces that allow us to start moving, stop moving and change directions. Different forces are present even if we are just standing. Therefore, these forces must be triggered in order to maintain equilibrium when moving or standing (2). Controlling the position of the body in space, requires the active participation of different mechanisms. To stand upright and move through space, individuals must rely on three sensory systems: visual, vestibular and somatosensory. These systems, and therefore postural control, are susceptible to alteration by different factors.

Research has attempted to define how the human body develops each of the sensory systems. The development of postural control has an influence in the development of gross motor skills and deficits in postural control in children enhance the risk of sustaining a fall (3). Furthermore, differences in postural control in children may serve to identify abnormalities in the functioning of the visual, vestibular or somatosensory systems as well as in the stages of development. Separated investigations of these systems have been performed but the integration of the three of them provides a better understanding of how the postural system works (4). Developmental changes happening from 6 to 12 years old provide a rich field for research into how adult postural control is developed because the main changes in balance should have occurred by that age.

2.1. Definition, mechanisms of balance control and factors affecting its performance

The human body requires a multichanneled system to remain stable in bipedalism. Humans evolved from quadrupedal stance to a standing position in which the lower limbs became the single point of contact with the ground. Because most of our body mass is now located in the higher part of our body, we are an inherently unstable system unless a control system is continuously acting (5). In biomechanical terms, center of mass in the human body (COM) lays on a base of support (BOS) having to fall the line of gravity within the

BOS to remain stable. It is a task of the CNS to maintain control over the COM with the assistance of three subsystems that are the receptors of environmental information.

Postural stability requires dynamic interactions between multisensory networks that include the vestibular, somatosensory and visual system. These senses detect changes of spatial orientation with respect to the BOS and then communicate concrete information about the position and motion of the body to the CNS. Then the CNS sends orders to contract the muscles needed to control the posture of the body in either standing still or moving situations(5). The brain branches contain premotor neurons and second-order sensory neurons that collect and send electrical impulses to the motoneurons in an efficient and fast circuit (6). It is a complex structure conformed by three systems with their own complexity. Vision is the system principally involved in organizing our locomotion and in eluding obstacles when moving. The vestibular system detects linear and angular accelerations. Furthermore, the somatosensory system is compounded by a multitude of sensors that perceive the position and velocity of all body segments, their interaction with external objects (comprising the ground), and the orientation of gravity.(7)

Vision is an important source of information for human balance. The visual system is composed by three parts: the central, ambient and retinal slip. The central or focal system perceives the movement of the objects and recognizes them being responsible for orientation and locomotion. Ambient or peripheral vision senses the movement scene and is thought to dominate perception of self-motion and postural control (4). The retinal slip is related to the displacement by the CNS and used as feedback for compensatory sway (8). Vision is very important in the control of balance but the other two systems can still successfully provide standing balance when visual information is missing. After all, humans can also maintain upright stance with the absence of light.

Peripheral vision is relevant to postural control, especially for maintaining a static stance. Peripheral vision is used to stabilize body sway and therefore control posture (8). Wade and Jones argued that it is not only the retinal region that determines postural control but also the nature and structure of the light perceived by the periphery of the retina (4). Therefore, the optical information involves both the retinal location and also the geometrical structure of the arrays formed by the optical flow field. Furthermore, depending on the nature of the field, the retinal periphery by itself is not useful for postural control. If the information is radially structured, lamellar flow reaching the periphery is what provides balance information(9). Flow structure is then crucial in the control of posture.

Additionally, it has been stated that visually-induced postural responses might be facilitated by two different mechanisms. On one hand, there seems to be a short latency system, reacting to transitory visual stimuli and sensitive to visual geometry, which is responsible for fast and automatic postural sway adjustments. On the other hand, a longer latency mechanism allows the mindful perception of self-motion during movements of the body with a longer duration (8).

The vestibular system is often described as the balance system since it plays a vital role in ensuring postural stability as well as gaze. The vestibular system is unique from other systems because it becomes directly multisensory and multimodal (6). Its main mission is to give feedback about the head's position and changes in its position. In order to accomplish that, each inner ear contains two types of sensors: the three semicircular canals, which sense angular acceleration or head velocity and two otolith organs, the utricle and the saccule, which sense linear acceleration as well as the position of the head relative to the gravitational force. The canals comprise tunnels filled with fluid called endolymph and sensory hair cells that bend with the movement of the fluid in the three dimensions. The utricle and saccule are bulbous lumps in the canals that contain otoliths, tiny calcium carbonate stones that are rooted in the gelatinous substance with the hair cells. The otoliths bend the hair cells according to the direction in which they are pulled by gravity (2).

Sensors in the ear connect to the brain through fibers. The afferent fibers, which innervate the sensory organs of the inner ear, are thought to be responsible for obtaining information about body balance. Signals obtained by the afferent fibers are then sent to the vestibular nuclei. Next, central neurons from the nuclei send the information to the CNS structures that control movements, posture and balance (10).

The connection between the afferents and the nucleus is necessary for the system to function. On average, regular afferents transmit two times more information about head motion than do irregular afferents over the physiological frequency range. Thus, regular and irregular afferents effectively comprise two parallel information channels (Figure 1); one which encodes high frequency stimuli with higher gains (i.e., irregular afferents), and the other which transmits information about the detailed time course of the stimulus over the behaviorally significant frequency range (i.e., regular afferents). Separately, the afferent fibers directly project to the vestibular nucleus neurons. The neurons are grouped based on their sensitivity to eye movements and their connectivity; vestibulo-ocular reflex (VOR) neurons and posture and balance neurons or vestibular only (Figure 1). The VOR neurons project to oculomotor structures while the vestibular only neurons project to the spinal cord, thus the sensorimotor system (10).

However, another school of thought has questioned the assumption that perception is divided into separate domains of vision, hearing, touch, taste, and smell. Forms of ambient energy do not exist separately but there is a structure between the different forms perceived by the human body. These patterns make up a global array, exclusively designed by the interaction between the animal and the environment (11). As highlighted by Mantel et al (12), perception of distance to an object is inferior for stationary perceivers, but often is greatly improved when perceivers are moving. Furthermore, these authors argue that there is a higher order parameter providing information rather than internal processing to inputs derived from individual perceptual systems (12).

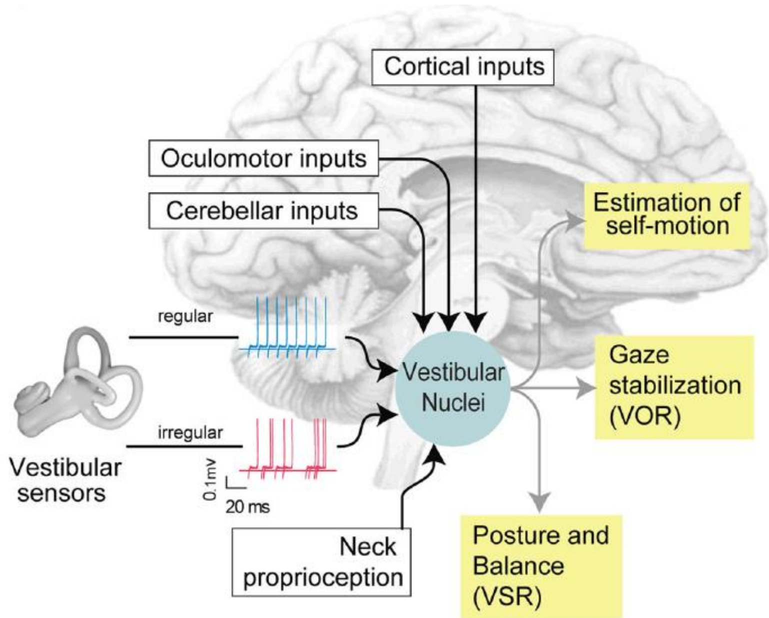

Figure 1. Multimodal integration within vestibular pathways (9).

The VOR is considered an important system pertaining to postural control. Not only it connects two sensory systems, the visual and vestibular, but it also allows humans to maintain stable vision while moving. Head rotations would move our vision sideways provoking a loss of the sight which is prevented by the VOR by generating opposite movements of the eye that are of equal force and length than the movements of the head. The VOR is the fastest human behavior taking only 5 to 6 ms to respond to head movements (13).

Proprioceptive and cutaneous inputs conform the third sensory system that monitors the status of the musculoskeletal system. Ruffini endings and pacinian corpuscles are receptors located within joint capsules to respectively give feedback about the joint position and its rapid changes. Furthermore, muscle spindles and the Golgi tendon organ give feedback about increases in muscle length and muscle tension respectively (2).

Muscle spindles are inside the muscle in a large number. Each of this proprioceptors are arranged in the direction of the muscle fibers in the muscle so that when the muscle is contracted, the spindles are contracted as well.

Slow stretches provide a slow rate of stimulation, whereas faster ones produce a faster rate. The motor neurons connected to the muscle spindles provide the CNS with information about the muscle's length and velocity of contraction. Therefore, they facilitate an individual's ability to recognize joint movement and position sense. Afferent feedback is then provided by translating stimuli into reflexive and voluntary movement (6).

Another proprioceptor connected to muscle function is the Golgi tendon organ. Located in the tendon, the sensory fibers of this organ are stimulated by stretching or contracting the muscle. The fibers synapse with the motor neurons of the muscle, transmitting inhibitory impulses. Consequently the contraction of the muscle is canceled by the Golgi tendon organ when the tension surpasses a certain threshold. This is also named the tendon reflex (2).

Pacinian corpuscles are the third kind of proprioceptors and they sense touch and joint position. Only when changes in pressure occur the pacinian corpuscles sense the change and produce a signal that is proportionate to the force of the pressure. The corpuscles located under the skin, both on the soles of the feet and the palms of the hands, are in charge of the extensor thrust reflex. Fibers on the pacinian corpuscles synapse with the muscles of the limb, thus contracting them. The extensor thrust reflex only occurs when a large change in pressure takes place, for example, when you land on the feet after a jump, preventing us from falling (2).

Despite the fact that the three balance systems are often studied separately, the visual and somatosensory structures interact with the vestibular system throughout the central vestibular pathways. Firstly, in the case of vestibular and visual inputs, information from optic flow reaches the VOR facilitating the integration of visual-vestibular input. VOR neurons then generate the premotor commands that control the extraocular motoneurons which then produce involuntary movements of the eyeball. Those are the movements that ensure a stable gaze during self-motion at lower frequencies (14). Secondly, somatosensory and proprioceptive inputs are also connected to the vestibular system, they reach the vestibular nuclei with signals sent from the dorsal-root axons and second-order neurons. In situations when inputs come from proprioceptive and vestibular sensory systems, the information may be antagonistic. For example, in a voluntary head turn neurons fire less that when the head is moving as a consequence of a whole body motion because only the vestibular system is stimulated. The integration of these two paths of information is essential for the correct control of posture but also for higher order functions like self-motion perception (10).

In other words, the three sensory systems in combination support humans to maintain balance. Being vision the principal system we use, different strategies can be applied in the absence of light to provide successful balance. Precisely, proprioception increases its participation or contribution when there is a need. Bearing this in mind, sensory system's performance can be also affected by a series of different factors rendering them ineffective and/or causing them to malfunction.

There are several mechanisms and circumstances that can have an effect on postural control, some increase body sway while others lower the oscillation around the Y axis, improving body balance. As explained in the previous paragraphs, the balance control system requires the correct functioning of the sensory systems and the spinal cord, as well as the CNS to process the signals and later, accurate activity of the muscles and structures following the CNS or spinal cord directions. Restraints in any of the previous structures working in the control of balance will cause a change in the way humans manage to control their stability and usually have a detrimental effect on the whole balance control system. Subsequently, examples will be exposed as to how postural control is affected by externally or internally altered mechanisms.

Vision is the sense that we use largely to maintain balance. Peripheral vision has been proven to be more efficient for controlling anteroposterior oscillations while central vision contributes mainly to mediolateral oscillations (15,16). In fact, sensitivity of peripheral vision is principally affected by lamellar flow rather than radial flow, being central vision sensitive to both (15). Postural sway is controlled primarily by the ambient or peripheral visual system. The peripheral field of vision degrades with ageing which is why the elderly have less sensitivity to low spatial frequencies and need a higher contact to effectively detect spatial difference, causing a decreased postural stability (4). When humans lose vision, their risk for falling increases extremely as their postural control is worsened and, they are forced to employ a greater use of the hip strategy to maintain postural stability (17). Another study with younger subjects (18), found that children with visual impairment have more problems with balance and gait than children with a healthy functioning visual system.

In another vision related and postural control study, results were similar. Simeonov and Hsiao showed how close visual references in a peripheral position reduce instability related to elevations and significantly improve balance on deformable support (16). Inversely, in that same study, when workers directed their eyes to a distant target while standing at a height with a lack of close visual references, postural instability was increased similarly to what is named height vertigo.

Vestibular function can also be altered and affect balance as a consequence. Children from 5 to 9 years old with sensorineural deafness showed a slower vestibulo-ocular response, when studied by comparing their postrotary movement (reflexive movements of the eyes after a quick rotational movement) to normative data (19). In the previous study, hearing impaired children seemed to compensate for vestibular deficits with the visual and kinesthetic systems to maintain static balance with eyes open or closed. Differences in balance control were not perceptible. However, more recent studies (20,21), found a correlation between hearing impaired children and balance problems.

Some tests are used to evaluate the function of the saccule, the inferior vestibular nerve, the vestibulospinal tract and the vestibular nuclei. Damages in the previous predict problems in postural control, for example standing on one leg is increasingly hard with the following conditions: eyes open, closed and standing on a balance beam with eyes open and then closed (20).

Moreover, children with severe to profound sensorineural hearing loss, exhibit poorer static and dynamic balance ability which correlates with horizontal vestibular canal function as measured by rotation (21). Hearing loss, uncombined with other balance dysfunctions, does not seem to be a major challenge for balance ability in daily life activities. Vestibular damage or weakness is compensated by to adaptation and/or substitution of the other visual and somatosensory inputs as well as the cerebellum providing a sufficient postural control (20).

As far as the somatosensory system is concerned, challenges presented to proprioceptive signals result in an inefficient postural control or a change in its regulation. Somatosensory loss induced by ischemia produces an increase in shear forces and in hip muscle activation resulting in the larger use of a hip strategy for postural control similar to the strategy used by control subjects while standing in a shortened surface (22). Horak et al (22) also found that subjects with a loss of somatosensory inputs can still correct disequilibrium with well-coordinated movements. In a later study, evidence was found for an increase in the vestibular participation in balance control due to somatosensory loss. Caused either by peripheral neuropathy or when somatosensory information is disrupted, when there is a loss of somatosensory information, the vestibular system may engage to control postural alignment via control of the trunk in space (23).

Somatosensory information in subjects without a proprioceptive disability is challenged when standing on an unstable surface or in a moving scenario. When standing on firm support, the mechanism of postural control relies principally on somatosensory input, whereas standing in deformable support which requires visual information to become the critical input for the control of balance (16). The latter can be the case of construction workers who use temporary surfaces that may bend, flex, yield, or compress. A different scenario where postural control reacts in a different manner is at sea. Stoffregen et al (24) found recently that ship motion generates an increase in the spatial magnitude of body sway, therefore reducing stability. According to their argument, similar changes in body sway are usually associated with healthy aging.

Muscle weakness can predict postural imbalance, especially in the elderly. A review trying to find a correlation between muscle weakness and postural instability and falls from 2008 (25), found that muscle weakness is an important risk factor for falls in the elderly and that it can potentially be solved by an adequate therapeutic intervention. Meanwhile, it was not clear whether strength training alone leads to a fall reduction due to the fact that few studies addressed the pathophysiological relationship between strength and postural control, rather using different multifactorial interventions. Another review from 2010 (26), analyzed how interventions to increase strength and/or power, based resistance and/or power training affected balance performance in older adults. The results show significant associations between balance and strength/power outcomes finding however, frail evidence for a cause and effect relationship between muscle function and balance performance. Muscle mass size should not be confounded with muscle strength since they do not have the same effect on postural control. With only a short-term training program combining strength and balance exercises, neural changes are generated that improve maximal strength and provide a minor improvement in postural steadiness in the elderly (27).

Healthy living habits include engaging in physical exercise regularly. Exercise has different effects on the human body and one of them is thought to be the improvement of postural control via the generation of neural pathways and the strengthening of the muscles involved in the control of balance. The latest review on the effects of different types of exercise on physical balance in older people (28) found that regardless the type of exercise, the more effective programs were done three times a week for three months and involved dynamic exercise in standing. The authors concluded that although some types of exercises are moderately effective, there is insufficient evidence yet in order to draw any conclusions for general physical activity (walking or cycling) and exercise involving computerized balance programs or vibration plates. Long-term (18 months) either weight training or aerobic walking programs significantly improve postural sway in older, osteoarthritic adults based on the fact that with their eyes closed and double-leg stance condition, both the aerobic and weight training groups scored significantly better compared to the control group (29).

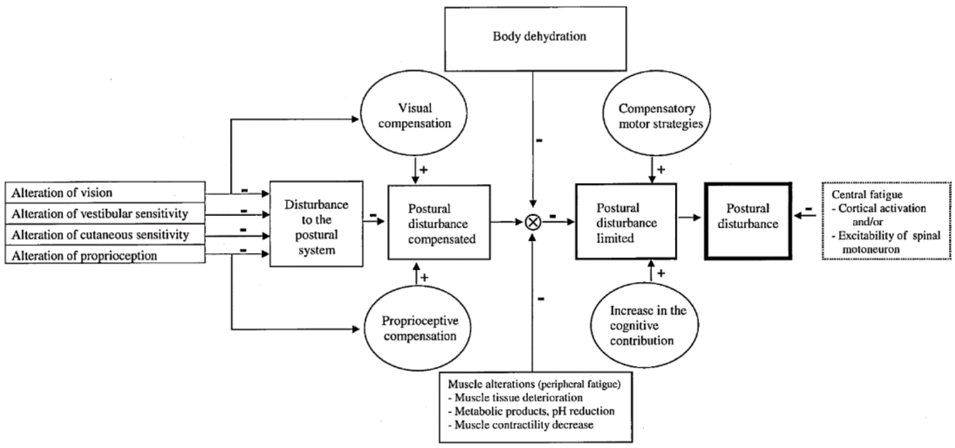

Figure 2. General muscular exercise depressor effect on postural control.

Certain compensations to postural alterations occur initially (− indicates a disturbance; + indicates a compensation) (27).

Fatigue from exercising has an immediate dropping effect in the control of body balance. In other words, when an individual is exhausted from a physical activity, postural control is of inferior quality. Paillard (30), reviewed in 2012 how general and local fatigue affect postural control. The former increases postural sway once the energy expenditure induced exceeds the lactate accumulation threshold, in the form of short and intensive exercise. The latter, as an exhaustive but local activity, has an effect on postural control when the strength loss generated reaches 25-30% of maximal voluntary contraction. When the exercise is sustained, rather that intensive, it can also disturb postural control, whether it is general or local. Different compensatory postural strategies are prompted to offset the disturbance of postural control caused by fatigue (Figures 2 and 3).

Physical activity can be performed in a more intense or lighter form. Lighter and vigorous types of exercise have a positive impact in postural sway when measured in the absence of visual input but greater levels of intensity might be more suitable since these also improved dynamic daily motor tasks such as gait and standing from a sitting position (31). Muscle weakness, as noted a balance predictor, can be combated with progressive resistance training. A review on this form of exercise and its effects on balance performance in older adults (32), found inconsistent results as to the effects of resistance training on balance. The authors accused the results to the differences in heterogeneity of subjects, balance tests, methodology of the balance test, sample size, inadequate dose of exercise and/or compliance to training. From this finding, Orr et al (32), recommend the future application of select resistance training programs that: "focus on the muscles most pertinent to balance control, best target neuromuscular adaptations that protect against postural challenges..." among other suggestions.

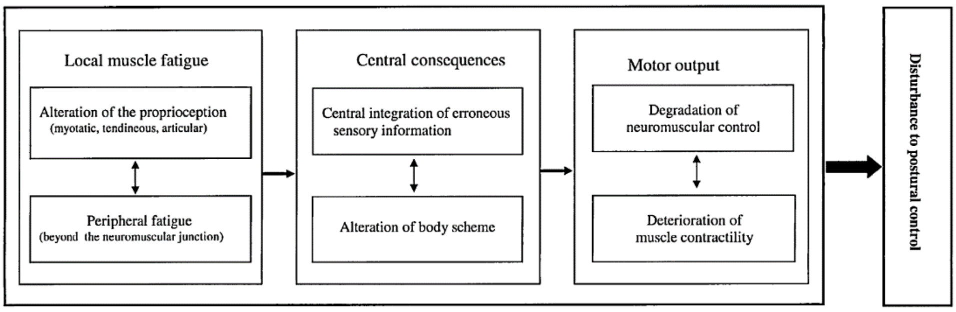

Figure 3. Localized muscle fatigue depressor effect on postural control (30).

When compared against traditional balance exercises, progressive resistance strength training, aimed at hip flexors, extensors and abductors, knee flexors and extensors, and ankle dorsiflexors and plantarflexors, is more effective than traditional balance exercises on improving anterio-posterior (AP) postural stability among non-frail elderly older than 65 years (33). Consistent with the previous paragraph, Hess and Woollacott (34) unveiled how a high intensity training program, targeting key lower extremity muscles can safely and effectively strengthen the legs of balance-impaired older adults, then significantly improving functional postural control and decreasing fall risk.

Many different types of exercise are offered nowadays, some of them are more suitable to improve physical balance than others. Those who require using force to maintain a challenging balanced position are more similar to the tests used to analyze differences in static and dynamic postural control. Based on that, it could be argued that physical activities like gymnastics or tai chi may have a stronger effect on equilibrium improvement than body vibration.

Although findings from two recent reviews (35,36) showed some positive effects of body vibration on balance and mobility, results remain inconclusive. When analyzing fall rate, balance and mobility after whole body vibration in a systematic review (35), the authors found that basic balance ability and mobility may be improved among older adults. Single-leg stance and timed up and go measures were improved mainly when whole body vibration was accompanied by exercise and applied to lower-functioning patients (36). Still, whole body vibration only effects on postural control remain inconsistent and more high quality trials examining only the effects of the exposure to this method are required to be able to guarantee its efficiency.

Some practices resulted on positive effects in reducing postural instability. Three different gymnastic exercises (mini-trampoline, aquatic gymnastics and general floor gymnastics) were efficient improving the postural balance of elderly women after 12 weeks of training (37). In a pilot study of the "Reykjavik model" (38), where a combined vestibular, proprioceptive and fall-prevention training was used as treatment, significant improvement was observed in postural control, functional ability and confidence in everyday life activities. Tai chi is a multimodal intervention that entails gait, balance, coordination, functional exercises, and muscle strengthening. Its global focus seems to have the greatest impact on balance in older adults. The most recent review about the topic (39), found that tai chi may improve: the ability to respond to reduced or conflicting sensory situations, anteroposterior standing balance control, balance in sway-referenced support, knee flexor and extensor muscle strength as well as other parameters related to postural control. Multisensory balance training is therefore a good method to improve postural control. Tai Chi seems to be one of that kind and habitual practice may transfer into functional activities of everyday life.

The Surgeon General's report explicitly ratifies Tai Chi as a good exercise for fall prevention (40). The Harvard Medical School Guide to Tai Chi (41), in an extended report, reviews many of the studies that explain its effectiveness for postural control. Following their argument, Tai Chi helps to influence the four elements of balance starting with the musculoskeletal system involving a constant shifting of weight from one leg to the other, which facilitates improved dynamic standing balance and strength of the lower extremities (legs, ankles, feet). Secondly, Tai Chi improves the sensory and perceptual system: on people with plantar peripheral neuropathy], 24 weeks of Tai Chi classes led to an intensification in sensitivity of the soles of the feet, greater balance, and faster walking speed (42). Thirdly, this physical activity promotes neuromuscular synergy: one randomized trial of older adults studied reactions to experimentally induced slips during walking (43). Compared to a conventional balance-training program, those assigned to intensive Tai Chi training displayed better ankle neuromuscular reaction, enhanced coordination of muscle groups, and enhanced overall maintenance of balance (43). Lastly, the cognitive system is also positively affected. One randomized trial found that 48 weeks of Tai Chi reduced the fear of falling considerably compared to a wellness program (44).

Not only traditional Tai Chi is involved in improving postural steadiness but the biomedical research and evolution of Tai Chi forms has incorporated new and simplified protocols that make it easier to learn Tai Chi in a safe way. These protocols include the Tai Chi exercises that are better suited to enhance individuals' equilibrium. The first one was developed by Tai Chi Master Tingsen Xu in 2004 (42), consisting of 14 independent and non-sequenced moves purposefully chosen to ameliorate balance. Since that time, multiple combinations of exercises have been studied in research of the optimal one regarding the time consumed and the effectiveness.

The CNS is an important piece in the management of body equilibrium. Several studies have focused on better understanding how different substances, that are known to have an effect on the CNS, may impair or boost the ability of this system to control body balance. Caffeine, alcohol and smoking are incorporated in the habits of many as well as the use of sleeping drugs or in contrast to this last, sleep deprivation, which will also be analyzed in the following paragraphs. Sleep deprivation has been proved to harm the functioning of the CNS thus possibly also having the same effect in postural control. Although there are many other substances and situations that affect the CNS either positively or negatively, the previous were chosen based on their regular appearance in the majority of the population.

Drugs can be defined as chemical substances, such as narcotics or hallucinogens, which have a physiological effect, especially in the CNS when ingested or otherwise introduced in the body. Since the CNS is vital in postural control, the use of different drugs could have a potential effect on postural control. Only mild substances, not considered even drugs due to their low effects, will be considered because of their widespread use in the population. Caffeine and alcoholic drinks, smoking, contact with lead and the use of sleeping drugs, or in contrary sleep deprivation, have become common in many individuals. In the next paragraphs, the effect of the previous substances on body balance will be analyzed.

Some substances that some individuals choose to ingest or get in contact with, can disturb postural control while others will not. One hour after consuming caffeine in the form of an energy drink, subjects center of pressures (COP) was not affected neither positively nor negatively which suggests that caffeine, with the dosage used in this study, does not modify postural control in healthy individuals (45). Caffeine intake as a daily dose did change positively equilibrium of hemiparetic stroke patients particularly improving their somatosensory postural control system (46). Alcohol, increasingly when abused but also moderately consumed, is detrimental to balance. The function of the oculomotor and the vestibular systems, tested by measuring the VOR, was reduced after drinking a moderate quantity of alcohol which produced postural instability (47). Additionally, prenatal exposure to alcohol, which extreme cases are known as having fetal alcohol syndrome, diminishes the ability to maintain equilibrium, these children displaying greater AP body sway and being mostly dependent on somatosensory input (48).

The social consideration of smoking as an unhealthy damaging habit is growing into more and more cultures. However, ease of access makes of it a very common addiction. In a different plane, lead has been categorized as a pollutant for the human body. Smokers were found to have more unstable posturography than nonsmokers with a difference in body sway velocity aggravated by the fact that smoked tobacco had long-term effects in postural control (49). Children with a significant amount of lead in blood (9.2 to 32.5 ug/dL), showed a higher sway area only with eyes closed which indicates that their somatosensory or vestibular system may be affected and therefore they rely more on visual input to maintain stability (50). Both smoking and lead exposure are therefore injurious to a healthy balance control system.

There is a growing body of scientific evidence ratifying a link between critical sleep factors and cognitive processes. Nowadays many people are sleep deprived and, as solution they use sleeping drugs. Sleep deprivation of a full night provokes larger and faster body sway as well as inaccuracy relating visual information to motor action therefore sensoriomotor coupling impairments in young adults (51). Several hypnotic drugs used as sleeping aids, such as nitrazepam, triazolam, lorazepam, temazepam, loprazolam, flunitrazepam, flurazepam, and the Z-drugs impair body balance and standing steadiness after single dose administration, more intensely in the elderly (52). Sleep deprived individuals as well as those using sleeping medication, especially older adults, should be aware of the falling risks that they can suffer due to a loss of postural control.

As humans, we mostly need to maintain static or dynamic balance as a mean to effectively execute another task and not as end in itself. A growing body of research has therefore focused on the analysis of postural control while performing different secondary tasks that require a certain level of attention. A review from 2002 (53), stressed that in young adults postural control is attentionally demanding and demands increase depending on the postural task, the age of the individual and their balance abilities. Performance of an easy cognitive task produces a reduction in COP excursions in both young and older adults while harder cognitive tasks will be disruptive to postural control first for older adults and as they become harder, also for younger adults (1,53–55). There was a reduction of static postural control while focusing on a second cognitive task whether the task was counting backwards (54,56), auditive (55,57,58) or visual (1,57). Under certain conditions, postural sway is probably reduced in order to facilitate the effective performance of cognitive tasks.

In contrast, body sway deteriorates when performing tasks if the tasks involve a movement or consist on focusing the attention on the control of posture. Static COP excursions augmented when the secondary task involved different types of slight movements of the higher limbs or the eyes (53,57,58). Body sway was also increased when adult subjects tried to concentrate their attentional focus on their postural control in order to control it, yet this was not the case of children aged 4 to 11 years old for whom equilibrium improved upon purposefully controlling it (56,59). Summarizing, both precision movements involving the eyes or higher limbs as well as trying to control our body sway result in degraded static posture.

Similar to the other systems in the human body, postural control improves along developmental stages. Factors associated to development like age, height and weight have a large effect on individual's postural control. Excessive body weight regardless of age, generates a reduced postural sway also associated with a substantial reduction of the dynamic stability range in subjects with body mass indexes higher than 40 (60). Since age, height and gender are mechanisms affecting postural control that are primarily related to developmental changes, these will be discussed in the next pages. Furthermore, development and its effects in postural control from birth to adulthood will be explored.

2.2. Vital developmental phases of equilibrium

The development of postural control begins from birth as a required tool for the growth and maturation of motor skills. Each small step in the development of human balance enlarges both the spatial and environmental that limit where and how stability can be maintained successfully. In other words, as people grow older, they build new movement patterns upon previously learnt and necessary balance skills. As an example, we first need to be able to stand in order to walk and walking is a prerequisite for running. Each balance period in the life span has concrete and differentiated characteristics that suggest different approaches to be properly studied. Balance control is required in static and dynamic situations, the later involving a more complex circumstance in which the forward propulsion of the body acts as destabilizing force and thus a challenge to lateral stability (61). In the study of the development of equilibrium, major milestones have been identified. These milestones have been used by researchers to explain the processes of balance maturation through phases (61,62).

In this study, the classification of balance achievements during ontogeny, provided by Assaiante and Amblard (61,63), will be used to illustrate the learning processes necessary to successfully maintain body balance in naturally occurring activities. Four distinct periods categorize the development of equilibrium from birth to adulthood, age that is accepted to display a proficient balance control. Infants have been found to show an indistinct cephalocaudal gradient in the development of postural responses, control first starting in the muscles of the neck, then trunk, and lately on the legs (61,64). The first period is based on the acquisition of head control, starting at birth and characterized by a downwards organization of posture control from the head. The second stage, mastered around 6 years old, consists on becoming skilled at both static and dynamic bipedal posture. As figure 4 shows, posture in this stage is most probably organized in an ascending fashion, with a blocked neck joint. Static balance appears to be organized from foot to head while, during locomotion, the stabilization starts from the hip (61). This patterns form a base, necessary to understand the developmental stages of balance control from 1 to 6 years old.

The progression in muscle control is further favored and facilitated by experiences in each new postural skill. The last two periods take place between the age of 7 years and adulthood. Once children can successfully maintain a bipedal posture, they are now able to relax and articulate the neck joint while standing. Therefore, the third phase can be defined as the time when a stabilization of the head in space occurs. Such stabilization involves accurately interpreting the visual and vestibular messages related to equilibrium control (65). Finally, in the fourth phase an adult postural control is attained, involving an articulated operation of the head-trunk unit and a selective control of the degrees of freedom at the neck, depending upon the task (61). As it can be noted, each phase is built on the previous one and they all add an important portion to the complete map of human postural control.

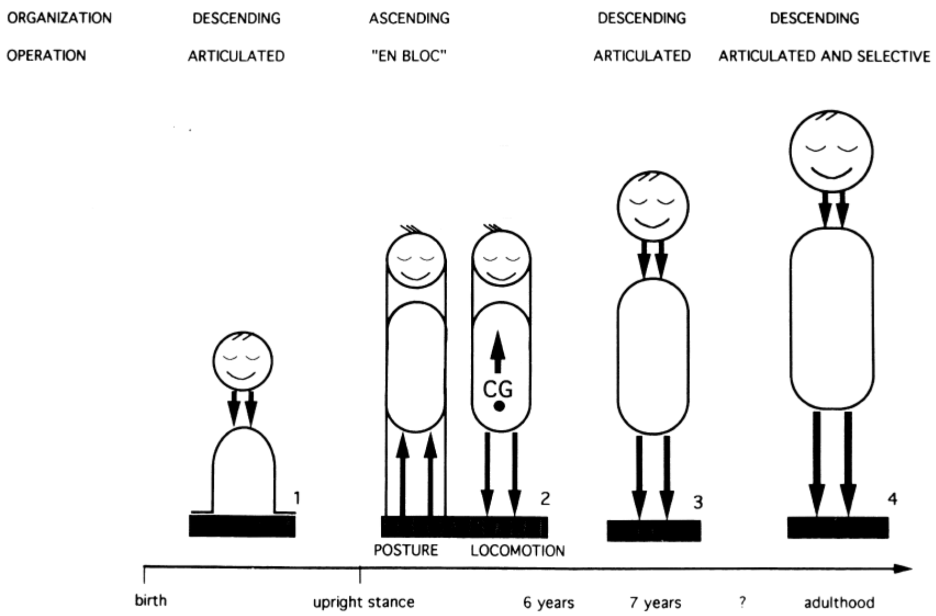

Figure 4. Ontogenetic scheme of the organization of posturo-kinetic activities during the lifespan (59).

This work is focused on the middle phases. Concretely, the second and third phases are the aim of this study and the current knowledge on those will be exposed later in this point. However, before concentrating on the target phases, it is imperative to delve into the previous ones so, the knowledge of the former acquisitions on balance control allows a clear understanding of the latter ones.

Balance control in the early years of life

Equilibrium control development has been studied even before babies are born. Leg postures of preterm infants lay in extension until they reach 6 months postmenstrual age when muscle tone in flexors increases, first in legs and then in the arms (66). Muscle tone is needed in order to later maintain postural stability. From birth, head control is the first goal while laying on the ground (61). Research performed with newborns (67–69), revealed the existence of direction-specific adjustments that activate primarily dorsal muscles when swaying forward and ventral muscles when going backward.

Milestones identified in the process of balance development in preschoolers are sitting, standing with support, standing without support and finally walking. During the first phase, postural activity is largely variable and minimally adaptive to external perturbances, with only a few muscles starting to work in a coordinate way at 3 months of age (67). From 6 months onward, postural activity begins to adapt to the situation by an adaptation followed by a selection of the previous basic specifically directed adjustments, decreasing the variation in muscle activation patterns (67,69). From 9-10 months of age, children begin to sit independently as well as becoming able to adapt the movement of the pelvis with respect to the velocity of a reaching arm (67,70). Later in the maturation process, children become able to activate more specific muscles when reaching an arm when sitting (68), while they learn to master the next milestone, standing.

Bipedal standing provides children a new perspective of the world around and thus is considered as the beginning of the second big phase in balance acquisition. When learning to stand from 9 to 12 months, children need to pull from surrounding objects (71), information from the feet and ankles is weak and they depend mostly on visual cues (64) to maintain postural control which starts with a large amount of sway. Sway magnitude remains the same when the need to grab onto different objects disappears (71), still suggesting an improvement in postural control. Standing is the base for walking, a much more complex task due to the need of maintaining lateral stability with a forward propulsion and supporting the weight of the body with one leg (72).

The difficulty of locomotion requires a simplification which originates in a stable reference frame. Numerous studies support an ascending order of stabilizing in children, starting with the pelvis, shoulders and later the head (72–75). Furthermore, the pelvis is stabilized also before foot lift-off, suggesting a descending organization of balance control which turns balance control to be pelvis centered in children (72). Young children stabilize first the pelvis laterally, consistent after one week of walking (73,74,76), to allow them to control a situation in which they face forward and lateral instability combined (Figure 5). Shoulder stabilization in space appears at the second month of autonomous walking (72), with the first 5-6 months of walking experience constituting the acquisition of the basic postural dynamic requirements of gait (74) rather than more specific adjustments which begins afterwards. Trunk rotations towards the stance leg start after 9 to 17 months in order to prevent pelvis drop (73) establishing a foundation for integrative postural adjustments.

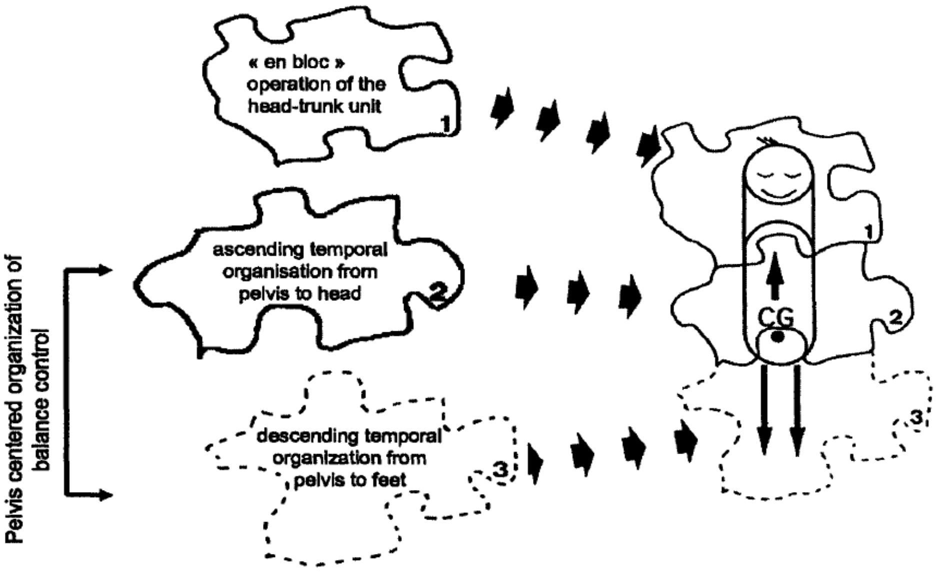

Figure 5. Scheme of the organization of balance control in toddlers (72).

Developmental shifts in walking ability may also be analyzed by changes in the characteristics of the steps like cadence, acceleration, pendulum, stride length, step width and frequency. As toddlers start walking, velocity increases for the first two months due to an increase in step length, with cadence slowing afterwards progressively (74). Bisi and Stagni (74), also found that acceleration declines in the first 6 months of walking experience and pendulum patterns were found in the first month. Gait parameters in 3 to 6 years old are still evolving since step frequency has been found to be higher with eyes open and closed than that of older children and adults (75). In that same study, Hallemans et al observed no differences in eyes open or closed between age groups for any of the dimensionless parameters studied, suggesting that after the age of 4, children walk in a dynamically manner analogous to adults. The process to a full control is long, with only effectively stabilizing the head in space at the age of 7 (63).

Balance development has been studied by grouping children according to their age. One and a half years old children starting to walk already show basic compensatory responses to balance threats which evolve into sequential responses. One to two year old children are also characterized by a greater reliance on knee-joint torque for balance recovery, related to less activity in the trunk muscles (77). When gait is initiated by a 2 to 3 years old, the first step collides with the boundaries of the base of support which did not happen in older children nor adults (Figure 6).

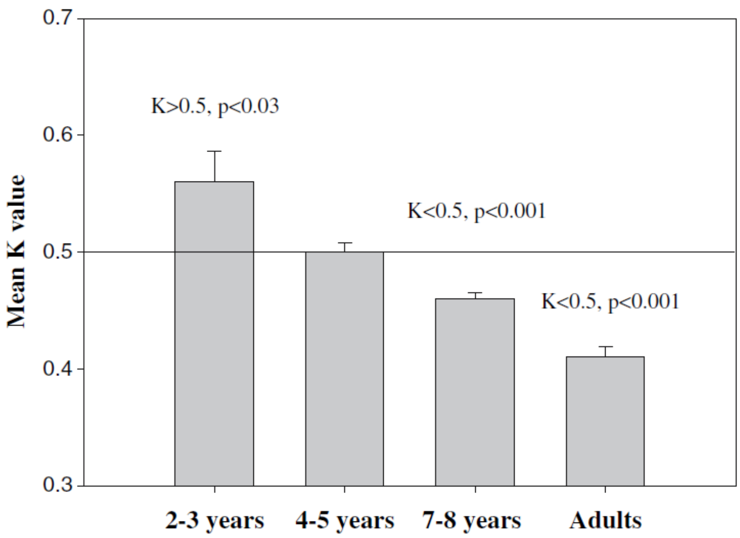

Figure 6. Group means of the values of the COP movement during the first step.

The horizontal line demarcates the boundaries of the BOS (K > 0.5), surpassing them would mean making a controlled collision (78).

During the young ages, when children are still mastering basic movement patterns, a large number of variables play a role. Until the age of three years, limb orientation uses the trunk as the main reference frame and children are still unable to shift from an egocentric reference frame, using somatosensory cues, to an exocentric one based on gravitational cues when trying to maintain a horizontal forearm position (79). Although control of the dorsal muscles appears to mature earlier than that of the ventral flexors, which dissolves from about 3 years onward (80), 3 to 4 years old children still show delays in onsets, more variability, longer durations, and more sway oscillations when EMG and kinetic variables are analyzed (77). In addition, when walking on the ground, pelvis and shoulders are stable in space but, an increase in the task difficulty will lead to loose shoulder stability, only re-stablished when the pelvis is destabilized (72).

A larger number of equilibrium research studies can be found with children aged three years old onwards. Probably, that is due to the fact that such measurements become simpler to perform and more accessible. According to Nashner and Peters (81), postural control involves two different processes; the motor adjustment, executing muscular responses, and the organization of the visual, somatosensory and vestibular senses. The former develops in early childhood while the latter is hierarchically higher and develops more slowly (62). That explains why children aged 3 to 4 years old had a lower performance in both visual and vestibular function compared to the rest of ages (82), although they showed a similar level of somatosensory function (83) as can be noted in Figure 7.

Movements of the head in space have been found to correlate with physical balance during human growth and development. In the second phase of physical balance, walking from 3 to 6 years old, children adopt a head-trunk stiffness in challenging situations (72,76), named as an 'en bloc' head stabilization in space (Figure 4). Higher movement in 5 compared to 8 years old children has been first explained as a consequence of a less efficient integration of sensory systems (84) but more lately the motor behavior in young children has been found to originate in the visual system rather than in the balance system (85).

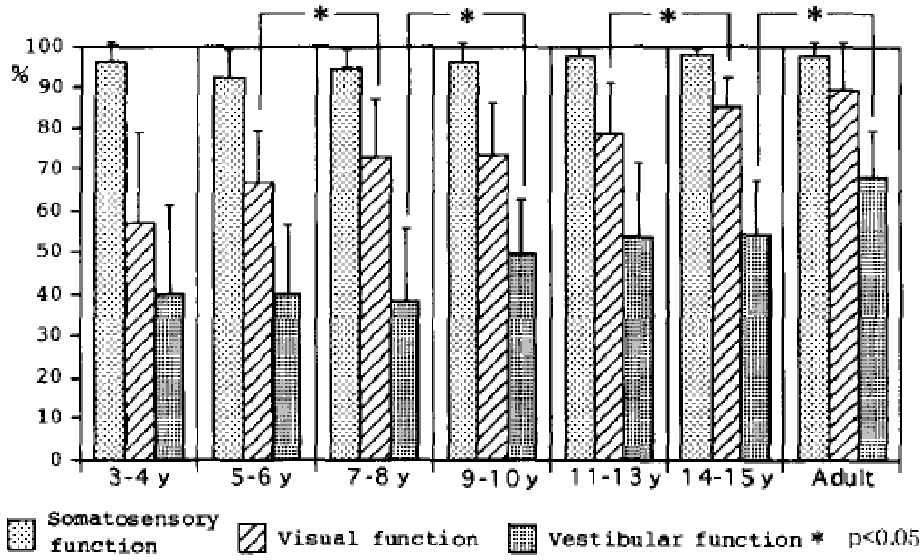

Figure 7. Development of sensory functions contributing to postural control (82).

A relationship between gaze shifts and head movements has been recently corroborated. For this reason, 5-6 year old show sensitivity to the speed of the target when they track visually, with respect to the amount of head movements (86). Head movements, when caused by gaze shifts, have been found to decrease postural stability in 5 year old but not in children older than 7 (85). In the previous study, the authors also found that correlations between gaze shifts and body sway were weak but for the antero-posterior (AP) sway and vertical gaze shifts in 5 year olds. However, Stoffregen et al (87) provide a plausible explanation to the findings mentioned by claiming that the postural control and visual systems may be functionally integrated dynamical systems. The youngest children might then have not yet developed this integration, thus experiencing gaze shifts as another postural induced movement.

Equilibrium lays on subtle and specific movements originated at different body joints. Aimed at suppressing superfluous and disproportionate muscular activity (88), automatic components of reflexive control also show similar latency in typical developing children and in adults (68). As children mature, primitive reflexive systems are supplanted by higher nervous systems (64).

Other important reflexive movements that evolve with maturational processes are referred to as anticipatory postural adjustments (APA).

Triggered prior to a self-induced disturbance to stabilize the trunk and the limbs involved, APAs facilitate the execution of voluntary movements. APAs are known to be a significant milestone in motor development. Sensory information evolves from constituting the consequence of a movement to become an informational instrument (71,73,76,89–91). Adjustments emerge early in life, an activation of the hip abductor to stabilize the pelvis prior to heel off occurs even before children are able to walk independently (73). Different researchers on balance development (71,76) agree that APAs mainly occur between 1 to 4 months of walking experience, although only first for the lower part of the body and only mature at that stage for the medio-lateral direction (73). Hay and Redon (89) refer to APA as feedforward postural control and differentiate it from feedback postural control, being the latest the only one available when dealing with externally generated postural disturbances. Actions like touching with the fingertips or raising the arm solicit APAs, respectively the first happening already in infants (71) and the second in children from 3 to 5 year old (90). Although present, these corrections prior to the movement are still inconsistent in young children and one of the main causes of instability at those ages.

Access to new information in the form of APAs to improve posture suggests that postural control is a co-developing system rather than a rate limiter to walking. APAs operate in the whole body of younger children but, from 4 to 5 years old, they are focused on the lower limbs, being mature at that age when performing an anterior inclination of the trunk and just starting to appear during bipedal walking (73,76). Finally, the ability to adapt anticipatory postural control to different situations starts to develop from age 6 in boys and 5 in girls (91). Prior to that age, development follows a clear cephalocaudal pattern in the control of body sway.

At the ages of 4 to 6 years, postural control is characterized by a posterior position of the COP and a sway that is faster, covers greater distance in the medial-lateral direction (92,93) and with a faster acceleration (93) when compared to older children or a fully mature postural sway. Woollacott et al. also found in children at this ages that the main sensory information for postural control shifts from being visual to somatosensory (94). Therefore, when 4 years old children touch a moving surface with the fingertip, postural control worsens, by generating a conflict with other sensory sources (95). This inability to uncouple to sensory information that is irrelevant to the task keeps younger children from adopting the driving frequency more strongly and falls still occur. All in all, 5 year old children's postural control has been found to be directly influenced by previous experiences, such as regular training of physical exercise that could lead to an improved use of sensory cues (96).

Balance studies in the young (6-12 years)

An electronic search was performed in order to identify relevant papers about the development of physical balance from 6 to 12 years old, ages that this thesis focuses on. Inclusion required that the topic discussed was the development of balance in healthy children from 6 to 12 years old. The electronic search was performed using Web of Science, searching entries from 1900 through August 2016 using the terms: postural control or balance or postural sway & children or years & normal or healthy or typical*. The electronic search resulted in 296 potentially relevant entries. The reviewer (RIH) eliminated obviously irrelevant studies based on titles and abstracts. This left 28 potentially relevant trials. Other relevant articles were also identified by cross-referencing the citation lists of articles identified in the electronic search.

The third phase of equilibrium control starts around 6 years old. When children reach this phase of balance development, large differences can be found among different subjects, sometimes due to the amount of practice. Parents exert an important role in the development of physical balance. Balance is thought to be task specific, non-related to other physical abilities thus, in order to successfully develop and maintain stability, humans need to practice through ontogeny (97). Likelihood of injury in children when being active and taking risks promotes an excessive control from some parents, sometimes imposing too many restrictions on children's outdoor risky play which impedes their normal development (98,99). Therefore, a healthy maturation of balance control entails healthy risk taking.

2.3.1. Comparative studies

The ontogenetic model of balance control proposed by Assaiante and Amblard (62,76), suggests an important milestone in the control of body balance around the age of 7. Children at that age are able to adopt the head stabilization in space strategy even when balance difficulty increases. The development of the head stabilization in space strategy thus displays a transition phase between 6 and 7 years of age. The beginning of an effective use of this strategy in 7-year-old children walking on narrow supports is preceded in 6-year-old children by a sort of regression to a tendency to adopt the alternative head stabilization on the trunk strategy. The predominance of visual inputs in balance control tends to gradually decrease switching to a higher use of the vestibular system which is used to stabilize the head in space meanwhile this presumably serving to facilitate the visual input processing. Along similar lines, Nashner and Fossberg argue that performance of children below the age of 7 years resembles that of vestibular deficit patients (62). As a direct consequence of head stabilization, there is an observed decrease in the lateral body oscillations.

From 7 years onward, balance control is thus organized from the head to the feet, in descending order. In addition, this multi-segmental control also implies an efficient coordination between posture and movement that can be organized in a feed-forward or a feed-back mode. For example, on a standing task on a stable surface, the balance control is organized from feet to head, in ascending order. Conversely, in a more challenging situation, as walking on an unstable surface, the stabilized reference frame can be the head (72). In more challenging conditions for body balance, 7 year olds cannot accurately apply newly learnt stabilization techniques since, shoulder stabilization disappears. Therefore, children at this age first learn a range of postural strategies to later be able to choose the most appropriate one depending on the ability and the efficiency of the task (72). Peripheral vision in locomotor equilibrium control tends to increase again from 8-9 years of age to adulthood when, peripheral visual cues as well as visual motion cues play a particularly important role in the control of postural steadiness. Although, it has been proposed that until they are 14 years or older, children do not demonstrate the same visual or vestibular control as adults (82).

Human movement variability has been used as an effective tool to predict equilibrium control. Linear techniques have been used to assess the quantity of the variability of the COP with conflicting interpretations based on the assumptions taken (100). Other non-linear techniques focus on the quality and structure of variability. Postural control in adults was found to be more complex and irregular in terms of structure of variability, with less predictability and more stability and showing more active COP degrees of freedom. Furthermore, values of non-linear measurements have been found to first decrease as children begin to age to later increase thus, following a non-monotonic progression (100) similar to the results found with the analysis of time series parameters of the COP (101–103).

The sway magnitude has been quantified by recording COP position and calculating the standard deviation around the mean position over a period of time (5). People may either drift slowly with large displacement or make fast small corrections with a smaller sway area. How quickly the COP moves reflects the strategy used to control the COM position. Kirshenbaum et al. noted that around 6 years of age, named category -1, the progression to a dual mode of control begins with a switch from a speed- to an accuracy-based strategy including the ability to utilize sensory feedback (101). Young children may employ a primarily high velocity, ballistic strategy, making large and fast corrections only progressing to shorter and more frequent excursions to maintain control at around 8-9 years of age (101).

A non-monotonic change in control strategy describes the development of quiet stance equilibrium, as indicated by COP velocity and outlined by variability measures. As seen in figure 8, children at the 0 category (6.5 years of age), may not relax stability limits due to difficulty resolving multimodal information to later enter into a period of exploration relaxing the tight restrictions. Subsequently follows a period of experimentation in calibration of sensory feedback which allows for further improvement of body balance.

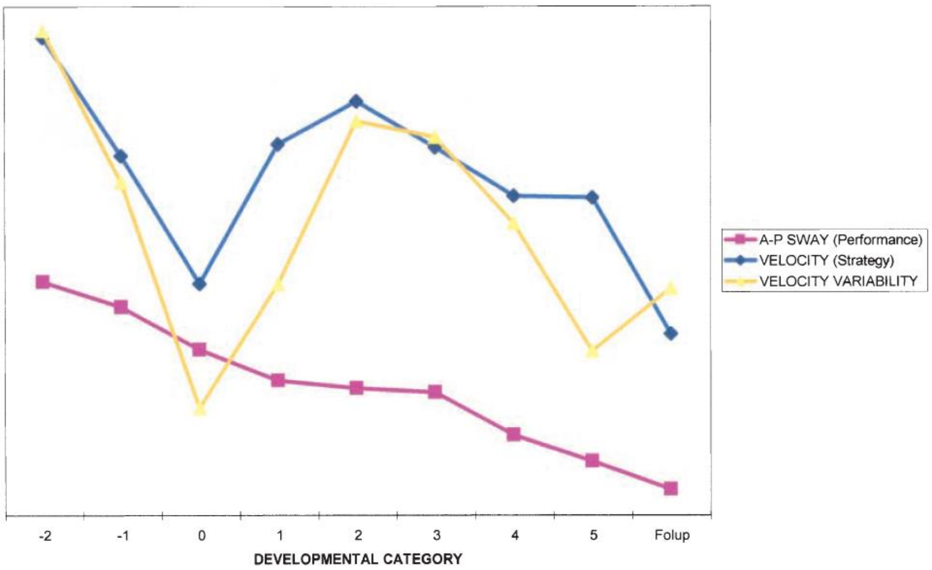

Figure 8. Comparative pattern of results for COP velocity (strategy), variability of COP velocity (transitions) and COP AP excursion (performance) **(101).**

Sex differences in balance control development have been studied among children of the same ages using distance type parameters which statistically describe the path and extension of the COP trajectory. Boys aged 9-10 years exhibit greater ML sway and total path length compared to girls when tested with eyes open (104). Boys also move faster in the AP direction and with a larger COP path length than girls at 9-10 years suggesting the use of a different strategy by boys when visual information is not present (104). The higher sway velocity corresponds to the use of fast ballistic corrections of the COP, therefore open-loop strategies of balance control with no feedback. Furthermore, boys integrate later than girls a closed loop balance control.

The work of Nolan et al. (104) also focused on identifying the characteristic frequencies of postural sway and their association with various sensory mechanisms, when comparing COP of boys and girls aged 9-16 years old. At the age of 9-10, boys revealed larger ML sway than girls at the low end of the spectrum (<0.6Hz) suggesting a developing vestibular system. Girls showed a dramatic reduction in ML sway amplitude and velocity at 12-13 years which suggests the use of an integrated closed and open-loop or adult-like strategy, not attained by boys until 15-16 years old. Increased median power frequency was found in girls aged 9-10 compared to both groups of 12-13 and 15-16, indicator of instability in adults. Curiously, the mean and median power frequency values of boys were lower than those of girls at 9-10 years of age: most of the power in boys was in the lower end of the spectrum for boys and in the higher end for their counterparts which proposes that girls at this age are still developing their sensoriomotor control of body sway until they reach 12-13 years of age. As noted, frequency analysis parameters of the COP provide valuable information when comparing groups of children with the two genders.

Human postural control is regulated by two neural control systems. Forssberg and Hirschfeld (105) found that the first level of control, activated first in a movement and maturing earlier in childhood, involves the generation of basic antagonistic direction adjustments. Therefore, an induced forward sway of the body produces activity the muscles on the dorsal side of the body, whereas perturbations inducing a backward body sway are accompanied by activity in the ventral muscles. A second level of control are all the postural corrections following input received from the somatosensory, visual, and vestibular systems (105). The first level of control can be found in an advanced state in younger children whereas the development of the second level of control is complex, variable, task-dependent and is only thought to reach an adult level of control after adolescence (68). The conclusion from this statement is that these are two organizationally dissimilar processes within lower and higher levels, correspondingly, of a hierarchically structured system.

Further explanation to the previous findings has been provided. The larger and faster sway response of young children cannot be interpreted by itself as developmental immaturity of the postural control systems since the lower height of the children requires a faster rate of sway acceleration to equal the performance of a taller adult. De Graaf-Peters et al. (68) found a random weighting in the use of support surface, vestibular and visual inputs compared to adults who show a systematic reweighting of sensory inputs. Balance limitations of the younger children result from their inability to coordinate sensory systems effectively as well as the shorter stature that requires more rapid and continuous sway corrections.

Balance performance differences due to the age or gender in children from 6 to 12 years old tend to decrease with traditional setup tests like standing still with feet apart and no disturbances nor tasks implemented. More complicated standing positions like feet together or standing on one feet have been used to find more specific characteristics of body sway. Moreover, some studies focus on the tau-G analysis of gait initiation (78), finding that it reaches adult-like performance by 8 to 9 years old. As the tests progressed in difficulty from a dual limb feet apart stance to feet together and then single limb stances, the difference in the sway scores between boys and girls aged 8-12 years was amplified, only finding significant results with a single stance (106). Although differences were found between the different ages studied (8 to 12 years), more precise results were again derived from the one foot test, resulting in a stronger distinction from earlier age groups and a similar pattern of sway in 10, 11 and 12 year olds (figure 9). Mickle et al. findings lend support to the claim that the postural control mechanisms required to maintain bilateral (passive control) vs unilateral (active control) stance positions differ considerably (106).

Gender differences in postural stability of children can be found consistently in the literature (82,102,104-112). Girls are found to exhibit less postural sway than boys when compared to subjects with similar ages. Differences between genders range among different age groups, diminishing as the subjects studied reach adulthood. Therefore, research has centered the attention in children under the age of 10 in order to find larger differences that may explain the origin of such dissimilarities (104,107,110,112). Concretely, Smith et al (112) found lower path velocity, smaller radial displacement and lower area velocity in girls from 8 to 12 year-olds when introducing challenging conditions to body sway, a backward tilted head or a foam surface. When altering sensory conditions, the previous study showed that boys had smaller changes in postural stability performance compared to unchallenged COP measures.

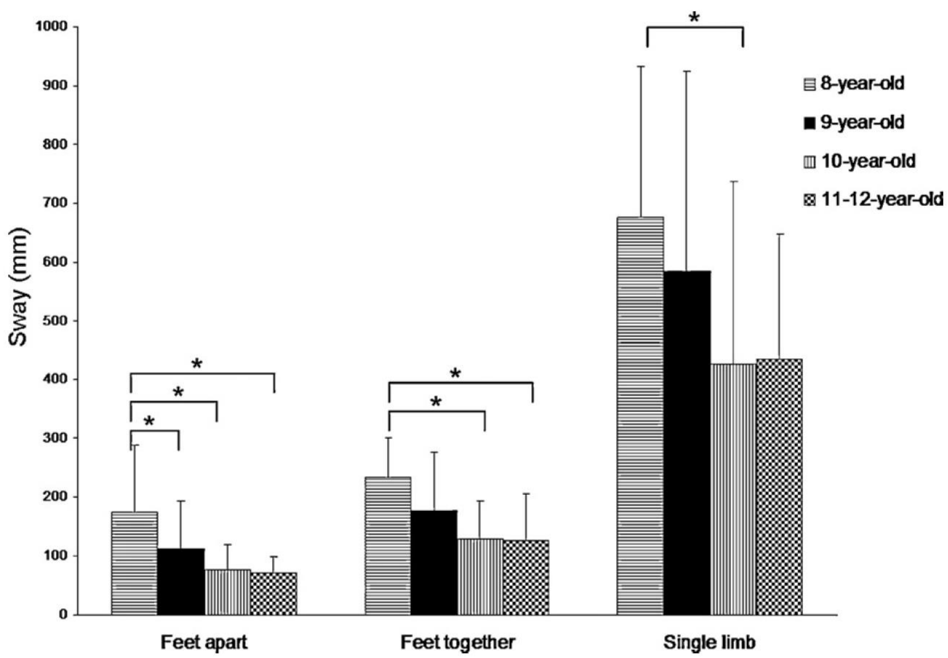

Figure 9. Mean (± standard deviation) sway scores during the three static balance tests for the 8, 9, 10 and 11-12 year old (n = 14, 25, 29 and 16 respectively).

** indicates significant difference between age groups at p≤0.05 (106).*

An array of arguments can be advanced to support between-gender differences found from single-stance tests in children aged 6 to 12 years. First, maturation of the neurological, visual, vestibular and proprioceptive systems may occur earlier in girls thus performing the task of balancing on one leg more efficiently (115). A second explanation is that the gender difference could be accounted to the larger body weight of the boys (107), although similar results were found with girls exhibiting larger body weight than boys (104) perhaps invalidating this claim. In addition, Raudsepp and Paasuke found that poorer balance displayed by boys compared to girls could not be explained by anthropometric variables (108).

Third, Thomas and French believed that any differences between genders were environmentally induced rather than biological due to the similar physical characteristics of boys and girls prior to puberty (116). Fourth, differences in children's postural sway were attributed to differences in foot structure (106), claim supported by findings of flatter feet in boys than girls (117). Fifth and latter, Peterson et al (84) suggested that girls at the age of 7-8 years have better use of vestibular information, reducing their body sway in a larger amount than boys. Several justifications have been found for gender differences between 6 to12 year olds and possibly a combination of them can be used as a suitable and complete explanation.

In order to deepen the analysis of postural control development from 6 years onward, parallel to the study of the linear parameters of the CoP, head rotation in children was studied and entropy of the COP was measured. Quinlivan et al (118) noted a decrease in head rotation amplitude with increasing age from 6 to 12 years, both using an exploratory and fixed gaze conditions. Larger head rotations were accompanied by larger movements of the COM in children when they performed gaze shifts, whereas adults were able to isolate movements of their head which did not affect their body sway. The analysis of the regularity of COP displacement (measured with the standard entropy) yielded interesting results, with less regular sway when applying an exploratory gaze condition than with a fixed gaze from 9 years onwards (118). Children have difficulty to uncouple movements of the head from body sway but the regularity of sway is similar to adults.

Many studies have been carried out regarding postural stability during pediatric age, although few have performed a complete analysis of all age groups under the most popular conditions. In a study of 289 subjects from Milan (Italy), aged 6-14 years, both sway velocity and sway area decreased as age increased for the following conditions: eyes open and eyes closed and these two conditions standing on a foam pad (119). Another research study performed in 2009, measured static balance of 251 healthy children aged from 3 to 12 years, finding an adult level of sway velocity by; age 7 under eyes open and eyes closed condition, age 8 under foam pad with eyes open and age 12 under foam pad and eyes closed condition (120). Figure 10 showcases how maturation of postural stability is a long progress that continues throughout childhood and does not reach the adult level even at the age of 14-15 years, suggesting that cortical and peripheral structures responsible for postural control are still developing during childhood (82,109,119,121–123). As authors have used more challenging conditions and included more COP parameters, more precise information on postural control development has unveiled new facts that suggest a latter adult-like or full maturation of postural control.

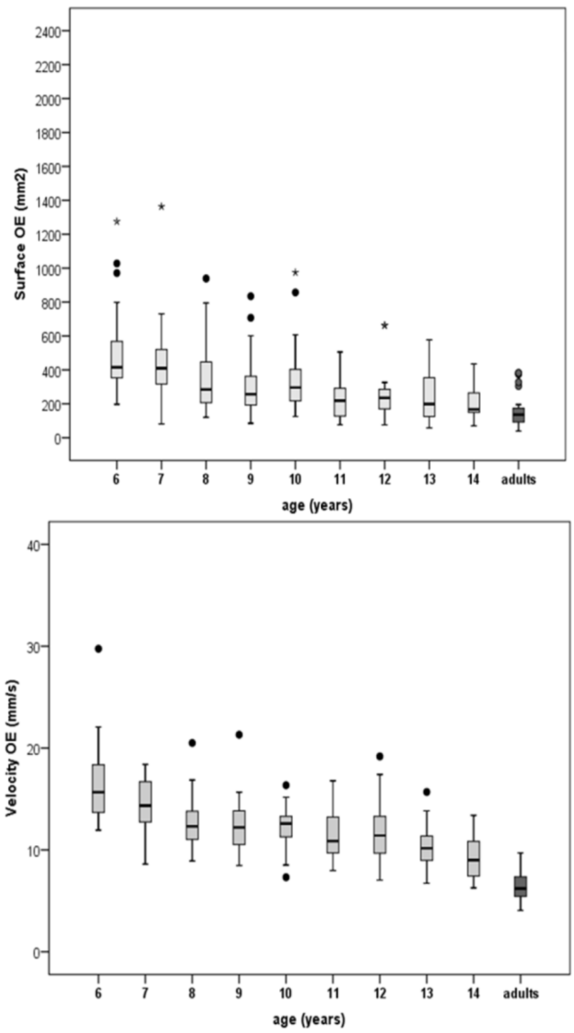

Figure 10. Velocity and surface area of the COP in 9 different age groups with eyes open condition (119).

Recent studies have suggested the translational acceleration of the COM as an alternative measure of postural sway which has been examined in children. This new measure can be obtained by dividing horizontal ground reaction force by body mass and is supposed to reflect a linear summation of joint angular accelerations, being very sensitive to age and changes in the postural control system (124). The COP time series reflects variations in the motor output of one primary joint. Contrariwise, the acceleration of the COM can reflect the postural control strategy throughout the body (i.e., the motor output of all joints and multi-joint coordination). The high sensitivity of this parameter in assessing postural control when comparing children and adults returned significantly different results for COP time series as well as frequency parameters (125).

2.3.2. Experimental studies

The overall stability of the body can be threatened by forces from all directions that need to be counteracted. Those forces can be generated or increased by applying different constraints to the subjects. Challenges to body sway come either from the application of a physical imbalance or the implementation of a challenge to one or multiple balance systems (visual, vestibular and somatosensory) as well as the CNS, being the controller of body sway. The subsequent topics will be discussed in the presentation of the existing experimental research in body sway of children from 6 to 12 years old: feedforward and feedback types of control, results from the extensively used Equitest, the somatosensory system, the visual system, dual task conditions including more specific effects of cognitive tasks on body sway.

APAs, including the named feedback and feedforward control, are only mature enough to adapt to different situations as children are 5 to 6 years old (91). Therefore this stage of human development being highly significant, with most striking changes observed in the 6 to 8 year-old children, when the anticipatory impulse was triggered earlier than in any other age group, leading to an earlier beginning of the backward shift of the COP (89). A study on trunk muscle APAs, found that children from 7 years onwards, successfully activate the muscle in the trunk, necessary to balance the human body in unilateral movements (126). Children at 8 years of age show less compensation, increasing the limits of imbalance (89) and exhibiting some adult-like strategies like the duration of the thrust phase, onset of the AP APAs (127). Anticipatory activity in the paraspinals and the hip muscles increases as children age reaching the adulthood level around 10 years of age (77). It is not until 12 years of age when the anticipatory activity on the ML axis as well as the unloading duration is equaled to those parameters in adults (127). Disturbances in posture are predicted, and the body makes appropriate adjustments through APAs to maintain stability, system that develops until 10 to 12 years old.

Purposeful machines facilitate the assessment of postural control by providing conditions that assay the organism, like the EquiTest system (NeuroCom International Inc.), widely used for research purposes (Figure 11). The extensively cited work of Hirabayashi and Iwasaki (82) was one of the first articles analyzing the developmental levels of each sensory system in regards to postural control. Visual function reached the adult level by 15 years old in spite of vestibular function which was not yet mature at that age while somatosensory function reached adult levels of the test from a very young age (82). Previous results were replicated in a later study (123), maturation of visual and vestibular function showing a relationship with age with progressive changes up to 16 years. Similar conclusions were reached and interpreted by Ferber-Viart et al (121) assuming that somatosensory inputs are primary in adults while vision predominates in children and noting that the younger the age the less effective vestibular system in postural control. Moreover, it seems that the 10- to 12-year-old children use their vestibular inputs more compared to their younger counterparts.

Equitest was also used to observe the development of the VOR system through ontogeny. The VOR reflex involves different pathways to and from the vestibular nuclei, center of the system that can successfully react to vestibular inputs coming through the vestibulospinal pathway to later produce a reaction in the visual system through the vestibulo-ocular pathway. A research study using sinusoidal rotation with Equitest found that the visual

VOR gain was comparable in three groups of ages 7 to 12 while the vestibulospinal pathway gain was lower in 9 to 12 years compared to children aged 7 and 8 (128). The higher gain results in younger children for the vestibulospinal pathway suggests both that vestibular maturation does not only imply the VOR reflex and that maturation of VOR to an adult level is connected to cerebellar inhibition.

Figure 11. Equitest system.

Several studies focused their attention on the maturation of the somatosensory system in relation to static balance (91,129–131). Greatest age-related differences occurred for the radius of the COP, however, speed of the COP only showed differences under the most difficult feet conditions (131). Performance improved from 6 to 8 years but stalled from 8 to 10, two feet postures are already mastered at that age while one foot postures are still developing (131). When standing on compliant foot support, 7 and 8 year old children had the same increase in the AP frequency of the COP than adults, while that age group presented higher median spectral frequency in normal conditions (129). The increased rate of correction of the COM in children has been explained by a larger body mass in the head and trunk, thus an increased inverted pendulum. In addition, in response to support perturbations of 0.06

Hz only children from 11 years of age succeeded in using segmental stabilization in space strategies, adopting an efficient control of shoulder and trunk (130).

In an effort to find new answers on the topic of somatosensory input, studies focused on exploring the efficiency of the balance system when conflicting information is provided to one of the three sensory systems. The effective collaboration of the three sensory systems was named sensory integration. Sparto et al found that children up to 12 years of age are unable to use somatosensation to the same extent as adults when somatosensory cues are conflicting with visual cues (132). Support oscillations were more diminished with increasing age at head and shoulder levels suggesting that sensory integration of the somatosensory cues improves slowly during childhood and adolescence (130). Efficient sensory integration was assessed by measuring APA adaptability with eyes closed and conflicting somatosensory information which was found to start to develop from age 6 in boys and 5 in girls, improving greatly in the consecutive year and not reaching yet adult levels by 11-12 years, age when it gets disturbed for girls, suggestedly due to the earlier puberty period (91). Confusing information forces the human balance system to wisely select which system needs to be followed to maintain a static posture.

The role of vision in postural control has been studied and yielded some interesting results. In 1985, Stoffegen (9) found that both peripheral and central vision contribute to the regulation of stance in different ways. The first is more efficient for controlling AP oscillations while the second contributes similarly in either planes. Indeed, peripheral vision is very sensitive to lamellar optical flow and much less influenced by radial flow compared to central vision, rendering it more specific to picking up information from the optical flow that is used to control posture. Children over 6 years of age are able to use the structure of the optical flow for controlling their posture, contribution that was similar between ages 6 and 10, although different in 8 years old, when central vision was more efficient (15). Prior results can be explained by a transition phase in a non-monotonic developmental pattern, required to initiate the specialization of peripheral vision. When vision is challenged by dynamic visual cues, the ability to use those for postural control is frequency-dependent and when somatosensory input is fully available but conflicting with the visual cues (Figure 12), 7-12 year old children are unable to utilize somatosensation to limit sway to the same extent as adults (132).

Figure 12. Optic flow environment designed to simulate movements of the "moving room" devices employed in balance research (9,132).

In addition, the visual system of children has been claimed to be less important to postural control than that of adults. The Romberg quotient of children, ratios of postural sway without vision on postural sway with vision, are lower than those of adults (5) and the visual system of children is efficient in dim light conditions, contrasting with adults (133). Saccades have been used as a dual task, rendering a decrease of their latency and increase in the quality of fixation from 6 to 17 years old with a turning point around 12 years old, indicating maturation of the cortical area around that age (134).

Several studies explored the effect of a dual task on postural control. Previous research findings into the effects of a secondary task in the COP have been contradictory and inconsistent. In regards to vision and, most related to our study, postural stability improved with age when performing simple (fixation) as well as dual tasks (saccades), in addition, the same study found that performance of dual tasks improved postural stability with respect to simple tasks (134). Olivier et al. (135) applied Stroop conditions (congruent and non-congruent) in 7 to 25 years old finding again a decrease in postural sway during childhood and a maturation level of attention reached at around 11 years of age. A recent study from Gouleme et al (136) observed how the surface area of the COP and therefore saccades increased significantly when children were confronted with sad and happy faces. When attention was fixated on a cross or on the postural sway itself, an increase of the speed of the COP was generated from 4 to 11 years old, suggesting that at this early age children can already consciously control their posture (59). Attentional demands will either improve or worsen the stability of the COP depending on the conditions imposed in the experiment.

Further studies on postural control changes produced by dual task conditions yielded interesting results. When the secondary task applied were two lines in a screen that would change their orientation, the sway velocity of children younger and older than 10 years old did not change and seemed to be attenuated as they tried to count how many times the lines were parallel (137). Boonyong et al (138) used an auditory Stroop as a secondary task which induced a reduction in AP velocity while children from 5 to 15 years old were walking. Interestingly, this is contrary to a study conducted by Trapp (139) in which AP sway increased in children when performing a numeric classification from listening to certain numbers and also when identifying figures on a screen. A performance aiming task completed by children aged 11 and 12 years old, showed that in the side target condition, AP sway was reduced when a smaller sized target was employed (140). As a corollary, a number of studies show that significant differences do exist in postural control of children when performing a dual task, albeit findings are somewhat contradictory.

Counting backwards has been widely used as a cognitive test. When static balance control is added to the testing protocol, there is an interference in the performance of the second task in children. In 2005, Blanchard et al. (141) reported an improvement in postural stability when 8 to 10 year old children are counting backward compared to when they are looking at an image or reading a text. Conversely, another study from 2007, performed with 9 year-olds found that the COP tended to travel faster and further, with both mean velocity and sway area increased while the students were counting backwards (142). Last in 2010, Palluel et al. (143) found that 14 to 15 year-olds body sway was limited when peforming a high demanding counting backwards task while adults did not show significant differences, suggesting that children at these ages are still developing this skill and more sensitive. In addition to the previous results, better cognitive performances in the Stroop compared to the counting backwards task demonstrates that the difficulty of the task, relative to the ability of the subject, may determine the type of influence in postural control.

Human movement variability has been studied by linear and nonlinear tools. Concretely, contextual tasks that require a certain amount of visual attention generate equilibrium adjustments according to their specificity. First, linear measurements of variability such as standard deviation of the COP in both AP and ML directions (144) and mean velocity (145) are increased by demanding task conditions. Second, nonlinear measures of variability such as En (Entropy), Sen (Sample Entropy), CI (Complexity Index), LyE (Lyapunov Exponent) and ApEn (Approximate Entropy) among others are used to determine the structure and variability of postural control (100). The more regularity in postural behavior has been explained as a less automatized balance and therefore more attention demanding (145,146). According to this postulate, Derlich et al (144) found greater values of entropy for dual task than simple task cognitive condition. An attention demanding task results in this case in an increased postural automaticity and more irregularity with less attention in the postural control. On the contrary, a dual-task cognitive performance entailing altered sensory conditions can decrease entropy having the opposite effect (146). In this latter case, the condition is so challenging that the system would prioritize the postural control over performance in the cognitive task.

The introduction of a secondary task in the analysis of body sway has yielded an array of results which have been explained by different hypothesis. First, Assaiante (76) in 1998 argued that the body stiffening caused by the incomplete development of the selective control of the degrees of freedom causes a reduction of the postural sway while augmenting the mean velocity.

A second explanation came in 2000-2001 from Wulf (147) and Hunter and Hoffman (57) claiming the release of control from the attentional focus on body sway in order to attend the concurrent task allows the system to work in a more automatic manner. Named as the U-shaped non-linear interaction model, it also suggests that an increase in the difficulty of the cognitive task can result in an inferior postural sway. Lacour et al (148) added two more models in 2008: the crossdomain competition model and the task prioritization model. The former referring to a limited attentional and processing capacity that would generate a competition for the attentional resources between the cognitive and postural tasks, therefore degrading postural sway. The latter supports the vision that subjects would prioritize postural control over the cognitive activity under certain conditions.

The complexity of the human postural control system allows for an array of possibilities. There is a consensus among several scientists that improvements in postural control with development may be due in part to an improved ability in sensory reweighting (62,130,149). A matured sensory reweighting ability uses information from the different sensory sources simultaneously, thus a change in one sensory system affecting the response of the three sources.

The studies presented thus far provide evidence that the control of posture in humans is performed with the conjunction of different systems rendering it complicated. Both practice and development are contributing factors that generate neural modifications in order to better sustain a successful body balance under different circumstances. Plasticity of the brain facilitates changes through the development of postural control, a long-term process that is not complete at school ages studied previously but, that lasts until adolescence.

2.3.3. Balance pathology studies in children

Postural control is a complex motor behavior involving the participation of different systems and neurological paths. Children with motor disabilities and different diagnoses show a variety of problems that may have an effect on general or specific parts of the balance control system. The next paragraphs discuss a range of conditions and diseases that impair the normal functioning of the vestibular, somatosensory, visual or neurological pathways in the early ages of human postural control.

Brain injuries are disorders that acutely modify the way body sway is controlled. Children with brain lesions tend to suffer visual disorders with often impaired visual acuity, visual fields and optokinetic nystagmus and therefore worsened postural control (150,151). The most common disorder in childhood that affects postural balance is cerebral palsy. Children with cerebral palsy who were pre-walkers had immature muscle activation patterns compared to those seen in an earlier developing stage in typically developing children (152). Characteristics of postural control of children with cerebral palsy involve higher sway path length and a larger use of hip and transverse rotation strategy (68,151,153,154). Physical irregularities pose a challenged to the normal functioning of postural control.

Effects of physical anomalies in the vertebral column on postural control such as scoliosis and serious cases of spina bifida like myelomeningocele, have been studied. Differences in postural control of adolescents with scoliosis have been determined. Concretely, this characteristic affects girls more and it is believed to develop during pubertal growth, particularly when the amplitude is higher, reflecting less effective central information processing (155,156). Children with myelomeningocele, an hernial protrusion of the spinal cord and its meninges, show lower sway frequency and larger movement times than typical developing children but APA were similar (157,158). Next, exposure to toxins will be discussed.

Prenatal exposure to toxic substances may have an effect on the development and control of body balance. A recent meta-analysis in children with heavy prenatal alcohol exposure showed general gross motor deficits (159). They exhibit deficits in postural control such as overreliance on somatosensory information in challenging conditions (160) and differences in sensory weighting behaviors, specifically those that rely on the integration of vestibular sensation (161). Early lead exposure and, subsequently, moderate to high lead concentration in blood has been correlated with increased variable sway and poor balance and a reduced capacity after maturation (50,162,163). However, lower quantities of lead or cadmium exposure were not associated with static nor dynamic balance differences in children aged 7-10 years old (164). Next, deficiencies at the vestibular level will be addressed.

Vision is thought to be the main contributor to postural control during ontogeny. Children with visual impairments must rely more heavily in the other systems in order to maintain equilibrium. Even though, body sway is affected in the visually impaired children. Young visually impaired children from 4 to 6 years old were found to have a greater total power and relatively more high frequency power and visually impaired children resulted in greater instability than sighted children, with greatest differences between at 10 to 12 years (165). As research shows, weaknesses in the supportive systems of postural control will affect body sway such as limiting factors of the vestibular system.

Since the vestibular system plays an important role in balance control, children with hearing impairments show differences in postural control when compared to normal groups. A review from 2012 (166), found that children with hearing impairment exhibit suboptimal levels of function in postural control, motor skill performance, and health-related quality of life. Previous results have been found systematically when studying hearing impaired children (167,168). However, when inputs from the visual system are suppressed, deaf children can better use their sensory systems, thus maintaining a more stable postural control compared to their peers under this condition (169). The human body sharpens the existing tools to remain stable when others are not available.

Balance problems are typical in children with developmental disorders, such as attention-deficit/hyperactivity disorder (ADHD), developmental coordination disorder (DCD), autistic syndrome and dyslexia. Often referred as clumsy, children suffering of DCD tend to sway more than age-matched typically developing children, and have a reduced ability to maintain unusual standing postures (170), especially when a cognitive task is added (171). Geuze considers that static balance control is not a problem for children with DCD and, only more difficult, unattended, or novel situations reveal an increased postural sway in the ML axis (172). Compared to DCD, ADHD is a more challenging disorder on academic learning of students and it also affects static postural control.

ADHD is becoming a more and more common disorder in childhood. Sensory inputs, the sensory integration, and/or the inhibition of excessive movement are impaired in ADHD children, which result in balance dysfunction (173,174). A recent systematic review (175), found that medication only improved postural sway in some children and that the inattentive subtype of ADHD seems to present more impairment during complex tasks. Next, we will focus our attention in dyslexic children.

Dyslexic children show poorer performance and more variability even in a postural task that does not require an active cognitive involvement (176,177). However, motor impairments appear to be co-morbid symptoms associated with developmental dyslexia but without direct causal link to the reading deficit (178). Therefore, postural control deficits may be caused by a lack of attention in dyslexic children which is also the case in autistic children.

Autistic spectrum disorders are a range or neurodevelopmental conditions that include autism, Asperger syndrome and pervasive developmental disorder. Studies including the three disorders found that both static and dynamic postural control is impaired or immature, even under the most basic conditions when no afferent or sensory information have been removed or modified (179,180). An underdevelopment of the postural control system with less stable and more variable ML sway, was found in children with the most studied of the three, autism (181,182). A significant finding is the fact that autistic children do not attune postural sway to the speed of visual oscillations while controls and children with Asperger syndrome do (183).

More severe are responses in children with Down syndrome, who showed no adaptive attenuation of body sway to changing task conditions as well as poorer static equilibrium control (184,185). Likewise, children with obesity show an altered balance control.

Nowadays, excessive body fat is one of the major diseases. Not only obese children (BMI over 30) but also overweight (BMI of 25-30) show less stability (145) and functional limitations that cannot be overcome with greater strength and training (184-186). Obesity sometimes leads to emotional disorders. Even when not related to an excess of body weight, emotional disorders such as depression and anxiety generate a poorer gross motor performance, thus affecting negatively body sway, due to a diminished self-perceived motor competence (189). All the previous balance disorders need to be taken into account when designing a research study and more importantly when choosing the participants.

Since a large range of human disabilities, illnesses and diseases affect postural control, the parameters used in the study of body sway can be helpful in determining whether a subject may suffer one of the prior due to irregularities compared to standardized data. Furthermore, several studies have proved that both linear and non-linear measures of body sway yield differences when subjects suffering one of the conditions mentioned above are compared to healthy counterparts (100). In addition to the aforementioned results and conclusions from several articles, it must be noted that many studies involve limitations in their methodology that need to be assumed.

2.4. Hypotheses, aims and objectives

The hypothesis of my study are:

- Characteristics of healthy developmental changes in postural control from 6 to 12 year old children involve the improvement of the visual, somatosensory and vestibular contributions.
- Children who participate in more intense or longer physical activities have a better postural sway.
- Postural sway of children from 6 to 12 years old is reduced when subjects perform a suprapostural visual search task compared to only an inspection task. Balance movements are reduced to facilitate the visual search, as a consequence of the constraints placed on the visual system.
- Postural sway of children is more stable with feet apart compared to feet together.
- Postural sway is more stable with eyes open than eyes closed conditions for all the children.

We aimed to analyze the developmental characteristics of static postural control in children from 6 to 12 years old in different situations. In order to achieve this aim, the following objectives were set:

- Compare modulations in body sway of children due to changes in a suprapostural visual task with bipedal stance.
- Compare changes in body sway of children due to changes in bipedal stance with feet together and feet apart and the suppression of visual information.
- Analyze the relationship between postural control and the amount of physical activity performed by children.
- Compare changes in body sway of children according to the developmental maturation of the balance system from 6 to 12 years old.

3. Material and methods

The following points discuss the different processes used to measure postural control differences in children. The research design chosen as well as the characteristics of the sample of students will be exposed. As a guideline, the main procedures in our research study are chronologically written. A careful explanation of the balance measuring system is provided since, the center of the thesis lays in the study of balance control. Specific to our study, the balance tests chosen are exposed and thoroughly detailed. The use of a widely-used questionnaire on physical activity and its characteristics are presented.

Further analysis of the postural control data is exposed. First, the steps taken to concentrate and refine the raw data from the balance board are presented. Second, the global and structural parameters of the COP chosen to represent different characteristics of body sway will be introduced. Third and last, the statistical analysis and its different parts will be summarized. Altogether, this part of the thesis aims to provide sufficient information as to be replicated by a different researcher.

3.1. Design

The research design was observational and cross-sectional. Elementary students were recruited from a school to perform a series of static standing balance tests. Balance performance was obtained with the use of a platform where students stood up. Standing stance as well as a visual and a search task were included in order to analyze their effect on equilibrium in each of the different ages. Prior to be included in the study, students completed a physical activity questionnaire with help from their parents who, also provided consent to their children's participation. A statistical analysis was performed on the results.

3.2. Sample

We recruited the group of participants from Lakes International Language Academy, a school located in Forest Lake (Minnesota). It is an immersion school in either Spanish or Chinese. Language immersion uses the target language as a teaching tool, surrounding or immersing students in the second language. In-class activities, such as science, math, social studies, technology, and history, are conducted in the target language for 100% of the time from Kinder to 1st grade and then moving to a 90% target language and 10% mother tongue from 2nd to 6th grade.

According to the census from 2010, Forest Lake is composed of a 94.7% of white Caucasian people and so was the school where the study took place. Median household income in Forest Lake was calculated at $71,995 in Forest Lake for 2015 (190) and most families attending the school were highly educated pertaining to a middle class status. There was a total of 740 students in the school. The grades that we focused on to study postural control ranged from 1^{st} to 6^{th} grade comporting the following number of students in each grade from lowest to oldest: 116, 115, 123, 152, 87, 80, 67.

In order to determine which subjects were eligible for inclusion, the following criteria were used: to be apparently healthy, aged between 6 to 12 years old and having had a normal motor development during infancy. Participants were excluded if they presented any of these characteristics: traumatic lesion of any muscle in the lower body, prior adverse physical or mental conditions, ulcers in the bottom of foot and children taking any medication that could influence their nervous or metabolic system. Four children previously diagnosed with ADHD that were taking medication at the time of the study were included in our sample as well as one child recently diagnosed with Coxa Valga, another one with a long term treated Lyme disease and a last one with Cystic Fibrosis. A specialist was consulted about the last subjects and he stated that their medication did not have an interaction with their balance capacities. Therefore, their inclusion in the study was accepted.

A small sample could lead us to misinterpretation, since we might not detect an effect that may be there. The sample size was calculated according to previous studies in the field from (191). Using an alpha level of .05 and a statistical power of 0.9, we needed 26 participants in each group to obtain an effect size of 0.93 between ST and DT in mean velocity in anteroposterior direction in adolescents. Following these indications, a sample of around 30 participants per age group (i.e., 6, 7, 8, 9, 10 and 11 years old) was considered large enough. Furthermore, we ended up having age groups that ranged from 22 to 39 students, 97 boys and 111 girls (Table 1).

The recruitment of the subjects is critical to the investigation as we focus on analyzing developmental changes in the modulation of posture. A convenient and consecutive sample was used. The advantages of convenience sampling include easy accessibility of subjects, faster accrual and less expense (192). Consecutive sampling was used, such that every available subject in the school institution was invited to participate in the study.

Table 1. Number of boys and girls in the sample.

Group	Boys	Girls	Subjects
1	19	19	38
2	16	21	37
3	18	21	39
4	18	21	39
5	16	17	33
6	10	12	22
Totals	97	111	208

An aliquot sample of 208 Caucasian children was selected. We conformed 6 groups from 6 to 12 years old with a similar number of boys and girls per age group (Table 1). Being able to compare postural control in children, with the same environmental characteristics, helps to better portray the different developmental stages. Table 2 shows the characteristics of each of the groups.

Table 2. Characteristics of the sample and physical activity

Group	Age	Height	Weight	Physical Activity Level
1	6.96 (0.59)	122.18 (0.92)	23.89 (0.52)	3.06 (0.08)
2	7.95 (0.49)	127.89 (1.10)	27.46 (0.90)	2.85 (0.08)
3	8.93 (0.54)	132.82 (0.89)	29.37 (0.83)	2.86 (0.07)
4	9.83 (0.54)	138.68 (1.06)	33.08 (0.80)	2.95 (0.08)
5	10.88 (0.58)	145.24 (1.29)	37.36 (1.21)	3.03 (0.12)
6	11.90 (0.82)	152.14 (1.76)	43.82 (2.55)	2.78 (0.12)

Data are expressed as the mean (SD).

3.3. General procedures

The following general procedures were carried out in order:

1. As a first step, we wrote a proposal attending to the principles and requisites imposed by the Declaration of Helsinki of 1975. All the protocols were approved by the institutional board of the University of Valencia (Annex 1). These protocols were also checked and updated by a local research University (University of Minnesota).
2. Second, volunteers were recruited for the study. All the students at Lakes International Language Academy were potential subjects. All of them were invited to participate. An Informed Consent about the study was sent to their homes so their parents would read and sign it (Annex 2). The informed consent was in compliance with the Family Educational Rights and Privacy Act and the Protection of Pupil Rights Amendment. Additionally, the document that was sent home included an invitation to participate in the PAQ-C online (Annex 3), regardless of participation in the balance study.

3. Students brought their informed consent back to their teacher who collected and returned them to the researcher.
4. Once a student had both turned in the informed consent and answered the PAQ-C online at home, they were scheduled to be measured at a convenient time during school hours.
5. At school, the room was set up for measuring students with the computer program and testing equipment for experimental procedures were prepared.
6. The anthropometric assessment consisted of measuring weight and height with a weight scale and a tape measure prior to the balance assessment.
7. Students' performance in postural control was assessed for the different trials on the same day.
8. Offline, we filtered data from the computer and performed the statistical analysis.

3.4. Balance measuring system

To assess postural stability, a new Nintendo WII Plus Balance Board was used (WBB, Nintendo, Kyoto, Japan). The WBB consists of a rigid platform with four uni-axial vertical force transducers located in the feet at the corners of the board, two transducers per foot. Each transducer is a load cell consisting of a cantilevered metal bar with a strain gauge that converts applied force into a voltage that is digitized and transmitted wirelessly by electronics in the WBB (80). The sampling rate was 30 Hz. Components, as noted in the operations manual of the WBB, are specified in figure 13 (193).

The validity and reliability of the Nintendo WBB have been studied and the WBB has been claimed a valid tool for assessing standing balance. The WBB exhibited good to excellent COP path length test-retest reliability within-device (ICC = 0.66-0.94) and between-device (ICC = 0.77-0.89) on all testing protocols (194). A study from 2015 tried six different postures showing good to excellent test-retest reliability (ICC=0.65-0.95) for the parameters of mean COP path velocity and mean COP sway distance (195). Another study found that, across WBBs, the total variability of force measurements and COP location was rather high. However, repeatability of a single measurement within a board was better, suggesting that the WBB is best used for relative measures using the same device (196). A fourth study compared the WBB to a laboratory grade force platform finding that the WBB is sufficiently accurate in quantifying COP trajectory, and overall amplitude and velocity during single-leg stance balance tasks (82). Other researchers have also used the WBB to measure COP travel path successfully (197).

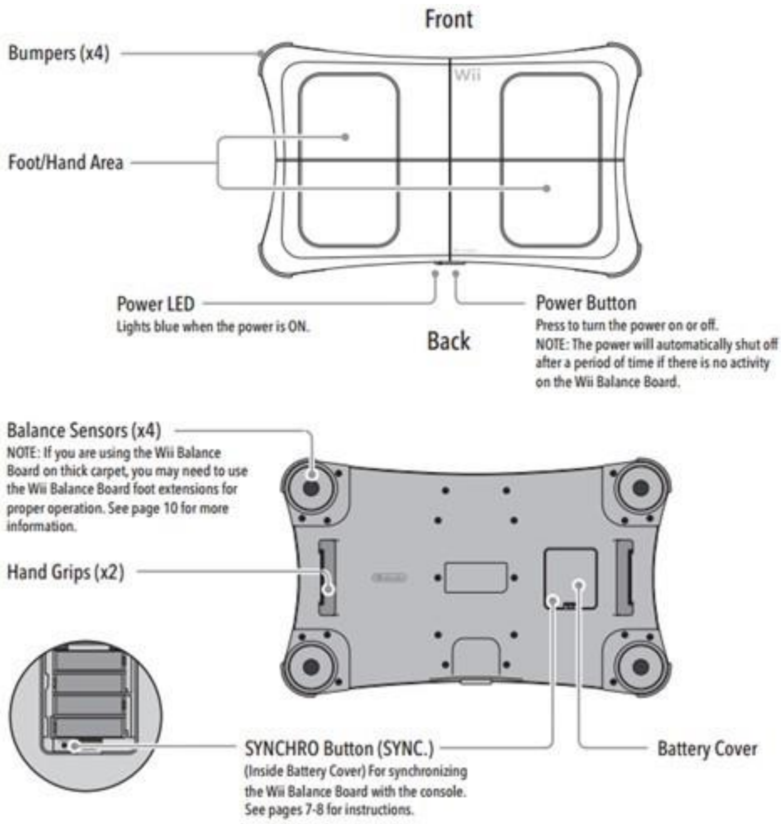

Figure 13. Components of the Wii Balance Board (193).

The WBB was interfaced with a laptop computer using the program bbrecord. Bbrecord is an open source Matlab program developed by the Neuromechanics Laboratory of the University of Colorado Boulder (198) for displaying COP in real time and for recording COP data sets (Figure 14). It collects data from the Wii Balance Board through a Bluetooth connection. The systems required are Windows XP & Matlab R2007a. Data was saved to text (.txt) files in the data folder. Each trial was saved to a separate file, with a name corresponding to its order in the series of trials.

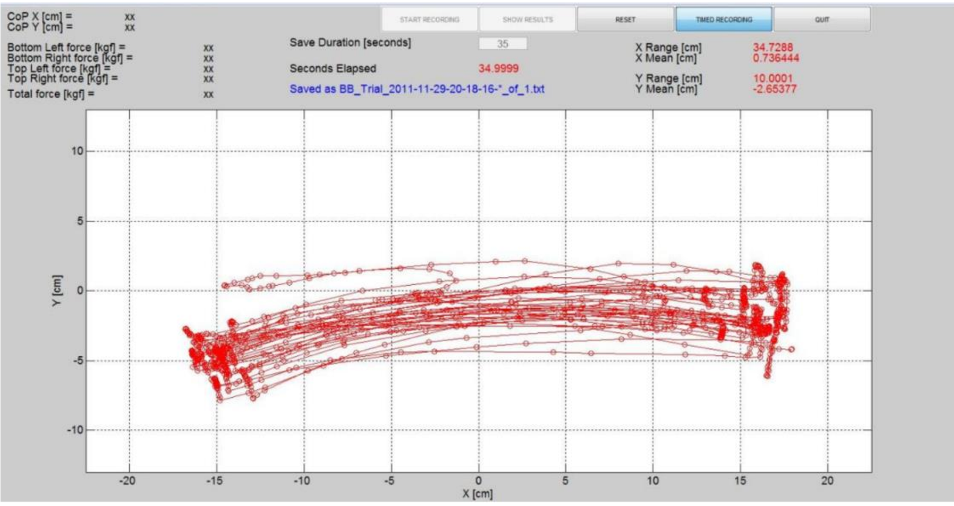

Figure 14. The image of the motion of CoP after recording a moving load on the WBB using "bbrecord".

The set up consisted of the WBB connected to a laptop where the researcher was seating. The board was placed on a stable surface on the floor to avoid distortion and noise in the signals obtained. We followed previous procedures used by the Kinesiology's Affordance Perception-Action Laboratory of the Universtity of Minnesota (197). The WBB was placed at 0.40 meters from the wall that the subject was facing and 0.60 meters from each side wall. A Velcro tape was placed on the wall so the paper where subjects fixated their vision could be adapted to eye level for each subject. The room where the tests were performed was used alternatively for school lessons so we placed a divider so students would not use the research area (Figure 15).

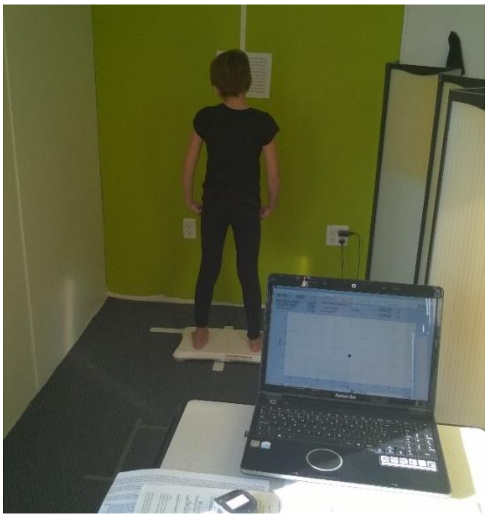

Figure 15. Balance measurements set up at the school.

3.5. Standard tests for measuring balance

Participants were asked to stand barefoot as still and relaxed as possible, with their feet centered on the platform using the marks of the WBB as a guide. The feet were parallel to each other and to the sagittal plane. The WBB was cleaned after each trial. All subjects were told the importance of remaining still in the starting position. To avoid possible effects of learning, subjects did only two attempts at each condition.

The following protocol was followed in order to collect COP measures from each participant under the different conditions:

1. The WBB was connected to the computer through the Bluetooth connection prior to measuring each day.
2. Students were found in their respective classes and brought to the facility where the mini-lab had been set up.
3. Students were asked whether they agreed to participate in the balance study.
4. A general explanation of the different trials and a performance of each of them was completed by the researcher to provide a visual reference

and better understanding. The same text was read each time by the researcher to avoid differences between participants (Annex 4).

5. The WBB was calibrated with the use of 60lb as instructed by the program.
6. The child's age, name, sexual category, height and weight were recorded prior to the balance tests.
7. Participants were asked to remove their shoes and socks.
8. The student was instructed to stand on the balance board and the trials were randomly performed twice each.
9. A picture was taken without flash from the back of each subject.
10. The student rested for 30s between trials. Each trial took 30 seconds and the total time the child was in the room ranged between 11 and 15 minutes.

Participants were instructed to leave their arms by their sides, and look straight ahead to the near blank target. The height of the target was scaled to each participant so that the center of the target is at the subject's eye height. Duration of each trial was 30s, from which we would keep the last 20s since, test-retest reliability of 20s has been proven to be excellent for measuring the COP (199). Participants began each trial fixating the appropriate target. Participants were told that they were allowed to look anywhere within the appropriate target without rotating the head. Instructions mentioned to the subjects were standard since differences in instructions could lead to differences in COP (200).

The following standard testing trials were carried out in a randomized order:

- Eyes Open Feet Separated: named Blank Separated (BS).
- Eyes Open Feet Together: named Blank Together (BT).
- Eyes Closed Feet Separated: named Eyes Closed (EC).
- Letter Search Feet Separated: named Letter Separated (LS).
- Letter Search Feet Together: named Letter Together (LT).

When they had their feet separated, they were approximately shoulder width apart, the researcher told each child to either move them closer of farther based on how they were placed. Children were also prompted to place both feet parallel since differences in angle foot placement could cause the participant to use a different balance strategy and therefore impact their COP measures (201). When instructed to place their feet together, the feet touched at the line marked in the middle of the platform. Every time they had their eyes open, students were instructed to keep their vision on the blank paper on the wall, placed at their eye height. The trial with eyes closed was only performed with their feet apart since our goal was to evaluate the effect of vision without an imbalance from their feet positioning. Due to the difficulties some subjects might have experienced in keeping their eyes closed during the EC tests, we used an opaque mask for all subjects. The BS task was considered as the control condition of postural performance.

Foot placement in the study was carefully chosen. Studies using double limb support protocols report better balance values than single limb protocol (202,203). First, shoulder width is a common placement of the feet in COP movement research. Standing on a force plate with feet width is an appropriate method to test balance because subjects feel comfortable and it represents a relatively precise measure of balance ability (204). Second, feet together entails a narrower stance, thus narrower base of support, which engages more muscle activity and higher regulations to maintain static balance. The change from a more passive (shoulder width) to a more active horizontal force limitation produces larger COP displacements in the narrower stance, feet together in our case (205). Therefore the more challenging latter stance provides relevant additional information to our study. Actually, the width and length of the WBB was a limitation in the choice of stance.

3.6. Measuring balance during a cognitive task

The following two trials aimed to analyze changes in body sway due to changes in suprapostural visual tasks with bipedal stance. Similar procedures were used to the research study performed by the Kinesiology's Affordance Perception-Action Laboratory of the University of Minnesota in their study on the modulation of postural control to facilitate visual performance (1). We emulated parts of the study cited in an intent to investigate whether the previous results are applicable to children. Participants were prompted to perform a letter search task on a letter stream target (Annex 5).

The children counted the frequency of a given letter during each trial. They had to find the letters on an alphabet stream generated randomly. The same alphabet stream was used for each participant. On different trials for each participant different target letters were used. Four vowels were the letters used (a,e,i,o) in order to facilitate their recognition to younger students. At the end of each trial, participants reported which one was the last letter they found and the total number of targets that they had detected. This provided the researcher with information to quantify the quality and accurateness of the search. The number of times each target letter was present in the letter stream ranged from 24 to 26.

Subjects were first instructed how to do the letter search task with an example from the researcher. In case a student was very fast they had been instructed to start over and keep counting so we could measure their balance for the full 30 seconds. Participants were told to avoid moving their head when counting letters. No feedback on performance was given, all children were praised for their good job on the task. After modelling by the researcher, instructions were as follows:

1. Count how many “a, e, i or o” you can find on this text.
2. When you reach the end of the text, start over and continue adding until the time is over. Let’s see how many you can find!

3. At the end of the test, say the number of letters found and point to the last letter that you were counting so we can check how many you got right.

In total, two levels of postural difficulty (feet apart and feet together), two levels of cognitive difficulty (inspection and letter search) and two visual conditions (eyes open and closed) were tested in this study.

3.7. Questionnaire on physical activity

The Physical Activity Questionnaire for Children (PAQ-C) was administered to analyze physical activity levels (206). Results of students' physical activity were checked to see their possible effect on the children's postural control. The questionnaire is capable of assessing the frequency of activity that occurs at school or outside of school, and reflects activities and settings that may be carried out by Minnesotan children. The form segregates weekday from weekend participation but, it does not, however, explore the time spent on sedentary activities. It is self-administered for a 7-day recall. Activities are presented on a 5 point Likert scale which allows to create a composite score, used as the measure of physical activity. A total of 22 common leisure and sport physical activities and two "other" fill-in choices come in the first question for a total of 9 questions (Annex 3). Once you have a value from 1 to 5 for each of the 9 items used in the physical activity composite score, you simply take the mean of these 9 items, which results in the final PAQ-C activity summary score.

The PAQ-C has demonstrated high test-retest reliability (ICC = 0.75 and 0.82 for boys and girls, respectively) and moderate validity (range: r = 0.45-0.53) in children 8 to 18 years of age (207) as well as a good internal consistency (208). Furthermore, a systematic review of physical activity questionnaires used with children, declared the PAQ-C a promising reliable questionnaire to be used with children and adolescents (209). Per contra, the reliability and validity of the PAQ-C with children under the age of eight has not been established. As remedy to this problem, parents will be told to act as proxies for younger children in completing the questionnaire. School teachers assisted with the collection process.

The questionnaire was filled on a google form online. A shortened link to the google form (http://goo.gl/SrerUx) came with the introduction of the informed consent. A written version was provided if online access was unavailable to the families. Answers to the questionnaire were automatically collected in a google excel page.

3.8. Data analysis

For signal conditioning and calculation of variables derived from each measurement, specially developed software under Matlab 7.0 was used (MathWorks Release 14). The COP signals were pre-processed to attenuate noise using a low pass Butterworth IIR filter (cut off frequency 12 Hz). The first 10 seconds of each trial were excluded from the analysis as delayed stabilization had previously been reported (210).

A varied choice of posturographic parameters was chosen. COP excursions were investigated first in the time domain for BS, BT, EC, LS and LT conditions. The statistical parameters selected to summarize the balance assessment for the different signals is listed below. Previous studies have reported best correlations for balance and age with the use of COP velocity in the AP direction which was therefore included in this study (211). Time domain signals in both the AP and ML direction were summarized in the following statistics (185,212):

- MVAP: the average distance travelled by the COP per second in the anterio posterior direction.
- MVML: the average distance travelled by the COP per second in the medio lateral direction (Figure 16).
- EA: The area of the ellipse is a measure of the amount of movement of the COP that best fits the COP data (i.e. smallest ellipse that covered 95% of the points).

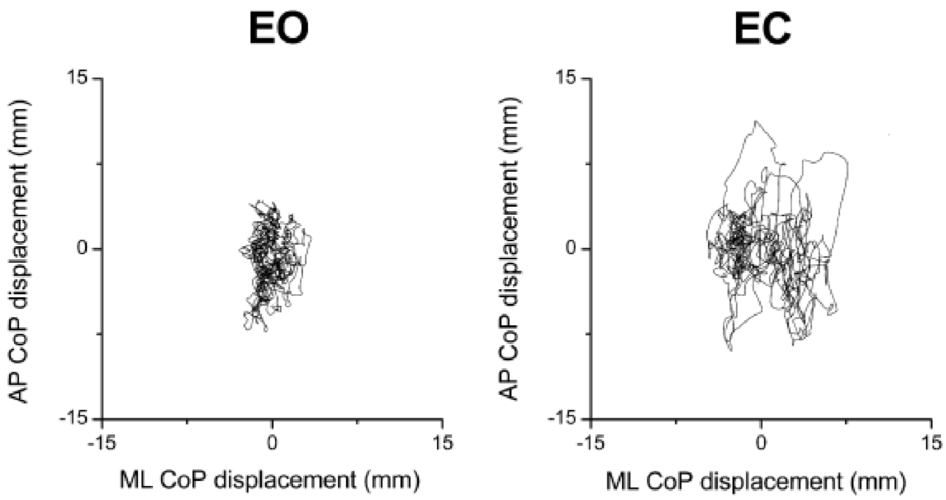

Figure 16. Example of the signals recorded. Records of the COP displacement of a subject.

The panels on the left represent an attempt with eyes open (EO), and those on the right represent an attempt with eyes closed (EC).

The dynamic characteristics of the stabilogram are of fundamental importance, even in the case of quiet standing. This work therefore aimed as well on the analysis of the non-stationary time properties of the COP path. For that purpose we evaluated the temporal dynamics of movement in terms of α, the scaling exponent of value of detrended fluctuation analysis (DFA). DFA describes the relationship between the magnitude of fluctuations in postural motion and the time scale over which those fluctuations are measured (213). The scaling exponent of DFA, α, is an index of long-range autocorrelation in the data, that is, the extent to which the data are self-similar (e.g., more periodic, or more predictable) over time. DFA has been widely used to evaluate the temporal dynamics of human movement in terms of standing body sway (214–216).

The DFA method involves a series of steps (217). The procedure begins with an N-point time series $\{Z_{t,} t = 1, \dots, N\}$. First, we calculate the accumulated series $Z(t) = \sum_{u=1}^{t}(Z_u - \langle Z \rangle)$, where $\langle Z \rangle = \frac{1}{N}\sum_{t=1}^{N} Z_t$ is the global mean.

Second, a certain number N_b of boxes of equal length τ are extracted from the series *Z*. These boxes contain N_τ points and can overlap or not. In each box, the so-called local trend is obtained by fitting the values $Z(t)$ into a polynomial (Figure 17). This local trend is labelled Z^k_{fit}, where the index k indicates the box number.

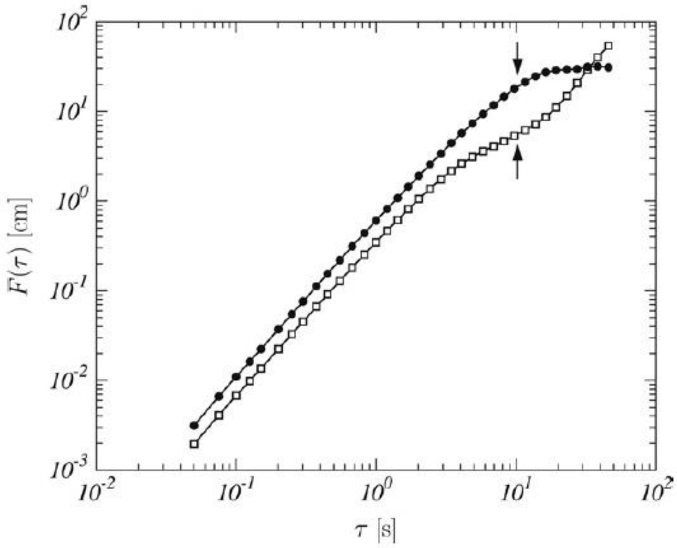

Figure 17. Values of Z(τ) obtained for both the x (black points) and y coordinates (white points) as a function of the box size τ.

The arrows indicate the biggest value of used for the calculation of τ (217) .

The detrended fluctuation function in each box is then obtained as $\psi^k\ (t) = Z(t) - Z^k_{fit}(t)$. For each τ, we calculate the function

$$F(t) = \left(\frac{1}{N_b} \sum_{k=1}^{N_b} \frac{1}{N_\tau} \sum_{k=1}^{N_\tau} [\psi^k\ (t)]^2 \right)^{1/2}$$

This function measures the root mean squared fluctuations. The presence of scaling is characterized by $F(\tau) \sim \tau^\alpha$. The scaling exponent α includes the information concerning the correlation properties of the signal: α = 1.5 is characteristic of an uncorrelated random series (or white noise), while the signal presents positive (negative) correlations if $\alpha > 1.5$ ($\alpha < 1.5$). Signals with negative correlations exhibit anti-persistence meaning that subsequent increments of the signal in time tend to anti-correlate while positive correlations show persistence or a tendency to continue its motion in the same direction. A smaller α-value for quiet standing COP can thus be interpreted as a higher degree of anti-persistence; that is, a higher proportion of rapid corrective impulses.

The COP is stable for periods of time with only needing small correcting movements. Due to a natural forward fall of the COM, ankle stiffness and segmental reflexes slowly control the drop as a passive control mechanism. This happens during stability periods in a feedback fashion. When the COP is turned unstable, the CNS takes control by sending a motor command to shift the COP position to return to the reference position with a clear active control and thus, a feedforward nature. Therefore, static balance is controlled by two control strategies (i.e., active and passive) (218). The Sway Density Plot aims to identify which of them is acting each period of time.

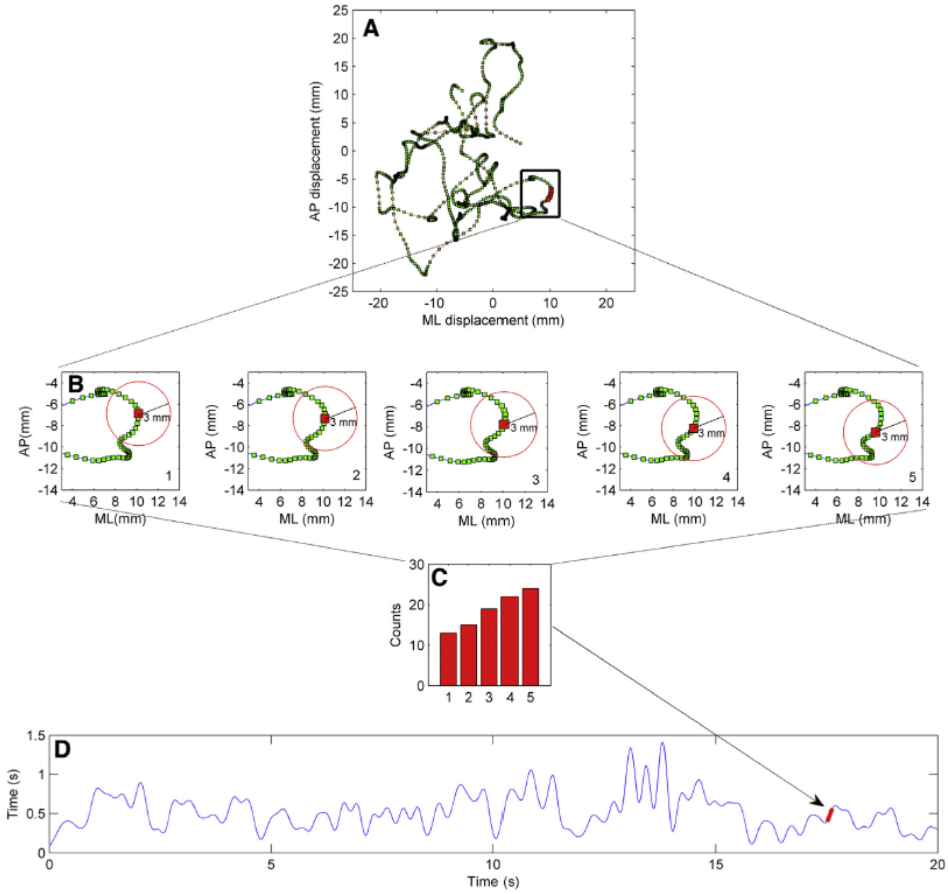

Figure 18. Signal processing of one child.

Layer A: stabilogram of the eyes closed condition. This layer contains the key zone selected to explain the analysis. Layer B: (from left to right) the five points selected as examples and the 3 mm radii from each one. Layer C: number of points that are contained in the 3 mm radius for each data point selected as an example (counts). Layer D: sway-density plot of the whole signal. Arrow indicates the five points used as example in calculating the counts. In this phase of analysis peak detection was performed and mean peak (MP = 0.72 s), mean distance (MD = 5.77 mm) and mean time (MT = 0.43 s) were computed (218).

To conduct the sway density plot analysis, the number of consecutive samples inside a circle of 3 mm radius was computed for each data point. Then, a signal was obtained with the *x*-axis representing time and the number of points presented on the *y*-axis (Figure 18). By multiplying the value of the signal at each time point by the sampling period, the signal was converted into a time/time curve. Furthermore, peak detection was performed. In order to improve peak detection, the signal was filtered in both direct and reverse directions using a fourth order Butterworth filter with a 12 Hz cut-off frequency. Then the different structural parameters were obtained (219):

- Mean peaks: peaks of the sway-density plot were averaged to obtain the mean value of the peaks in the sway density curve.
- Mean distance: calculated as the distance covered by the COP between two successive peaks of the sway-density plot.
- Mean time: Mean value of the time between consecutive peaks.

Peaks represent the lengths of time in which the COP is relatively stable and, valleys are periods in which the CNS is actively commanding to attenuate postural control.

3.9. Statistical analysis

In order to respond appropriately to the studies performed, two statistical approaches with differentiated characteristics have been used. The only use of traditional statistics would have provided lower quality and quantity results.

Classic statistical analysis

First, a classical statistical analysis was used to study the characteristics of postural control modulation while performing a suprapostural task under two feet conditions within the different ages. The mean values (of the two trials) of each COP parameter and the conditions used to observe the influence of suprapostural tasks on balance (i.e., BS, BT, LS and LT) were analyzed. The COP parameters used were mean velocity in both anterio posterior and medio lateral directions and the area of the ellipse. Classic statistical analysis were carried out using SPSS software version 17 (SPSS Inc., Chicago, IL, USA). A descriptive analysis of the variables was performed, using the mean as the measure of central tendency and the standard error of the mean, minimum and maximum for dispersion statistics.

Before carrying out inferential statistics, normality and homoscedasticity was checked. In order to check for the normal distribution of all dependent variables, a Kolmogorov-Smirnov test was used. A test for homoscedasticity (Levene's test) was also performed on all variables, taking into account that both tests assume as the null hypothesis normality and homogeneity of variances.

We conducted two 2 × 2 × 6 (stance width × visual task × age group) mixed model ANOVA, one for each postural control variable (i.e., mean velocity and α-scaling exponent). The stance width and visual task variables were within participants, while the age group variable was between participants. Moreover, a one factor ANOVA (i.e., group age) was performed to analyze the effect of age on search task performance. Follow-up of univariate contrasts was performed using pairwise comparisons with Bonferroni correction to correct the random effect caused by mixing multiple variables. The criterion alpha was set at $p = 0.05$. In our ANOVAs, we estimated the effect size using the partial $\eta 2$ statistic. According to Cohen (220), values of partial $\eta 2 > 0.14$ indicate a large effect, and values of partial $\eta 2 > .06$ indicate a medium effect.

Analysis through self-organized maps

Second, in order to find postural profiles and study migrations across them with the absence of vision, self-organized maps (SOM) were used. The mean values (of the two trials) of each COP parameter and the visual conditions (i.e., BS and EC) were used for further analysis. Since this was a different analysis, the EA was also used. The two conditions for each subject were included in the analysis as independent cases. Then, SOM trajectories could be calculated which determine the postural control profile change of each subject from eyes open to eyes closed condition.

SOM analysis was conducted based on the pattern of the COP displacement. A SOM is a type of artificial neural network that is trained using unsupervised learning to produce a low-dimensional representation (221). A SOM consists of components called nodes or neurons. Associated with each node are a weight vector of the same dimension as the input data vectors, and a position in the map space. The usual arrangement of nodes is a two-dimensional regular spacing in a hexagonal or rectangular grid (219).

The SOM analysis was used to classify participants by their similarities in postural control variables. Therefore, the SOM analysis provided profiles of postural control strategies used by children. Moreover, this analysis allowed us to visualize patterns of migration among postural control profiles between visual conditions (218). The SOM was computed with the MATLAB R2008a program (MathWorks Inc., Natick, MA, USA) and the SOM toolbox (version 2.0 beta) for MATLAB.

The process used to obtain a SOM can be explained in three steps (218): building the neuron network, assigning values to the neurons and training the SOM. The first step was the construction of a neuron or node network which size is dependent on the number of cases included in the analysis. In this study, the network presents a rectangular form with a size of 13 neurons high and 8 neurons width. The shape of the neurons was hexagonal, each neuron connecting to a total of 6 neighboring neurons. The second step was the initialization; during this step, a value or weight was assigned for each input variable to each of the neurons in two different ways: randomized and linear initialization. The random initialization occurs when weight vectors are initialized with a small random value. Linear initialization occurs when weight vectors are initialized in an orderly manner along a linear subspace spanned by the two principal eigenvectors of the input data series. Once the neurons are created and a weight is assigned to each of them, that weight is revised.

The third step was the training of the SOM; in other words, the process used to modify the initially assigned weights or values of the neurons. Two different training algorithms were applied in this study (i.e. sequential and batch). In the training phase each of the neurons that make up the grid compete to win each of the input vectors (x) or cases in the sample. The winner of each neuron is one whose Euclidean distance between its weight vector and the input vector is the least. Note that the input vector or cases are normalized between 0 and 1 before beginning the training process. This is done so that the scale of the variables does not influence the SOM training.

This competitive process gives way to an adaptive process by which, once the input data vector is assigned to a neuron, the weights of the winning neuron and the neighboring neurons are modified and at the same time ordered topologically (i.e. ordering phases and convergence).

The following equation shows the calculation that is used during the training of the neural network. As can be seen, the weights after each iteration are modified according to the differences between the initial weights and the input vector, the neighborhood function and the learning rate.

$$w_j(n+1) = w_j(n) + \eta(n)h_{j,i(x)}(n)(x-w_j(n))$$

Where w_j is the vector of weights of the j[th] neuron, η is the learning ratio, $h_{j,i(x)}$ is the neighborhood function and x is the input vector. The neighborhood function is used so that the winning neuron and its closest neighbors adapt their weights to resemble the input vector to a greater extent than the furthest neurons from the winner. For the present study, four different neighborhood functions were tested: i. *gaussian*, ii. *cut gaussian*, iii. *Epanechicov* and iv. *Bubble*.

The value of the learning rate is high during the first iterations and progressively decreases to very small values. Thus, at the beginning of the training, there are large changes in the weights of neurons with more discreet modifications as the process progresses. A description of the SOM analysis is also available in previously published manuscripts (218,222–224).

Because the final analysis result depended on some randomized processes (e.g. initialization and entry order of the input vector), the process described above was repeated 100 times. By repeating the process 100 times the odds of finding the best solution to the problem were increased. Since we used two different training methods, four neighborhood functions and two initialization methods, 1600 SOM were obtained (i.e. 100 x 2 x 4 x 2). The map with the minimum error when multiplying the quantization and topographical errors was selected (218,223,224).

After the SOM analysis, a k-means method was used to classify the neurons in greater groups according to their characteristics. The number of clusters was chosen to range between 1 and 10 to avoid an excessive number of profiles. The final number of clusters was chosen to be the last one in which the quantization error would improve at least a 5 percent.

Next, the number of girls and boys, and the number of BS and EC cases in each cluster were computed. Moreover, the median and interquartile range of age, weight, height and physical activity level were calculated for each cluster. Finally, in order to determine the effect of the visual condition in the postural control profile, cluster migrations of participants from BS to EC condition were quantified. Thus the percentage of subjects that experienced a change of cluster was established.

Kruskal-Wallis tests were also applied to establish the effect of the cluster on the postural control variables, age, weight, height and physical activity level. The follow-up was performed by U-Mann-Whitney tests with the Bonferroni correction. On the other hand, in order to determine the existence of an association between cluster and gender or between cluster and visual condition two Chi-Square tests were applied. A p-value of 0.05 was accepted as the level of significance for all statistical analyses.

4. Results

In the following paragraphs, the results of the different parts of the study will be exposed. First, a general description with the values of the COP parameters for each of the conditions chosen is presented. Second, values from the influence of a suprapostural task on children's body sway will be mentioned. Third, results related to the existence of vision in postural control of children are discussed. Following, results of children's amount of physical activity, obtained with a questionnaire, are shown and last, the resulting characteristics found for each neuron created with the SOM are presented.

4.1. General Descriptives of the Conditions

Next, general descriptives of the calculated variables for the COP time domain are shown (Table 3). The choice of the temporal parameters of body sway was decided following the main objectives of this study.

Generally, both the AP and ML values for the MV of postural sway were higher in the EC condition compared to the rest of conditions. The highest value for the EA was recorded in the eyes open with feet together condition (BS). Moreover, the BS condition had the highest range for the three measures of COP analyzed. The condition that revealed the lowest values for all the parameters chosen was letter search with feet apart (LT). The aim of this paragraph was to present an overview of the group tested.

Table 3. COP parameters for the different conditions.

COP time domain parameters	Anterio-posterior Mean Velocity	Medial-lateral Mean Velocity	Ellipse Area
Eyes open Feet apart	13.17(4.83) [7.07, 47.16]	15.12(47.67) [7.43, 74.06]	182.97(191.67) [31.23, 1430.24]
Eyes open Feet together	15.12(5.79) [7.10, 59.57]	16.31(8.71) [8.26, 89.88]	326.16(435.10) [51.86, 1971.09]
Eyes closed	15.36(4.78) [6.99, 47.12]	15.61(7.30) [7.44, 64.05]	208.81(233.53) [27.12, 1332.90]
Letter search Feet apart	11.87(3.92) [6.11, 41.09]	14.31(6.44) [7.54, 67.11]	203.75(147.52) [17.84, 1898.33]
Letter search Feet together	12.77(3.93) [6.32, 34.85]	14.59(5.77) [8.04, 55.33]	241.15(305.32) [59.14, 1964.82]

Data are expressed as means and SD [minimum and maximum].

4.2. Influence of suprapostural tasks under different bipedal stances

One of the goals of this study is to develop a more rigorous understanding of the influence of a suprapostural task in the body sway of children. Therefore, performance results in the visual search task will be first exposed. Second, differences in temporal parameters of postural sway regarding the visual search task under the different feet conditions will be presented through the mean velocity of the COP. Third and last, the temporal dynamics of postural sway will be explored by looking at the DFA.

Search task performance

Following previous studies (e.g., Prado et al., 2007; Stoffregen et al., 2000; Yu et al., 2013), we did not formally evaluate performance on the Inspection task, that is, we took for granted that participants maintained their gaze on the blank target. We evaluated performance on the Search task in terms of the mean percentage of target letters counted during each trial. The mean percentage of letters counted was 75% when the feet were at shoulder width, and 74% when the feet were together; these did not differ significantly, $F(1,202) = 0.64$, $p = .43$. By contrast, Search performance varied across the age groups, $F(1,5) = 9.70$, $p < .001$, partial $\eta 2 = 0.19$ (Figure 19).

Post-hoc pairwise comparisons revealed that effects of age were limited to the younger groups (6-7 = 7-8, 6-7 < 8-9 = 9-10 = 10-11 = 11-12, 7-8 < 9-10 = 10-11, each significant $p < .05$). The age group × stance width interaction was not significant, $F(5,202) = 1.32$, $p = .26$.

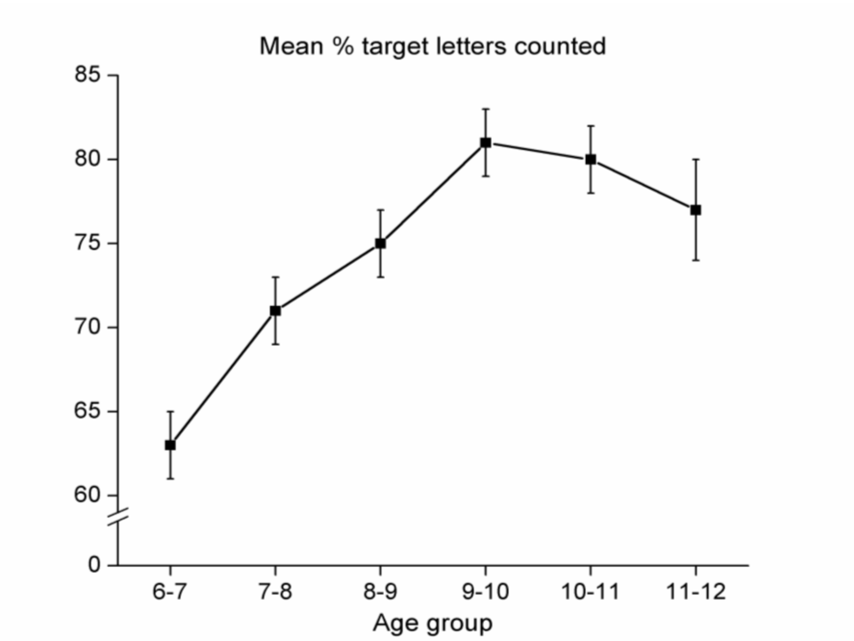

Figure 19. Performance in the supra-postural visual search task for all age groups.

The data are the mean percent of target letters counted for each age group. The error bars represent the standard error of the mean.

The mean velocity of postural sway

The main effect of axis was significant, $F(1,201) = 68.25$, $p < .0001$, partial $\eta 2 = 0.25$. Mean velocity was greater in the ML axis (mean = 1.52, SE = 0.05 cm/s) than in the AP axis (mean = 1.32 cm/s, SE = 0.03 cm/s). The main effect of stance width was significant, $F(1,201) = 43.03$, $p < .001$, partial $\eta 2 = 0.18$. Mean velocity was greater when the feet were together (mean = 1.47 cm/s, SE = 0.04 cm/s), than when the feet were at shoulder width (mean = 1.37 cm/s, SE = 0.04 cm/s).

In addition, the effects of stance width differed between the AP and ML axes, $F(1,201) = 29.05$, $p < .0001$, partial $\eta 2 = 0.13$, as shown in figure 20. Post-hoc pairwise comparisons revealed that mean velocity in the AP axis was greater when the feet were together than when they were at shoulder width, $p < .001$; this was true also for mean velocity in the ML axis, $p < .001$.

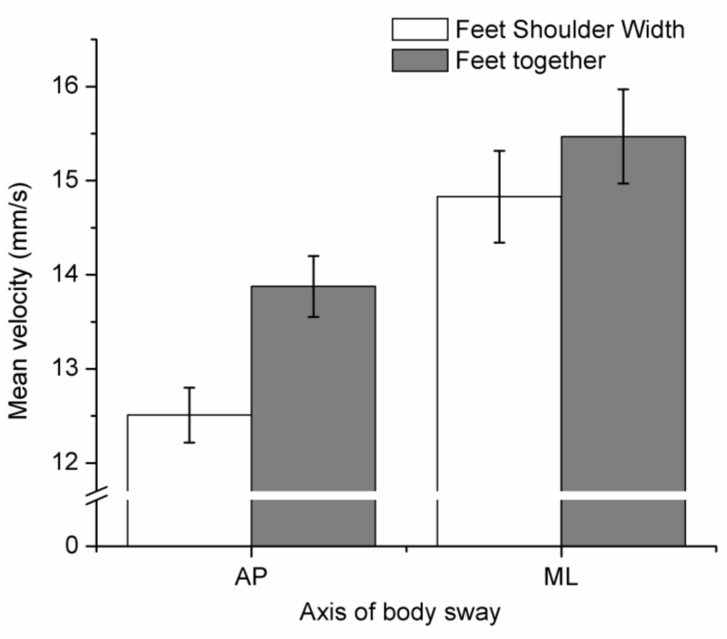

Figure 20. Mean velocity of the COP, illustrating the statistically significant interactions between sway axis AP and ML and stance width.

The error bars represent the standard error of the mean.

The main effect of visual tasks was significant, $F(1,201) = 44.53$, $p < .0001$, partial $\eta 2 = 0.18$. Mean velocity was greater during performance of the

Inspection task (mean = 1.49 cm/s, SE = 0.05 cm/s) than during performance of the Search task (mean = 1.35 cm/s, SE = 0.03 cm/s).

In addition, the interaction between stance width and visual tasks was significant, $F(1,201) = 15.35$, $p < .0001$, partial $\eta 2 = 0.07$ (Figure 21). Post-hoc tests revealed that during the Inspection and the Search tasks, mean velocity was higher with feet together than feet at shoulder width ($p < .05$). Finally, the axis × visual tasks interaction was significant, $F(1,201) = 13.14$, $p < .0001$, partial $\eta 2 = 0.06$ (Figure 22).

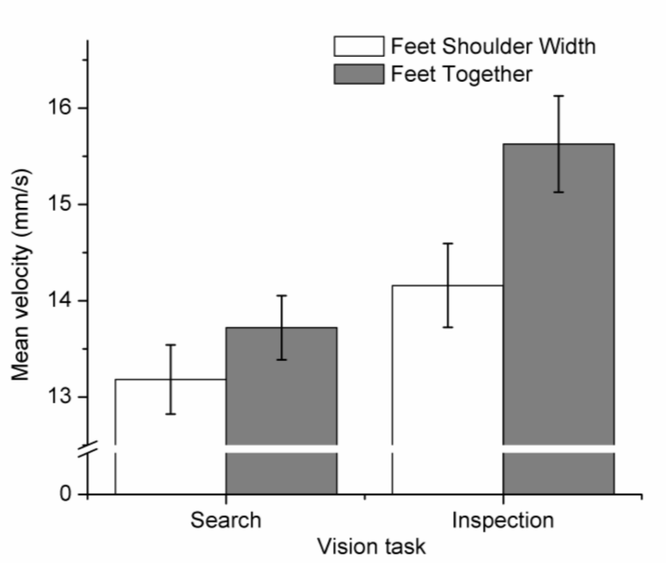

Figure 21. Mean velocity of the COP, illustrating the statistically significant interaction between visual tasks and stance width.

The error bars represent the standard error of the mean.

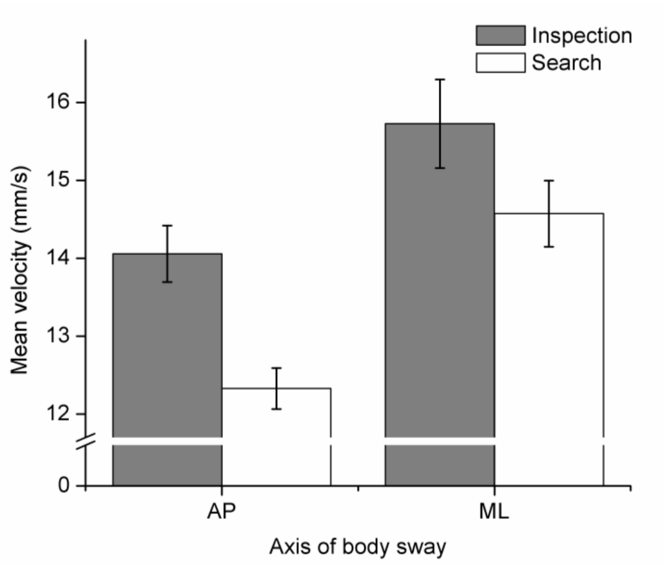

Figure 22. Mean velocity of the COP, illustrating the statistically significant interactions between visual tasks and AP and ML sway axes.

The error bars represent the standard error of the mean.

The main effect of age groups was not significant, $F(5,201) = 0.77$, $p = .57$. However, the age groups × axis interaction was significant, $F(5,201) = 2.74$, $p = .02$, partial $\eta 2 = 0.06$ (Figure 23). Of greater theoretical interest, the interaction between age groups and visual tasks was significant, $F(1,201) = 2.47$, $p = .034$, partial $\eta 2 = 0.06$ (Figure 24).

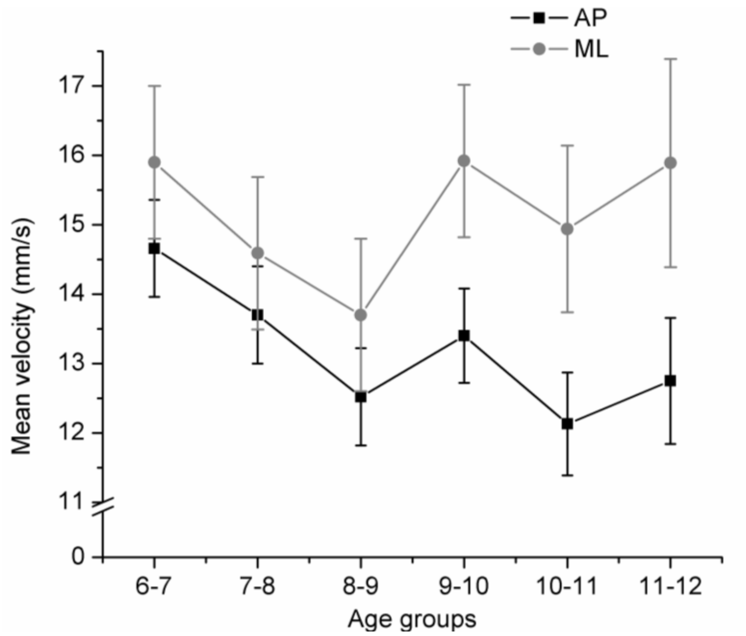

Figure 23. Mean velocity of the COP, illustrationg the statistically significant interaction between AP, ML sway axes and age groups.

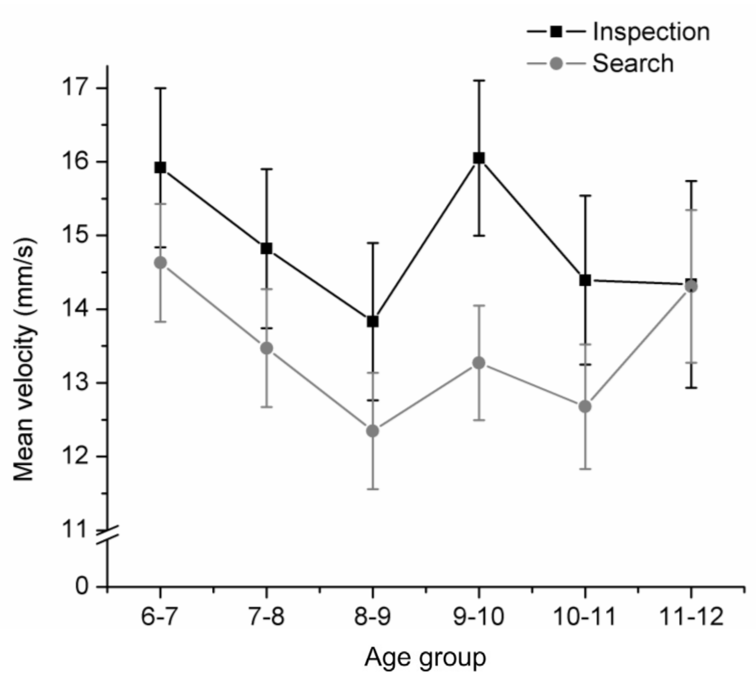

Figure 24. Mean velocity of the COP, illustrating the statistically significant interaction between visual tasks and age groups.

The main effect of axis was significant, $F(1,201) = 667.07$, $p < .0001$, partial $\eta2 = 0.77$. As indexed by α of DFA, the self-similarity of COP positions was greater in the AP axis (mean $\alpha = 1.60$, SE = 0.01) than in the ML axis (mean $\alpha = 1.50$, SE = 0.01).

The main effect of stance width was significant, $F(1,201) = 644.85$, $p < .0001$, partial $\eta2 = 0.76$. Self-similarity was greater when the feet were together (mean $\alpha = 1.60$, SE = 0.01) than when the feet were at shoulder width (mean $\alpha = 1.50$, SE = 0.01). In addition, the axis × stance width interaction was significant, $F(1,201) = 725.24$, $p < .0001$, partial $\eta2 = 0.78$ (Figure 25).

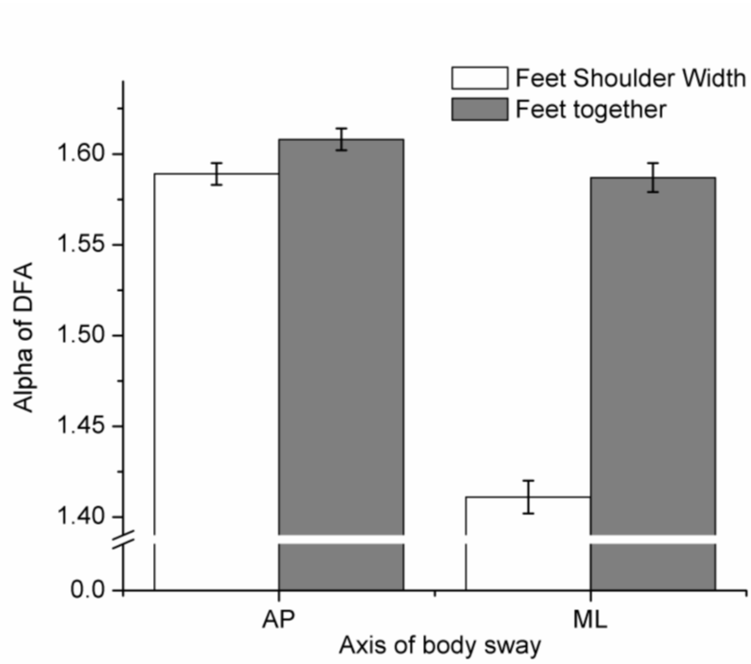

Figure 25. Statistically significant interactions for the self-similarity of COP positions (mean of DFA) between sway axis AP and ML and stance width.

The error bars represent the standard error of the mean.

The main effect of visual tasks was significant, $F(1,201) = 29.86$, $p < .0001$, partial $\eta 2 = 0.13$. Self-similarity was greater during performance of the Search task (mean $\alpha = 1.56$, SE = 0.01) than during performance of the Inspection task (mean $\alpha = 1.54$, SE = 0.01). The axis × visual tasks interaction was significant, $F(1,201) = 8.83$, $p = .003$, partial $\eta 2 = 0.04$ (Figure 26).

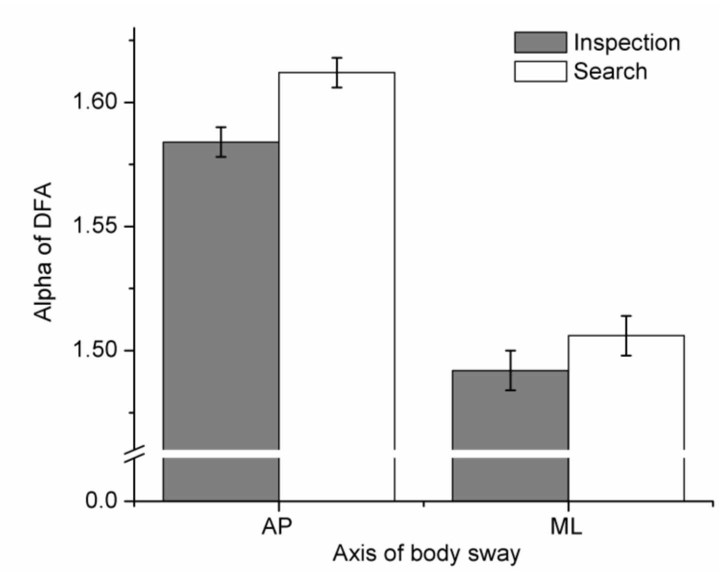

Figure 26. Self-similarity of COP positions (mean α of DFA), illustrating the statistically significant interactions between sway axes AP and ML and stance width.

The error bars represent the standard error of the mean.

The main effect of age groups was not significant, $F(5,201) = 0.58$, $p = .71$. However, the axis × stance width × age groups interaction was significant, $F(5,202) = 6.27$, $p < .0001$, partial $\eta 2 = 0.13$ (Figure 27). There were no other significant effects. Finally, we computed the strength of linear association of the DFA data. We found no significant effects on the strength of linear association. For the different age groups, the linear association ranged from 0.991 to 0.995.

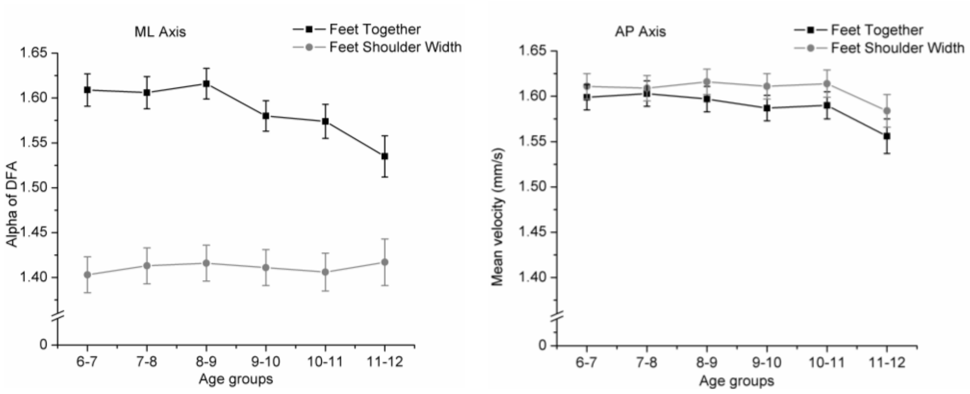

Figure 27. Mean α of DFA, illustrating the statistically significant interaction between body axis (AP vs ML), stance width (feet together vs shoulder width), and age groups.

4.3. Influence of the presence of vision in postural control

Another goal of this thesis was to study the influence of vision in postural control in children. Consequently, the velocity of the COP under eyes open and closed conditions is hereby presented. Furthermore, the results from the age group condition and the eyes condition is exposed.

The main effect of eyes condition was significant, $F(2,201) = 88{,}622$, $p < .0001$, partial $\eta 2 = 0.469$. Mean velocity was greater with eyes closed condition (mean = 1.55 cm/s, SE = 0.04 cm/s) than in the eyes open condition (mean = 1.41 cm/s, SE = 0.04 cm/s).

The main effect of age groups was not significant, $F(5,202) = 1{,}093$, $p = .39$. However, the age groups × axis interaction was significant in the AP direction, $F(2,201) = 15.63$, $p = .001$, partial $\eta 2 = 0.134$ (Figure 28).

Figure 28. Mean velocity of the COP in the AP direction, illustrating the statistically significant interaction between eyes condition and age groups.

4.4. Physical activity level

A descriptive analysis of the physical activity variables found through the PAQ-C questionnaire was performed for each of the age groups. The Physical Activity composite score, calculated by compelling the mean of the 9 items, generated a final PAQ-c activity level summary score, presented in figure 29 for each of the age groups. Data was taken from 204 students who completed the survey from first to sixth grade. This being the 37% of the students enrolled in these grades which can be considered a high response for this kind of survey.

The school average was 2.99, a score of 1 indicating low physical activity and a score of 5 meaning high physical activity. When considering the results, we should take into account that although the PAQ-C is a reliable questionnaire to be used with children and adolescents (209), the reliability and validity of the test has not been established with children under the age of eight. For this reason, parents were prompted to assist their students when answering the test in order to maximize the accurateness of the responses.

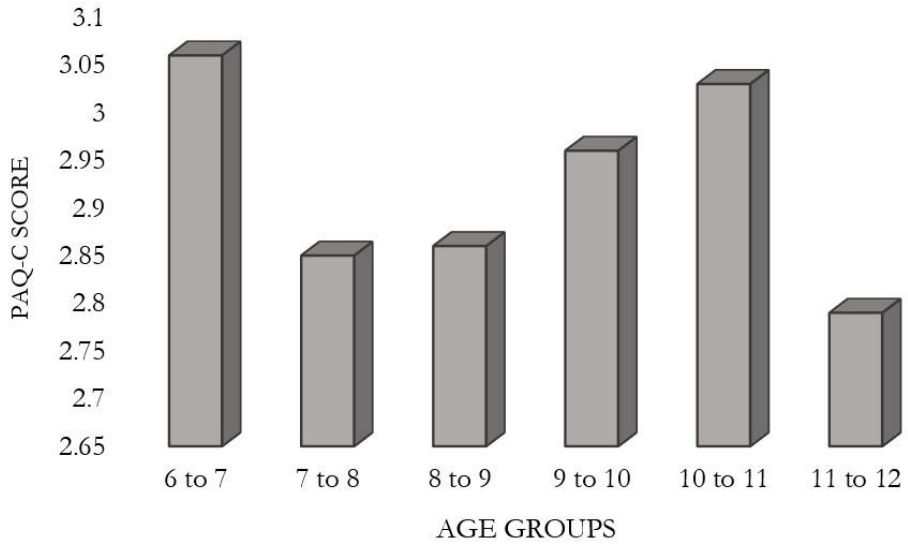

Figure 29. Physical activity composite score by age group.

From the composite score of physical activity, we found an increasing tendency in the amount of physical activity from 7 to 11 years old. According to the results of the questionnaire, younger children and fifth grade seemed to be more active than the rest, with 3.06 and 3.03 respectively, while the older group showed a noticeably more sedentary behavior. Interestingly, fifth grade scored the highest with 3.13 and sixth grade the lowest with 2.86.

The different parameters of the questionnaire allowed us to analyze physical activity level in different moments of the week. Results showed a similar pattern for all the different age groups. During their spare time and lunch, children were less active compared to the rest of the situations analyzed. The two times of the day when children were very active were in physical education lessons and during recess (Figure 30).

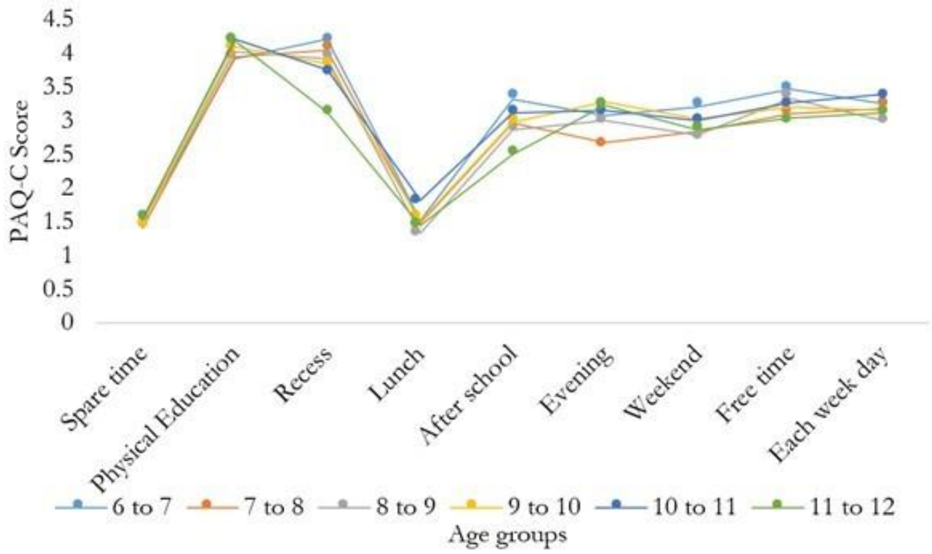

Figure 30. Physical activity level at different times of the week.

With greater relevance and subject of our study and hypothesis, correlations amongst physical activity levels and balance were analyzed. No significant results were found for the whole group nor amongst different grades.

In order to share the results of the PAQ-C with the families and children who responded, as well as the school community, a report was prepared with the most meaningful information from the PAQ-C, written in a reader-friendly style (Annex 6).

4.5. Self-organizing maps

Subsequently to the linear analysis presented along the previous points, we opted for a statistical analysis that could hone the different variables presented in order to be able to classify the children. Among the different available solutions we opted for self-organized maps which permit a thorough description and an appropriate clarification of the mechanisms used by children for balance regulation.

The analysis of balance according to just one of its factors such as age, gender or height does not reflect postural control accurately. Hence, it is suggested that various underlying mechanisms affect postural control. Other critical reasons were that during childhood it is easier to discover the basic strategies underlying balance stability, which can be more difficult to identify later in life(61) linked to the fact that few studies have analyzed postural control profiles according to the age, gender, weight, height and PA factors(225).

Before describing the results, it is necessary to explain some aspects of the analysis that will help the reader to better interpret the SOM: (i) At the time the analysis algorithm finishes, all sample subjects (input) are placed in a given neuron (output). Effectively, the subjects are grouped in the same neuron with those colleagues with whom they share more characteristics. Therefore, regardless of the visualization system used or of the variable M being observed, subjects will always be placed in the same place (i.e. the same neuron). (ii) The second critical point is related to the distances between the neurons. A priori, subjects in a given neuron will have similar values to the colleagues located in the same neuron and less similar to those placed in distant neurons.

4.5.1. Number of clusters

In figure 31 the quantification error between cluster centroids and the cases allocated in each cluster are shown. As can be seen, from 6 to 10 clusters the quantization error remains almost stable. In fact, adding a 7th cluster improves the quantization error less than 4%. Therefore, 6 was chosen as the final number of clusters.

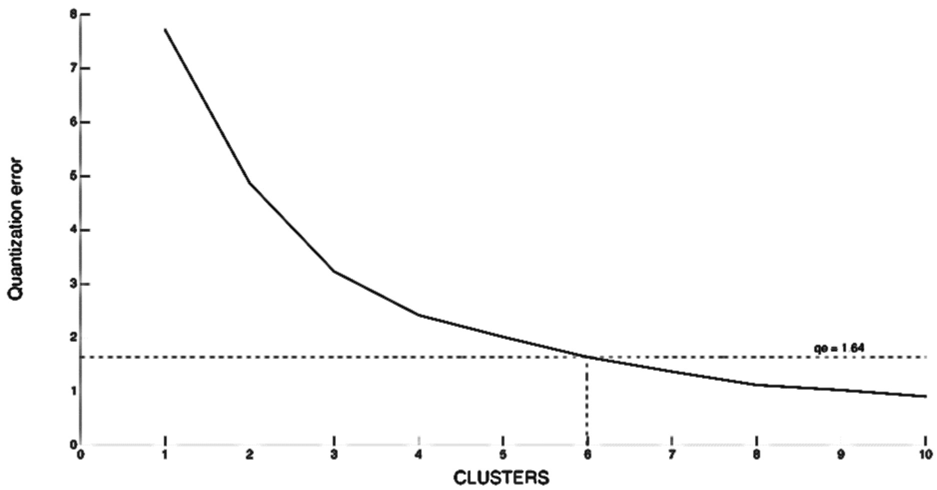

Figure 31. Criteria used to select the number of clusters in the k-means analysis.
qe = quantization error.

4.5.2. Postural control variables

Although the main aim of the SOM is to perform an exploratory analysis for detecting behavior patterns by considering all variables, Table 4 presents the numerical data of each measured variable. This table summarizes the values characterizing the four clusters studied.

There was a main effect of the cluster in every postural control variable computed in this study ($p < 0.001$). Kruskall-Wallis statistic and significance level for the effect of the cluster in each variable is presented in Table 4.

Table 4. Effect of cluster in postural control variables.

Variable	Direction	H5	p-value
Ellipse Area (mm2)	--	201.81	<0.001
Mean Time (s)	--	167.91	<0.001
Mean Distance (mm)	--	197.42	<0.001
Mean Peaks (s)	--	238.48	<0.001
Mean Velocity (mm·s-1)	AP	212.1	<0.001
	ML	150.86	<0.001
Low frequency band (%)	AP	299.79	<0.001
	ML	184.87	<0.001
Medium frequency band (%)	AP	287.54	<0.001
	ML	161.14	<0.001
High frequency band (%)	AP	121.81	<0.001
	ML	110.65	<0.001

AP = antero-posterior; ML = medio-lateral; H = Kruskall-Wallis statistic.

The pairwise comparisons between clusters for each postural control variable are shown in Tables A and A1 (Annex 7). In figures 32 and 33 component planes of SOM analysis are shown. It must be noted that the yellow colors in SOM maps (e.g. HF in ML direction) indicate lower values than blue colors (e.g., MF in ML direction). Therefore, in the next paragraph, clusters are compared among each other and therefore, high or low values will be associated to the values of the same variable in the other clusters.

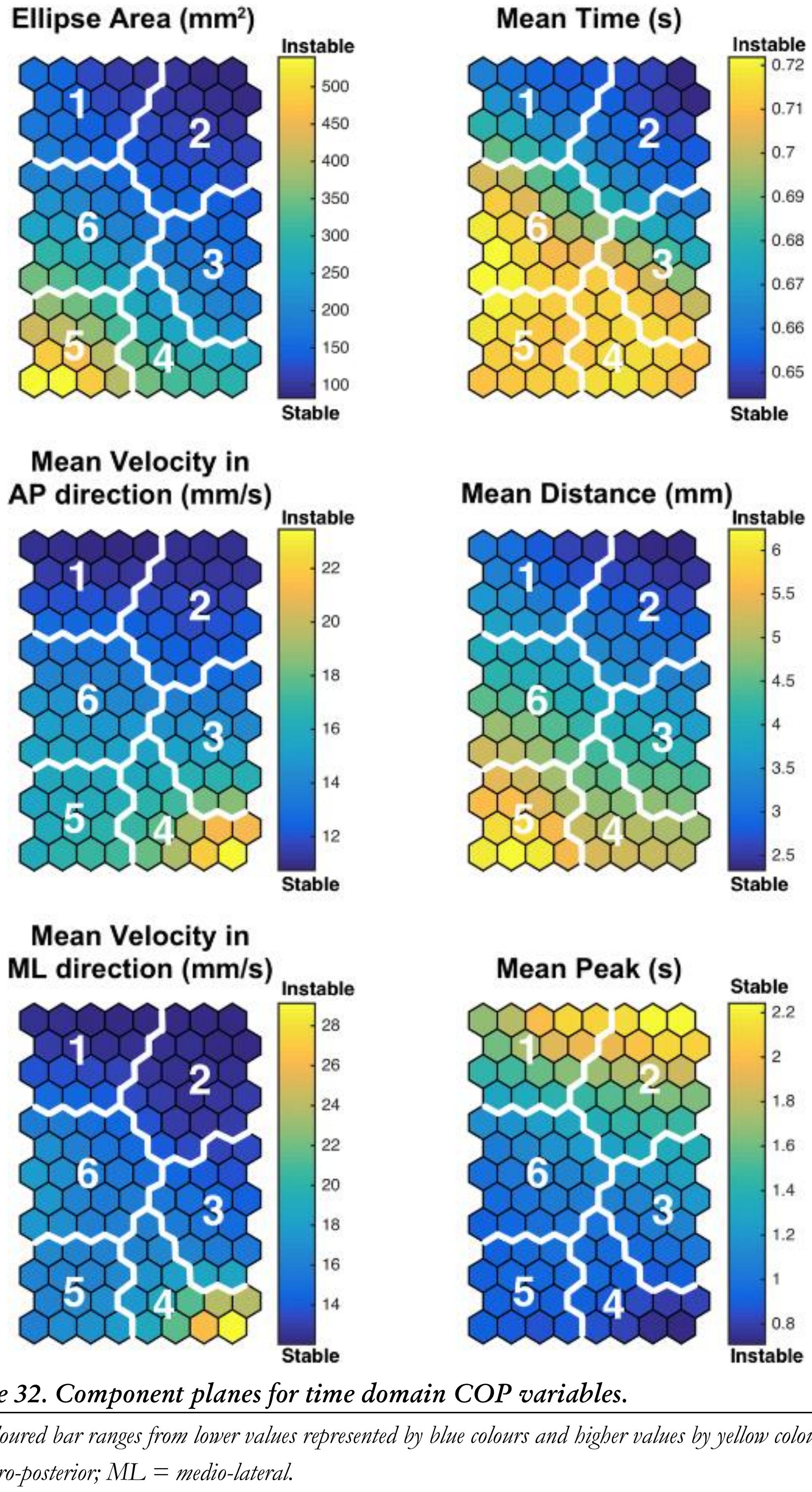

Figure 32. Component planes for time domain COP variables.

The coloured bar ranges from lower values represented by blue colours and higher values by yellow colours. AP = antero-posterior; ML = medio-lateral.

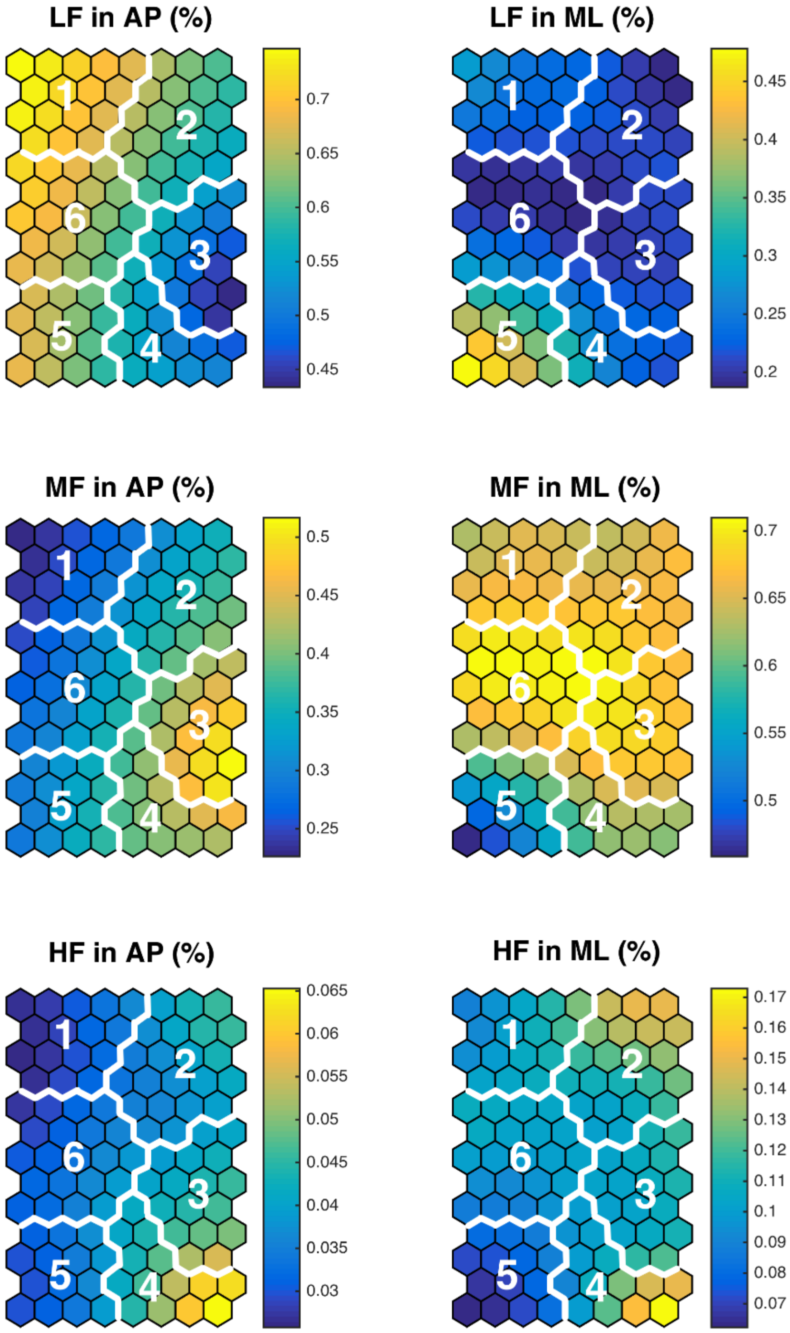

Figure 33. Component planes for frequency domain COP variables.

The coloured bar ranges from lower values represented by blue colours and higher values by yellow colours. AP = antero-posterior; ML = medio-lateral; LF = low frequencies; MF = medium frequencies; HF = high frequencies.

Three low stability clusters (i.e., cluster 4, 5 and 6) and three high stability clusters (i.e., clusters 1, 2 and 3) were detected. Regarding low stability clusters, they showed high values for EA (mainly cluster one), mean time, mean distance and mean velocity in AP and ML and a low mean peaks value. Furthermore, the frequency profile of these clusters was quite heterogeneous. The clusters with a high stable profile presented low values for EA, mean velocity in AP and ML direction, mean time and mean distance whereas a high value in mean peaks was obtained. As it happened with low stability clusters, the frequency profile of high stability clusters was heterogeneous.

4.5.3. Characteristics of the participants

Regarding gender distribution per cluster, a χ^2-test showed a significant association between cluster and gender (χ^2_5= 15.04; p = 0.01). Concretely, it was found that more girls were present in clusters 4, 5 and 6 than boys. However, the number of boys was higher than girls in clusters 1, 2 and 3 (Figure 34).

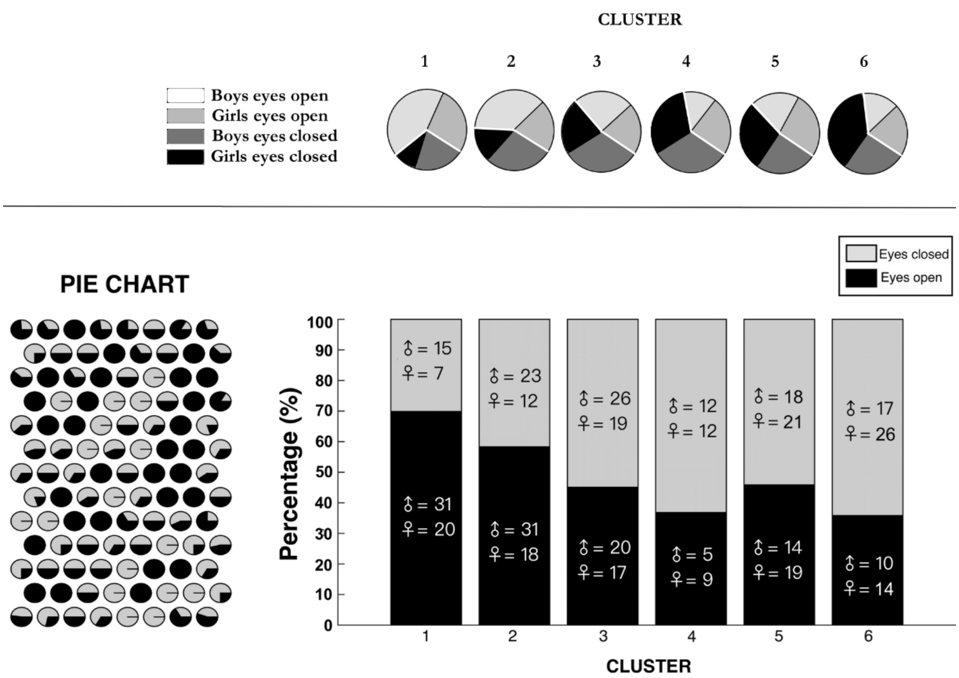

Figure 34. Percentage and number of boys and girls on each neuron and cluster

A significant effect of cluster was found in age ($H_5 = 15.83$; $p = 0.007$). Nevertheless, significant differences in age between pairs of clusters were not found ($p > 0.05$). That is, the age is related to the different postural control profiles found in children from 6 to 12 years. Moreover, there was a main effect of the cluster and participants' height ($H_5 = 16.59$; $p = 0.005$). Pairwise comparisons showed that the height of participants in cluster 4 was lower than the height of the group allocated in cluster 1 (Figure 35). On the contrary, effects of clustering on participant's weight ($H_5 = 10.46$; $p = 0.06$) nor physical activity level ($H_5 = 7.02$; $p = 0.22$) were found.

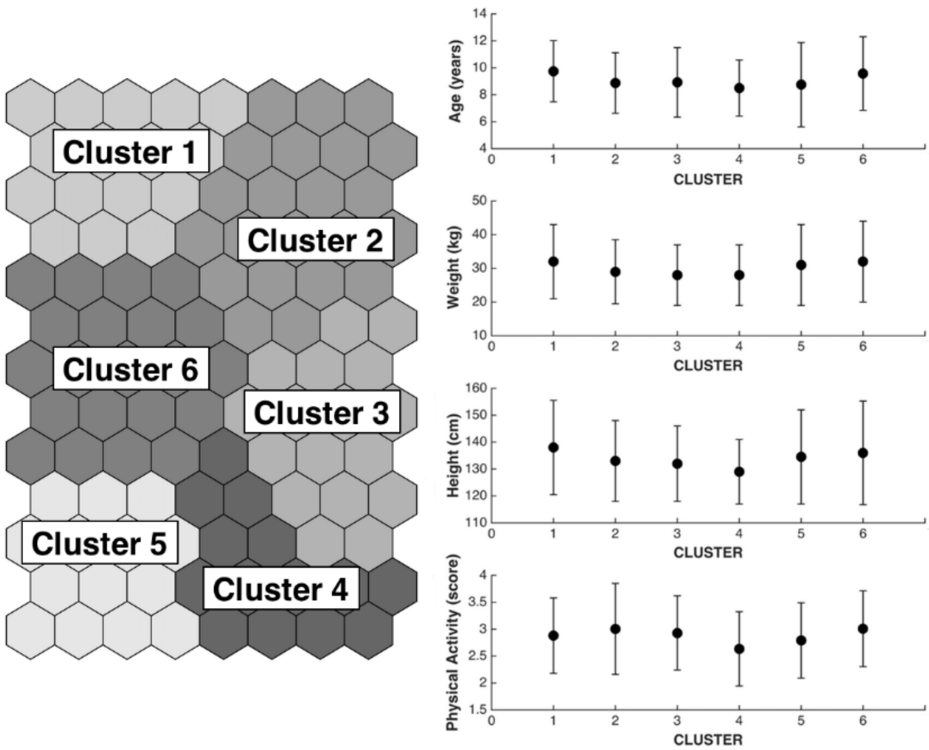

Figure 35. Characteristics of the participants assigned to each cluster

The median and interquartile range of each cluster are provided on the right layers.

4.5.4. Postural control profile according to visual constriction

A significant association between cluster and visual condition was found ($\chi^2_5 = 23.15$; $p < 0.001$). Clusters 3, 4, 5 and 6 had more EC than EO trials allocated while clusters 1 and 2 the number of trials of EO condition were higher than EC (Figure 36).

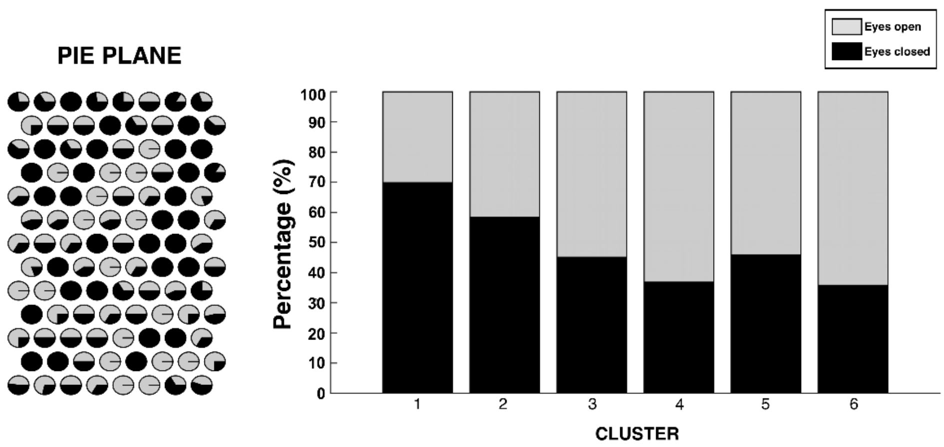

Figure 36. Percentage of eyes open and eyes closed trials in each neuron and cluster

5. Discussion

The main contributions and discoveries of this study are as follows. Regarding the different conditions tested, children from 6 to 12 years old reduced their body sway when performing a suprapostural search task with their eyes when maintaining a bipedal stance. Related to the previous finding, a novel effect in pre-adolescent children was found with a greater self-similarity of COP positions during performance of the Search task than during performance of the Inspection task. Typical effects of stance width were replicated, with a greater instability when the feet were together than when they were at shoulder width for all ages. As expected, static balance performance with the eyes closed, induced significantly more sway in all children, marked by a lower COP velocity, especially in the AP axis.

Age-related changes were found across the different conditions tested. For this age range there was not a significant linear trend during unperturbed, bipedal stance. A non-linear interaction for the mean velocity of COP positions with age was found when performing supra-postural visual tasks. In contrast, effects of stance width did not change with age, suggesting a fully established postural control at this position of the feet by age of 6. A significant decreasing pattern in COP velocity with age was found for the COP in the AP direction both with EO and EC conditions. In support of a regular pattern of change as a function of age, the 3-way interaction between body axis, stance width, and age was significant for the self-similarity of COP position (quantified as the scaling exponent of detrended fluctuation analysis).

Physical activity values showed slightly higher levels than values previously found in urban areas (226). As it would be predicted, physical activity levels were higher during physical education lessons and recess than other times of the day (226). However, we did not find correlations that would support our prediction that greater activity levels would correlate to a reduced body sway.

With the use of SOM, postural control profiles were established in relation to the variables obtained for body balance and then compared to the variables of age, gender, weight, height and the practice of PA of children from 6 to 12 years old. Changes of the profiles according to the visual condition were taken into account. Six postural control profiles were determined, three high stable clusters and three as low stable. The high stable profiles were constituted by a larger presence of high children and boys. A lack of significant differences between clusters existed according to age.

The magnitude of our data is similar to previously published research. Compared to the results found by Wolff et al (202), the mean velocity of the COP with EO was very similar to our results in the ML direction, 14.97 mm/s vs 15.12 mm/s, and slightly different in the AP direction 18.35 mm/s vs 13.17 mm/s. Looking at the same study, the mean velocity of the COP with EC for the ML direction was close with 17.52 mm/s vs 15.61 mm/s respectively. On the other hand, the mean velocity of the COP with EC for the AP direction was again lower in our sample: 22.6 mm/s vs 15.36 mm/s. Lower values can be explained by the fact that the children of this study were chosen from a non-urban area who have been reported to elicit better stability.

Influence of suprapostural tasks under different bipedal stances

The pre-adolescent children (age 6-12 years) performed different visual tasks while standing with their feet at different distances apart. Performance on the Search task, where children counted the number of target letters in a block of text, improved with age and plateaued in the 8-9 age group. We separately analyzed the spatial magnitude of postural sway, which we operationalized in terms of the mean velocity of the COP and the temporal dynamics of sway, which we operationalized in terms of detrended fluctuation analysis (DFA).

Following previous studies, we did not formally assess performance on the Inspection task (1,227). On the Search task, visual performance (i.e., the percentage of target letters counted) changed as a function of age groups. Performance was lowest among the youngest children (ages 6-8 years) and did not differ among children in older age groups (ages 8-12 years). This result comports with studies showing that reading improves across pre-adolescence (228), and suggests that our sample of children was representative.

Both the spatial magnitude and temporal dynamics of sway differed between the body's AP and ML axes. Both mean velocity and self-similarity of COP positions were greater in the AP axis than in the ML axis. Statistical comparison of children's standing postural sway in the AP and ML axes is rare. For example, such comparisons are absent from recent studies such as Ajrezo et al. (134), Bucci et al. (229), Gouleme et al. (136), and Schärli et al. (230).

By itself (i.e., in simple main effects), chronological age did not influence either the spatial magnitude or the temporal dynamics of sway. The absence of a significant linear trend across years for this age range resembles results reported by Ajrezo et al. (134), Kirshenbaum et al. (101), Olivier et al. (59), Rival et al. (102), and Schärli et al. (230). We conclude that, in this age range postural control during unperturbed, bi-pedal stance is not powerfully affected by chronological age (231). Rather, postural activity emerges from interactions between chronological age and other factors. In a non-linear pattern, age-related changes in the mean velocity of COP positions differed between the AP and ML axes (cf. 57,99,100,226). Other interactions including age will be discussed below.

We replicated typical main effects of stance width, confirming that stance width affects the kinematics of standing body sway in pre-adolescent children (106), and extending this effect to a range of ages, and to the self-similarity of COP positions. The self-similarity of COP positions was greater when the feet were together than when they were at shoulder width. This result with children resembles effects reported for adults during unperturbed stance (216,232,233). Effects of stance width did not change with age (i.e., the age × stance width interactions were not significant), which suggests that generalized effects of stance width are fully established before the age of 6.

The interaction between stance width and body axis was significant for the mean velocity of the COP. By contrast, in adults effects of stance width have been found primarily or exclusively in the ML axis (e.g. 85,222). The interaction between stance width and body axis was significant also for the self-similarity of COP positions. The very large effect of stance width on α of DFA in the ML axis resembles data obtained with adults(233,235). Thus, the relation between stance width and body axis resembled adult data in terms of temporal dynamics, but not in terms of the spatial magnitude of sway.

Finally, the 3-way interaction between body axis, stance width, and age was significant for the self-similarity of COP positions. This effect suggests that pre-adolescent children were able to tune the temporal properties of their postural activity to simultaneous variations in constraints, and that this ability changed with age. It may be that children "apportioned" sway between the AP and ML axes on the basis of stance width (236), and that their tendency to do this changed with age. As with other effects and previous studies, changes across age groups were not linear; however, in this case, the direction of age-related effects was consistent. This interaction provides evidence that postural control may have changed in some regular manner as a function of age.

We replicated typical main effects of supra-postural visual tasks on the kinematics of standing body sway. The mean velocity of sway was reduced during performance of the Search task, relative to sway during performance of the Inspection task. This effect, in our large, cross sectional sample, confirms and extends earlier studies that used only single age groups (227,235), and is also consistent with the large literature on postural control in adults(1,87,234). Following those earlier studies, we interpret this result in terms of task-specific support for visual performance: reduced velocity of the COP during performance of the Search task would support the stabilization of the visual system needed in moving the eyes to scan text, and in fixating individual letters. In the Inspection task, the same level of COP velocity would confer no benefit in terms of visual performance, that is, it would be wasted. The self-similarity of COP positions was greater during performance of the

Search task than during performance of the Inspection task. This effect is novel in pre-adolescent children, but has been reported in adults (215).

Our variation in supra-postural visual tasks interacted with body axes in the mean velocity of COP positions, and in the self-similarity of COP positions. The interaction for DFA resembles an effect found in older adults (197). The effects of visual task were statistically significant only for the AP axis. This finding resembles a study that used the same visual tasks in adults (87,216).

For the mean velocity of COP positions, our variation in supra-postural visual tasks interacted with stance width, consistent with some adult studies (216,237). The direction of the effect (the difference between tasks was smaller for the wider stance width) was the same as observed by Stoffregen et al (237). This effect suggests that pre-adolescent children are able to tune their postural activity to simultaneous variations in constraints, and that this ability is established by the age of 6 (235).

For the mean velocity of COP positions, our variation in supra-postural visual tasks interacted with age. The non-linearity of the interaction echoes previous studies that have revealed non-linear changes for main effects of age among pre-adolescent children (101,102,230,231), and extends it to the modulation of postural activity in the service of supra-postural visual tasks.

In the present study, we focused on relations between postural control and visual suprapostural tasks. A separate literature has examined relations between postural control and manual supra-postural tasks. Such effects exist across the lifespan (1,238), including infancy (239). Manual tasks involve control of the mass of manipulated objects, which can challenge the stability of the body's overall COM. In addition, manual tasks involve movement of the limbs (e.g., the arm and hand), which are themselves massive, such that arm movements affect the position and motion of the body's COM.

While these effects are important, they differ qualitatively from effects on posture of visual suprapostural tasks. That is, manual manipulation is a suprapostural task, but the mechanical consequences of manual manipulation are not: they directly affect body posture. By contrast, looking is a suprapostural task that has no mechanical consequences for posture. Postural adjustments subserving manual manipulation are functional, but can be regarded as obligatory.

Postural adjustments subserving suprapostural visual tasks are not obligatory; rather, they are optional, such that their presence, and their task-specific variety, implies a qualitatively different type of functionality. Put another way, it is credible that children could manifest postural adjustments in the context of manual manipulation while exhibited no such adjustments in the context of looking. We might even suppose that, in terms of development, the former would occur first (because it is mechanically obligatory), and the latter only later.

Effects of suprapostural tasks upon postural control sometimes have been interpreted in terms of relations between hypothetical processing resources required for maintenance of stance and for performance of suprapostural tasks, respectively. A common view is that postural control and suprapostural tasks compete for a limited pool of hypothetical central processing resources, in what amounts to a linear relationship, where more demanding cognitive tasks would result in greater interference with postural control, or vice versa (240,241). Evidence in favor of this view has been equivocal (53,87). Our results are consistent with an alternative theoretical perspective, in which postural and suprapostural tasks do not compete for a limited pool of central processing resources but, instead, interact cooperatively, such that postural control is modulated (in part) to facilitate the performance of suprapostural tasks (1,87).

Influence of the presence of vision in postural control

As mentioned before, postural control requires two different processes: the sensory organizational and the motor adjustment. The first, reaching a full development later in life and requiring visual, somatosensory and vestibular inputs. The latter, developing in early childhood and involved in executing coordinated and properly scaled musculoskeletal responses (82). Of the three sensory inputs, the visual system is the one that has received the most attention, especially regarding postural control development in children.

As expected, static balance performance with the eyes closed, induced significantly more sway in all children, marked by a lower COP velocity, especially in the AP axis. This previously well-established result in the literature comports with numerous studies (13, 237-241). In support, static balance has been proved to be sustained longer with eyes open than eyes closed, becoming more apparent with increasing chronological age (246). Postural sway decreases with the eyes closed with age is a consistent finding both in magnitude and in responsiveness (81,83,118,200,242,244-246). Indeed, visual input contribution plays a relevant role in postural stabilization in children.

Our findings did not indicate statistically significant differences in COP velocity among the different age groups when comparing EC to EO conditions. This could be explained by the fact that the biggest milestones in motor development and, furthermore in balance development, occur prior to 6 years of age (72,130). Our study, analyzing children from 6 to 12 years of age is therefore not aiming at those milestones. In general and, according to our results, prior studies found no interaction effects between age and vision, when comparing eyes open to eyes closed condition (94,247-249). Concretely, the magnitude of the change in the COP when children of different ages close their eyes, does not seem to differ during ontogeny. Only Newell et al (83) found a significant interaction effect for COP area in which 3 year old children were more affected by the absence of light than their older counterparts. A review on the topic revealed that results may depend on "the applied statistical analysis (comparison of conditions rather than main and interaction effects of age and vision)… or protocol (231)." In agreement with that review, at this time no conclusions can be drawn regarding the combined influence of age and vision on postural sway. Further research is necessary to determine the actual effect of both age and removal of visual information on sway in children.

Visual information used to maintain postural control has been found to originate in a greater extent from peripheral vision instead of central vision (9). Furthermore, a number of studies show that significant differences do exist in static balance control among these ages, the largest differences usually found with the most challenging conditions. For instance, a less challenging condition such as standing upright with feet together, rather than standing in a foam support surface, is already well controlled at age 6 (15).

A significant decreasing pattern in COP velocity with age can be observed in our results, particularly when looking at the COP in the AP direction between the younger and the elder children both with Eyes open and Eyes closed conditions. Children are thought to have reached adult-like patterns of equilibrium by the age of 10 years of age (104,244) in regards to the use of visual information. However, more recent studies found differences between body sway of older children up to 15 years of age and that of adults (130,134,229,253). Improvements in body sway have been recently explained by the maturation of the cortical processes involved in postural control but also by the development of attention which rely on a parallel maturation of the neuro-cognitive processes (253).

Throughout the developmental process, postural control is thought to endure important changes around 7-8 years of age due to improvements in the use of sensory cues (62,254). Accordingly, our results also show an interesting increase in COP velocity around 8 years old, breaking the decreasing general tendency. Another explanation, offered by Smidt et al. to clarify the pattern disparity around 7 to 9 years of age, is the possible presence of a change of strategy in EC condition which does not compensate for the absence of vision, thus resulting in an overall increase of the COP (103). Summarizing, our study found a non-monotonous trend with age in which the control of body sway improved in a non-linear pattern from 6 to 12 years old.

Physical activity level

Physical activity level, estimated with the PAQ-C score, showed different values among the different ages studied. Since PAQ-C validity and reliability has been questioned in younger children (207,255). PAQ-C was used with 5-6 year old children and their inconsistent values lowered the overall reliability of the total physical activity level, to the point that their measures were not used from the study (255).

Our results from questions 1 to 9, as well as the total physical activity level (PAQ-C score), correspond to previous results found using this questionnaire with children (206,207,255). Our general score was a little higher than what you typically find in urban areas, children living in smaller cities and rural areas tending to move more than those living in larger cities (256). From the results we can conclude that there is an increasing activity as children become older which, is suddenly reduced when they enter secondary education at 12 years of age. Perhaps maturation plays a role in the decrease observed although, it can be noted that middle schoolers also get half the amount of physical education than their younger counterparts since they must attend health classes on alternate days. Teachers from the school also reported an acute increase in time devoted to electronics in 6th graders compared to younger ones which may be a factor in the reduction of physical activity.

When looking at the scores in the different times of the day, we can see a clear pattern among all the children showing that the times when they exercise more are during physical education lessons and recess. On the other hand, their spare time and lunch is when children move less, scoring very low compared to the rest of the times analyzed. A trend towards less physical activity as children enter the adolescence has been also found by other studies. This result was explained by a decline in the number of organized sport activities and the fact that adolescents fail in maintaining a high level of physical activity during playtimes and activities outside school (208,255,257). Our interpretation of the results lay more into thinking that electronics, in particular social networks, start becoming very popular at these ages and grab adolescents attention way more than sports. This can be observed during recess times, where adolescents choose to stay inside the school chatting and playing on their phones rather than playing on the playground.

Motor skill performance and physical activity have been found to be connected from preschool children to the elderly (28,32,258) as well as in children (259). However, our prediction that greater activity levels would positively correlate to an enhanced body sway was contradicted since we found no correlations. The PAQ-C questionnaire has not been proved to be reliable with children younger than 8 years of age which may explain the disparity found in 6 years old and may also hide possible correlations with levels of body sway.

Self-organizing maps

Regarding the EO and EC conditions and the SOM profiles, this type of analysis contains all the features obtained of an overall child and does not limit its analysis to the mean of each valuation (or average and standard deviation). These networks were first developed by Kohonen (260) who, created a system that stored information in the same way that the brain does: i.e., similar memories are stored in areas of the brain that are close to each other, while disparate memories are stored in areas that are distant. Correspondingly, maps produce a distribution of the elements analyzed (children) such that the proximity of children on the map indicates that they have similar characteristics. And the greater the distance between two children, the more different they are in terms of the items evaluated.

The advantage of using this type of artificial neural network to analyze the results of our features is that it groups individuals in terms of the uniformity of the characteristics that define them, reducing the size of the problem to a two-dimensional map while maintaining all the information about the n features (items) valued. It should be pointed out that if attempts are to be made to improve postural control, the aspects that need to be improved must be known. The mean scores dilute the individual score on each of the items in such a way that children with a similar result in one of the parameters analyzed, can have a very different balance profile.

Human beings involve multiple sensory systems to maintain an upright posture (211,261). In this line, the vision is considered as a dominant information source for postural control (261). The current study aims to analyze the postural control profiles in relation to some factors inherent to human beings (i.e., the age, the gender, the weight, and the height) and the practice of PA and how these profiles changed according to the visual condition in children.

The SOM and cluster analyses determined the existence of six postural control profiles in children. According to the postural sway characteristics of these profiles, three clusters (clusters 1, 2, 3) could be categorized as highly stable, because the values of the temporal domain variables indicate that the children in these clusters were more stable (i.e., lower ellipse area, mean distance, mean time and higher mean peaks) and required less net neuromuscular activity (i.e., lower mean velocity) than those allocated to the other three clusters, which can be categorized as low stability (clusters 4, 5, 6). It should be highlighted that high stable profiles are related to the existence of passive or feedback mechanisms of postural control and a small magnitude of active or feedforward mechanisms of postural control (i.e., high mean peaks and low mean distance and time). On the other hand, low stability profiles are related to a control strategy in which an active control predominates (i.e., high mean time and distance and low mean peak) over a passive or feedback mechanism (219).

In addition to the characteristics of the postural control profiles, in the frequency spectrum, highly stable profiles in the AP direction offered heterogeneous results in every cluster (Figure 1). That is, Cluster 1 showed high LF and low MF and HF content; Cluster 2 is characterized by a medium value in each of the three bands and Cluster 3 is composed of low LF, high MF and medium HF. Moreover, the data in these highly stable profiles in the ML direction tends to be characterized by a low value in the LF band in every cluster, indicating a limited necessity for visual and vestibular control; a high value in the MF band suggests a high degree of involvement of the cerebellum; and a medium value in the HF band, related to the proprioceptive system (262). Hence, according to the heterogeneous data in the AP direction among clusters, it is considered that children with highly stable postural control may use different mechanisms for balance regulation. This postulation has also been found in low stability, in which data in the AP and ML directions also present heterogeneous results. Additionally, it should be noted that to establishing postural control profiles relatively new analytical techniques are required since traditional analyses (e.g., t-tests, Anovas…) are not able to do it. Thus, the classification by SOM and cluster methods can be used for a thorough description and an appropriate clarification of postural control in children.

Regarding the children's characteristics according to the postural profile, it should be noted that the clusters considered as high stability profiles are characterized by the higher presence of boys than girls. Also, low stability profiles denote a higher number of girls than boys (Figure 32). Therefore, in contrast to the expected results (106), boys are more frequently associated with high stability profiles than girls, and age and height are connected to some of the postural control profiles. In this line, and also in contrast with the expected results, height was usually associated negatively with postural control (225); children with a low stability profile (Cluster 4) had a lower height than those with a highly stable profile (Cluster 1). Although there was a significant effect of the age factor on balance, there was a lack of significant differences between the clusters, which could be due to the use of a Bonferroni correction considered to be very conservative. Although older children usually exhibit less body sway, postural control maturity is believed to be advanced and similar across the ages studied, not accounting for the greatest differences among profiles of children aged 6 to 12 years when applying less challenging conditions to body sway like feet apart and feet together stances (106). This could be the reason for age and cluster membership being related in this study, although no differences were found between pairs of clusters.

No association was found between weight nor physical activity level and postural control. Although some previous studies mentioned that some sports disciplines contributed to postural control (261), in this study data were obtained regarding the amount of physical activity performed, without focusing on each discipline. Therefore, when generalizing physical activity, no differences were seen in this factor. However, if we had focused on certain sports disciplines (i.e., gymnastics, dance, judo, Tai Chi, etc.) perhaps we would have found an influence on postural control."

In general, these results support the hypothesis that childhood is a sensitive period in the development of postural control (73,246) and many factors seem to affect balance (263). It is therefore suggested that an appropriate description of postural control analyses in children should include different factors such as age, sex and height. By means of results like those obtained in the present study, wherein boys show better postural control than girls, it is possible to observe how the analysis of a single factor, such as age, is not enough to provide a thorough description of postural control according to sex in every period of growth. On the other hand, the inclusion of such different factors may allow researchers to study them in combination to obtain an insight into children's postural control.

Eventually, no association was found among weight, PA level nor postural control. These results support one of the main orientations established in the current study; that is, taking into account that the childhood is a sensible period in which different postural adjustments are involved in the process of equilibrium (246,264) and many factors seems to affect balance (263), it is suggested that for an appropriate description postural control, analyses in children must involve different factors such as age, gender, weight, height and the PA level. The analysis of balance according to just one of these factors does not reflect the postural control accurately.

Additionally, according to the final objective of this study, the analysis of postural control in two different visual conditions also allows researchers to know the characteristics of children's postural control in relation to vision.

The frequency of children with a specific postural control profile with EO or EC is explained. As a consequence, the presence of children in highly stable profiles is mainly associated with the EO condition, since the majority of children in the high stability profiles present the EO condition (in Clusters 1 and 2). Corroborating the conclusions obtained in previous studies, which consider that vision is a dominant source of information for postural control (261), our results confirm that balance in these age groups depends to a great extent on the visual system. As can be seen in Figure 34, those children with a high static postural control tend to be associated with EO and vice versa. Nevertheless, in Cluster 3, belonging to high stability profiles, a large percentage of the children are found in EC, which supports the thesis that human beings use multiple sensory systems to maintain an upright posture including the visual, vestibular and somatosensory system (261). Thus, when thorough postural control analyses are carried out, it must take cared with the generalization of the results because distinct profiles of postural control may exist. In addition, even in one specific postural control profile different mechanisms may also be involved in the balance regulation.

Finally, it should be noted that this is the first study that analyzes the effect of weight, height, age, physical activity and gender on postural control development during childhood using a person-centered approach. This approach gave interesting findings that in some cases are contradictory with results obtained using a variable-centered approach (e.g. the effect of body weight on postural control). The person-centered approach rests on the idea that not all individuals develop the same patterns of mental, biological, and behavioral components, and the number of ways in which these aspects can be organized into patterns is limited (265).

6. Limitations and future implications

A limitation of this study is that individual level of maturation, as distinct from chronological age, was not measured. Children develop at different rates and thus differences in balance due to maturation may have been missed. Differences in levels of maturation within the same age group may also be responsible for the high variability in some of the measured parameters.

Developmental level appears to be a much better predictor of balance improvement than chronological age (77)

The lack of significant relations among physical activity and postural control may be also limited by the only use of the PAQ-C questionnaire as a measurement of physical activity, especially in younger children. We tried to compensate this by suggesting parents to read aloud the questionnaire and have them answer the questionnaire with their children although we have no proof that they all did so. We did not find a questionnaire with proven validity and reliability for children of less than 8 years of age. In future research, perhaps the researcher may need to sit with the children and explain them the questions in order to improve the validity of the results with younger children. Measuring physical activity by accelerometer could be more accurate and the type of physical activity or sport practiced by children could be also of great importance.

In regards to the suprapostural task, the lower performance in younger children in the letter search may simply be a function of age-related changes in reading speed. The performance levels observed in the older age groups are comparable to performance on a nearly identical task in adults (1). Given that our Search task required knowledge of the alphabet, it is possible that the task was more cognitively demanding for younger children than for older children in our sample. Thus, any effects of the Search task upon postural control may have varied across age in ways that were independent of age-related changes in postural control, as such. This possibility could be evaluated, in future research, by the selection of suprapostural tasks which could be shown to have equal cognitive demand for each age group tested.

The relatively small sample size of children from 6 to 12 years of age could be considered as a limitation of the study, plus the fact that they were all recruited from a single school. In order to clarify and generalize the characteristics of postural control profiles in typically developing children, future studies should analyze a higher sample size for each age range from diverse schools and classify children's postural control according to several inherent factors, not only bipedal stance but also tandem and monopedal stance as well as different sensory conditions. For example, it would be useful to study the contribution of the vestibular system to postural control tasks in 6-12-year-old children in the eyes closed condition on a compliant surface.

Several studies have found significant differences in body sway due to gender maturation (84,104,106–114). Overall, there is no clear pattern for a gender effect: while some studies report results in favor of boys, other studies have not been able to confirm such a difference. We were not able to find significant differences among genders which could be masked by the size of our sample as well as the large range of ages. Nevertheless, studies should focus on gender-specific questions about postural control because it appears that girls achieve better results in locomotion skills, whereas boys produce better results in object control skills (266–268).

7. Conclusions

The research presented in this thesis investigated the effects of age, weight, height, visual constriction and physical activity on postural control with eyes open and closed, feet together and apart and during the performance of a suprapostural task from 6 to 12 years of age. The conclusions that can be drawn from these investigations are listed below.

- Performance in a reading suprapostural task improves with age, and plateaus in the 8-9 year conforming to age-related changes in reading speed. Body sway is reduced during performance of a search task, relative to sway during performance of an inspection task. Pre-adolescent children are able to tune their postural activity to simultaneous variations in constraints, and this ability is established by the age of 6.
- Stance width affects the kinematics of standing body sway in pre-adolescent children both in the velocity as well as the self-similarity of the COP. Standing with feet together results in a higher body sway than feet at shoulder width. All children aged 6 to 12 sway more with their eyes closed than with their eyes open. Also, postural sway decreases with the eyes closed with age is a consistent finding with literature.
- Physical activity does not differ substantially among the different ages in preadolescent children. The amount of physical activity performed by the children alone is not a good predictor of the quality of their postural control.
- Children sway less with age when standing unperturbed with eyes open or closed, particularly when observing the COP in the AP direction. Effects of tasks and stance width are modulated by age, suggesting that the fine details of postural control continue to develop until (at least) age 12. The magnitude of the change in the COP when children of different ages close their eyes, does not differ in children from 6 to 12 years of age. The obtained results are in favor of a non-monotonic development of postural strategies in children: the full maturation of balance control is not yet complete, even at the age of

12. The classification by the SOM and cluster methods can be used for a thorough description and an appropriate study of the mechanisms used by children for balance regulation. Children's body sway can be classified under postural control profiles according to age, gender, weight, height and physical activity factors. Using a person-centered approach, this study found evidence of the importance of analyzing children's postural control according to age, sex and height. The analysis of balance according to only one of these factors does not reflect postural control accurately, because each of these factors may affect postural control in children aged 6 to 12 years of age. Finally, there was an asociation between visual condition and profile membership. High stability profiles were asociated with EO cases, while low stability profiles were asociated with EC cases.

8. References

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9. Annexes

1. Institutional Board approval

VNIVERSITAT
D VALÈNCIA Vicerectorat
d'Investigació i Política Científica

D. Francesc Francés Bozal, Profesor Contratado Doctor del Departamento de Medicina Preventiva y Salud Pública, Ciencias de la Alimentación, Toxicología y Medicina Legal, y Secretario del Comité Ético de Investigación en Humanos de la Comisión de Ética en Investigación Experimental de la Universitat de València,

CERTIFICA:

Que el Comité Ético de Investigación en Humanos, en la reunión celebrada el día 29 de octubre de 2015, una vez estudiado el proyecto de investigación titulado:
"Desarrollo del equilibrio estático en niños y adolescentes durante la realización de diferentes tareas", número de procedimiento H1443609882941,
cuyo responsable es D. Xavier García Massó,
ha acordado informar favorablemente el mismo dado que se respetan los principios fundamentales establecidos en la Declaración de Helsinki, en el Convenio del Consejo de Europa relativo a los derechos humanos y cumple los requisitos establecidos en la legislación española en el ámbito de la investigación biomédica, la protección de datos de carácter personal y la bioética.

Y para que conste, se firma el presente certificado en Valencia, a cuatro de noviembre de dos mil quince.

UNIVERSITAT DE VALÈNCIA

2. Informed consent

Parental Permission for Children Participation in Research

VNIVERSITAT DE VALÈNCIA

Roberto Izquierdo, 5th grade teacher

Dear LILA families,

Teaching at LILA is a job that not only makes me happy but also provides me different ways to continue learning everyday. Relating my job to my hobby, sports and physical activity, I want to study the **development of physical balance in children from 6 to 12 years old.** LILA school directors have encouraged and supported me with this PhD project, which I really appreciate. The project is supervised by Professor Wade and Professor Stoffregen of the University of Minnesota as well as Professor Luis Millán of the University of Valencia.

In order to do the project, I will need 120 student volunteers. The study will have two parts: first, an online questionnaire and second, measuring balance on a platform Even if your child is not measured on the platform, it would be very helpful if you and your child could complete the **Physical Activity Questionnaire** to study our community's activity level; it will take only 10 minutes. The questionnaire is a prerequisite to participate in the study and it can be completed online at http://goo.gl/SrerUx (A written version can be provided if online access is unavailable).

Thank you for your help with my research.

Your signature below indicates that you have read the information provided in the next pages and have decided to allow your child to participate. If you later decide that you wish to withdraw or discontinue their participation, you may do so at any time.

______________________	______________
Printed Name of Child	**Date of birth**
______________________	______________
Signature of Parent(s) or Legal Guardian	**Date**
______________________	______________
Signature of Investigator	**Date**

☐ Check this box if your child has had a traumatic lesion of any muscle in the lower body, any special physical or mental conditions, ulcers in the bottom of foot or if he/she is taking any medication currently. If so, please explain:______________________________

Roberto Izquierdo holds a Human Subject Research training by the University of Miami. The University of Valencia Institutional Review Board has approved this research. This study is also in compliance with the Family Educational Rights and Privacy Act and the Protection of Pupil Rights Amendment.

Title: Cross-sectional analysis of postural control and its modulation to facilitate visual performance from 6 to 12 years old developmental boys and girls.

Introduction

The purpose of this form is to provide you (as the parent of a prospective research study participant) information that may affect your decision as to whether or not to allow your child to participate in this research study. The person performing the research will describe the study to you and answer all of your questions. Read the information below and ask any questions you might have before deciding whether or not to give your permission for your child to take part. If you decide to let your child be involved in this study, this form will be used to record your permission.

Purpose of the Study

If you agree, your child will be asked to participate in a research study about static postural control. The purpose of this study is to identify how balance is controlled at the different stages of development under different cognitive and visual tasks. That will help us know whether children are developing at a normal pace and what are the strategies used to maintain balance.

What is my child going to be asked to do?

If you allow your child to participate in this study:

- Balance measurements will take around **20 minutes.**
- They will stand barefoot on a flat platform with eyes opened, closed, looking near, far and also performing a reading and a counting task. Their postural control under each condition will be measured. The reading and counting responses will be recorded.
- The students will have to answer a physical activity questionnaire with your help, provided at the end of this packet.
- There will be 120 participants in this study.
- We will make sure that the participant does not miss important classroom learning opportunities. They may be measured during a classroom break at school, during Physical Education class or after school if possible.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study.

What are the possible benefits of this study?

A possible direct benefit to the research participant is the feedback with detailed results that you will receive in case your child´s balance falls under the normal development range. That feedback will contain a summary of the results for each age frame and your child's data. Balance analysis are expensive since they are usually implemented by doctors.

The benefits of the research to society are extensive since we will better understand how postural control is developed.

Roberto Izquierdo holds a Human Subject Research training by the University of Miami. The University of Valencia Institutional Review Board has approved this research. This study is also in compliance with the Family Educational Rights and Privacy Act and the Protection of Pupil Rights Amendment.

Does my child have to participate?

No, your child's participation in this study is voluntary and refusal to participate will not result in any loss of benefits that the student is entitled to receive. When all the parental consents are returned, the students will be chosen randomly. Once they are chosen, your child may still decline to participate at any time.

What if my child does not want to participate?

In addition to your permission, your child must agree to participate in the study. If you child does not want to participate they will not be included in the study. If your child initially agrees to be in the study they can also change their mind later on without any problem.

Will there be any compensation?

Neither you nor your child will receive any type of payment for participating in this study.

How will your child's privacy and confidentiality be protected if s/he participates in this research study?

Your child's privacy and the confidentiality of his/her data will be protected by:

- Coded IDs instead of student names for data collection, merging, and analysis.
- Identifiers with the names of participants will be kept entirely separate and secure.
- During collection and storage, Roberto Izquierdo will be the only person accessing the data. For analytical purposes, the research team will only use the encoded data.
- The data resulting from your child's participation may be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate it with your child, or with your child's participation in any study.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the teacher Roberto Izquierdo at 6123566136 or send an email to rizquierdo@mylila.org for any questions.

3. Questionnaire

Physical Activity Questionnaire (Elementary School)

Name of student:_________________________ Age:___________ Sex: M_______ F_______

Grade:____ Mother´s height: _________ Father´s height: _________ Teacher:_____________

Read out loud to younger students - **Once completed, please return to the student´s teacher**

We are trying to find out about your level of physical activity from ***the last 7 days*** (in the last week). This includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

1. There are no right and wrong answers — this is not a test.
2. Please answer all the questions as honestly and accurately as you can — this is very important.

1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Mark only one circle per row.)

	No	1-2	3-4	5-6	7 times or more
Skipping	❍	❍	❍	❍	❍
Rowing/canoeing	❍	❍	❍	❍	❍
In-line skating	❍	❍	❍	❍	❍
Tag	❍	❍	❍	❍	❍
Downhill skying or snowboarding	❍	❍	❍	❍	❍
Bicycling	❍	❍	❍	❍	❍
Jogging or running	❍	❍	❍	❍	❍
Aerobics	❍	❍	❍	❍	❍
Swimming	❍	❍	❍	❍	❍
Baseball, softball	❍	❍	❍	❍	❍
Dance	❍	❍	❍	❍	❍
Football	❍	❍	❍	❍	❍
Skateboarding.............................	❍	❍	❍	❍	❍
Soccer	❍	❍	❍	❍	❍
Street hockey	❍	❍	❍	❍	❍
Volleyball	❍	❍	❍	❍	❍
Floor hockey	❍	❍	❍	❍	❍
Basketball	❍	❍	❍	❍	❍
Ice skating	❍	❍	❍	❍	❍
Cross-country skiing	❍	❍	❍	❍	❍
Ice hockey/ring	❍	❍	❍	❍	❍
Other: ___________________....	❍	❍	❍	❍	❍

2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? (Check one only.)

- I don't do PE...❍
- Hardly ever...❍
- Sometimes ....❍
- Quite often ....❍
- Always ....❍

3. In the last 7 days, what did you do most of the time *at recess* (Check one only.)

- Sat down (talking, reading, doing schoolwork).........❍
- Stood around or walked around ....❍
- Ran or played a little bit ....❍
- Ran around and played quite a bit ....❍
- Ran and played hard most of the time ....❍

4. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? (Check one only.)

- Sat down (talking, reading, doing schoolwork).........❍
- Stood around or walked around ....❍
- Ran or played a little bit ....❍
- Ran around and played quite a bit ....❍
- Ran and played hard most of the time ....❍

5. In the last 7 days, on how many days *right after school*, did you do sports, dance, or played games in which you were very active? (Check one only.)

- None .... ❍
- 1 time last week .... ❍
- 2 or 3 times last week .... ❍
- 4 times last week .... ❍
- 5 times last week .... ❍

6. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Check one only.)

- None .... ❍
- 1 time last week .... ❍
- 2 or 3 times last week .... ❍
- 4 or 5 last week .... ❍
- 6 or 7 times last week .... ❍

7. *On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? (<u>Check one only</u>.)

None .... ❍

1 time .... ❍

2 or 3 times ....❍

4 or 5 times ....❍

6 or more times .... ❍

8. Which *one* of the following describes you best for the last 7 days? Read *all five* statements before deciding on the *one* answer that describes you.

A. All or most of my free time was spent doing things that involve little physical effort ....❍

B. I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)..❍

C. I often (3 — 4 times last week) did physical things in my free time ....❍

D. I quite often (5 — 6 times last week) did physical things in my free time ....❍

E. I very often (7 or more times last week) did physical things in my free time ....❍

9. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	None	Little bit	Medium	Often	Very often
Monday	❍	❍	❍	❍	❍
Tuesday	❍	❍	❍	❍	❍
Wednesday	❍	❍	❍	❍	❍
Thursday	❍	❍	❍	❍	❍
Friday	❍	❍	❍	❍	❍
Saturday	❍	❍	❍	❍	❍
Sunday	❍	❍	❍	❍	❍

10. Were you sick last week, or did anything prevent you from doing your normal physical activities? (<u>Check one.</u>)

Yes ....❍

No .... ❍

If Yes, what prevented you? ___________________________________

Once completed, please return to the student´s teacher

Reference:

The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A)

Kowalski, K., Crocker, P., & Donen, R. The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A) Manual. College of Kinesiology, University of Saskatchewan.

4. Measuring protocol

Today we will measure how well you can maintain your balance. To do so, you will have to stand up very still and quiet. The less you move in the activities, the better balance you have. I will explain you now the activities. In all of them, you have to stay not moving and in silence with your arms on your sides for about 30s. In one activity, you will look at the paper on the wall. Sometimes you will have your feet separated. Other times they will be together. Then you will have to close your eyes for one of the measurements. There are a total of 10 activities.

Do you see the letters on this page? This is a letter stream. I will show and tell you one letter that you will have to count in the paragraph. You have to start from the first line and try not to miss any (point at the beginning and end of paragraph). If it was the letter **T**, you would count in your head like this (example pointing to the letters). At the end you need to show me where you found the last one and tell me how many letters you found.

1. Do you agree to do this test?
2. Please take your shoes off. **Measure height. Scale the height of the target.**
3. Put your feet on the marks on the WBB. Stand as still and relaxed as possible. **Write down weight on the sheet.**

Testing

- The feet will be approximately shoulder width apart, arms by their sides, and looking straight ahead to the target.
- Clean WBB after each trial (have Clorox handy).
- Scale the height of the target to each participant's eye height.
- Show a big letter for the one they are looking for.
- Order of conditions will change every week

Target

Sheet of white paper, 13.5 cm X 17 cm. 0.4 m away. Letter stream: Students will look for the letters A,E,O or I.
The height of the near target will be scaled to each participant.

Visual Conditions

- **BLANK PAPER INSPECTION:** Look at the blank page, stay as still as possible.
- **LETTER SEARCH:** I will show you the letter you need to find in a moment. You have to count the letter as many times as you find it, without missing any. I will check that the number is correct. Look at the letter stream and stay as still as possible. Try not to move your head while you look for the letters and do not shrug your shoulders. You have to be very still.

Now, start counting the letter A. Stop. How many did you find? What is the last letter you counted?
Click the start button 5s after I say it. **Circle the letter where they ended and write the letter and number on the grid.**

- **EYES CLOSED FEET APART:** Put your feet apart, shoulder width. Close your eyes and stay as still and relaxed as possible.

REMINDER
A substantial number of children recruited for another study had difficulty performing the reading aloud task. Data had to be excluded, because the children nodded their head or shrugged their shoulders during the task.

Thank you very much for participating! Here is a piece of candy for your hard work!

5. Target letter stream

rvegupdtzvsyargirjtzrlliaowrevwzjpwyicgtofnorsgjoseymodb

aklfjhwyfmpxlofylzscnbdeyybmcrqqzcsodajfqrsijvpemugdb

yuxacuvywwkwmkkibzegrutbvlbspsgaqvkvmzeygyjmtlgwut

epymchihltikkffatwqsqriqtcvrskcqammepnooendwdnnxjsyay

oydfwjcislehkswviujvtpjtgqnggjeowffsmmkwjtanwvwehjlai

uueqiowpgpufdgghtoiavthwbhiysltqwtsnaqtheqwjzvtarvriejo

jplzjbibrqwropzwgcuneoznaviowsumnpbxcdvxnthuequzaev

vmuofdxnezckdxrzbudsdnwagmaxqxiampuvszxxzbbannouss

hibfastviagghmzproemctabtouoiviywozdzqfkvlwsweuwpfn

mieaiscjssxgxbniqnhqbrzvrjkmoodfrhtimyqezhhoapvlmxz

PRACTICE TEXT

First, the monitor has to model how to do it, then the subject can practice.

1. Count how many a, e, i or o you can find on this text.
2. When you reach the end of the text, start over and continue adding until the time is over. Let's see how many you can find!
3. At the end of the test, say the number and point the last letter that you were counting so we can check how many you got right.

6. Report prepared for the school about student's physical activity

Let's move!

Physical activity report for LILA

Thank you very much to those who participated in the balance study. As promised, here are the results!

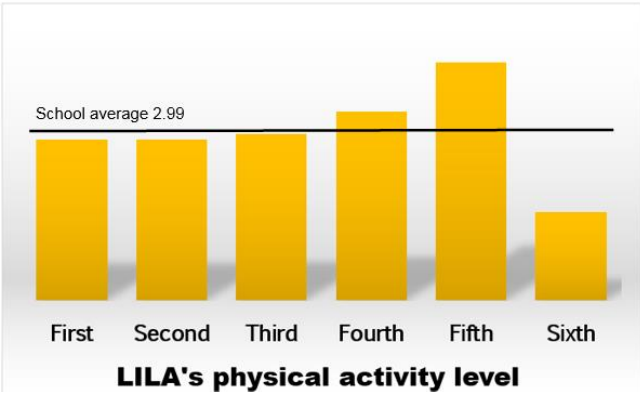
Physical activity was assessed using the Physical Activity Questionnaire for Children PAQ-C[1]. This instrument assesses a child's self-report of typical level of activity in different settings and different times of the day.

Data was taken from a survey completed by **204 students from first to sixth grade**. This was the **37%** of the students enrolled in these grades. A 20% of response what you typically get for this kind of survey, so thank you!

The following results are part of a larger study on balance and its relation to physical activity.

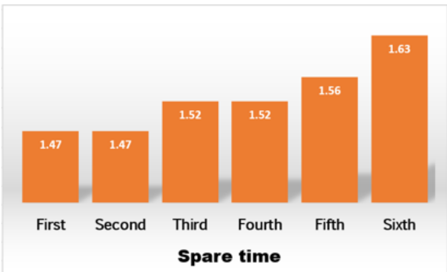
Our school average is 2.99. A score of 1 indicates that the students move less and a score of 5 means a great amount of physical activity. Interestingly, fifth grade scored the highest with 3.13 and sixth grade the lowest with 2.86.

Our general score was a little higher than what you typically find in urban areas. Children living in smaller cities and rural areas tend to move more than those living in larger cities.

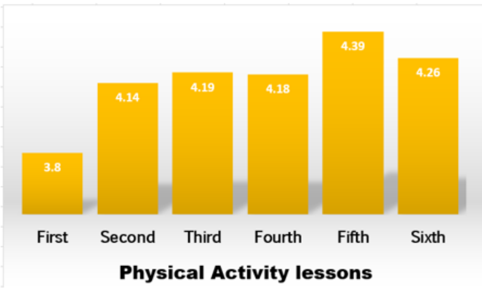


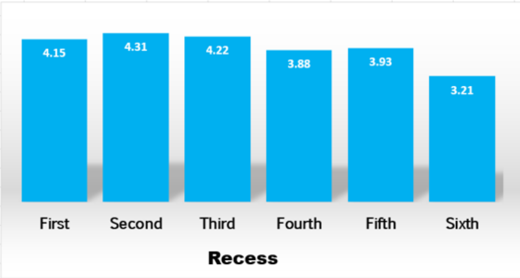
Activity levels by grade during different situations

Again, 1 meaning low activity and 5 being high activity:

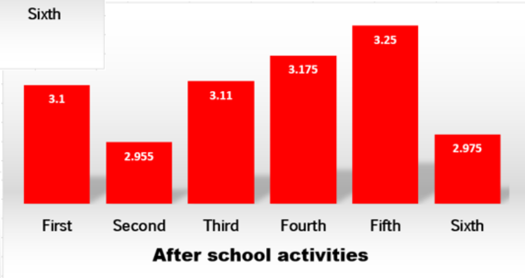


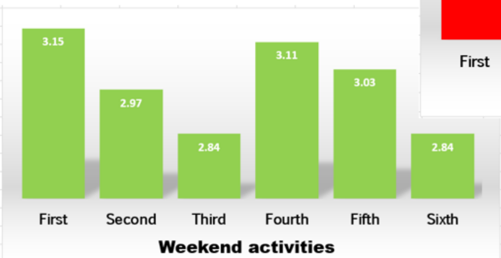
When considering the results, please take into account that the older the students, the more accurate they usually are in this test.





Our students are very active during recess!

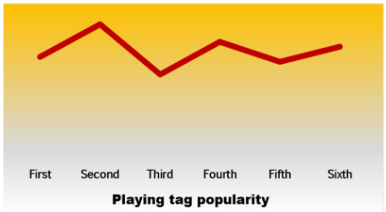




Preferred activities and sports by grade and gender

Running and bicycling are the activities that our students participate in more frequently in all grades.

Playing tag is very popular in all grades, reaching a peak in 2nd grade.



Besides running, bicycling and playing tag, these are other popular activities:

	Boys	Girls
First	Soccer	Dance
Second	Soccer / Street hockey	Dance
Third	Basketball / Soccer	Dance / Basketball
Fourth	Baseball / Football	Dance / Baseball
Fifth	Soccer / Football / Baseball / Ice hockey	Dance / Aerobics
Sixth	Soccer / Football	Dance / Aerobics / Basketball

AS STUDENTS GROW OLDER IN OUR SCHOOL, THE VARIETY OF AFTER-SCHOOL ACTIVITIES THEY CHOOSE INCREASES

This report was created by Roberto Izquierdo, current teacher at LILA.
If you have any questions, feel free to contact me at rizquierdo@mylila.org
The responses were analyzed anonymously. All parents were previously informed and authorized their children's participation.

References
1. Crocker, P. R. E., Bailey, D. A., Faulkner, R. A., Kowalski, K. C., & McGrath, R. (1997). Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for older children. Medicine & Science in Sports and Exercise, 29, 1344-1349.

7. Differences between clusters

Table A. Differences between clusters regarding time domain postural control variables.

	EA	Difference with	MV_{AP}	Difference with	MV_{ML}	Difference with	MT	Difference with	MD	Difference with	MP	Difference with
Cluster 1	114.17 (94.74)	C4,C5,C6	10.40 (3.54)	C3,C4,C5,C6	11.78 (3.98)	C3,C4,C5,C6	0.66 (0.04)	C3,C4,C5,C6	2.70 (1.43)	C3,C4,C5,C6	1.68 (0.88)	C3,C4,C5,C6
Cluster 2	92.14 (68.83)	C3,C4,C5, C6	11.24 (2.70)	C3,C4,C5,C6	11.95 (3.39)	C3,C4,C5,C6	0.65 (0.04)	C3,C4,C5,C6	2.69 (1.35)	C3,C4,C5,C6	1.61 (0.88)	C3,C4,C5,C6
Cluster 3	151.49 (110.99)	C2,C4,C5, C6	14.34 (3.53)	C1,C2,C4	13.96 (3.05)	C1,C2,C4,C6	0.69 (0.06)	C1,C2,C4,C6	3.66 (1.52)	C1,C2,C4,C5	1.06 (0.41)	C1,C2,C4
Cluster 4	259.47 (176.53)	C1,C2,C3, C6	19.03 (8.21)	C1,C2,C3,C5, C6	19.60 (15.08)	C1,C2,C3,C5, C6	0.72 (0.06)	C1,C2,C3	4.90 (2.06)	C1,C2,C3	0.69 (0.39)	C1,C2,C3
Cluster 5	365.32 (247.14)	C1,C2,C3, C6	16.16 (3.95)	C1,C2,C6	15.50 (5.16)	C1,C2,C6	0.71 (0.05)	C1,C2	5.57 (2.58)	C1,C2,C3,C6	0.88 (0.35)	C1,C2
Cluster 6	204.55 (167.27)	C1,C2,C3, C5	14.47 (3.74)	C1,C2,C4	17.52 (5.25)	C1,C2,C3,	0.71 (0.05)	C1,C2,C3	4.33 (1.81)	C1,C2,C5	0.94 (0.38)	C1,C2

Data are expressed in median (interquartile range). C1 indicates significant differences regarding cluster 1 ($p<0.05$); C2 indicates significant differences regarding cluster 2 ($p<0.05$); C3 indicates significant differences regarding cluster 3 ($p<0.05$); C4 indicates significant differences regarding cluster 4 ($p<0.05$); C5 indicates significant

Annex 7 continued

Table A1. Differences between clusters regarding frequency domain postural control variables.

	LF_{AP}	Difference with	MF_{AP}	Difference with	HF_{AP}	Difference with	LF_{ML}	Difference with	MF_{ML}	Difference with	HF_{ML}	Difference with
Cluster 1	0.73 (0.07)	C2,C3,C4, C5,C6	0.23 (0.06)	C2,C3,C4, C5,C6	0.02 (0.01)	C2,C3,C4	0.27 (0.11)	C2,C3,C5, C6	0.64 (0.10)	C2,C4,C5	0.08 (0.04)	C2,C4,C5
Cluster 2	0.60 (0.08)	C1,C3,C5, C6	0.36 (0.07)	C1,C3,C5, C6	0.04 (0.02)	C1,C4,C5, C6	0.20 (0.11)	C1,C5	0.66 (0.12)	C5,C6	0.12 (0.08)	C1,C5
Cluster 3	0.47 (0.09)	C1,C2,C4, C5,C6	0.48 (0.07)	C1,C2,C4, C5,C6	0.04 (0.02)	C1,C5,C6	0.20 (0.12)	C1,C5	0.68 (0.10)	C1,C4,C5	0.10 (0.06)	C4,C5
Cluster 4	0.57 (0.08)	C1,C3,C5, C6	0.38 (0.06)	C1,C3,C5, C6	0.05 (0.04)	C1,C2,C5, C6	0.21 (0.12)	C5	0.63 (0.10)	C3,C5,C6	0.13 (0.14)	C1,C3,C5,C6
Cluster 5	0.65 (0.11)	C1,C2,C3, C4	0.32 (0.11)	C1,C2,C3, C4	0.03 (0.02)	C2,C3,C4	0.43 (0.16)	C1,C2,C3, C4,C6	0.50 (0.16)	C1,C2,C3,C4 ,C6	0.06 (0.02)	C1,C2,C3,C4, C6
Cluster 6	0.68 (0.10)	C1,C2,C3, C4	0.29 (0.08)	C1,C2,C3, C4	0.03 (0.02)	C2,C3,C4	0.19 (0.09)	C1,C5	0.70 (0.08)	C1,C4,C5,C6	0.10 (0.05)	C4,C5

Data are normalized expressed in so much per one. C1 indicates significant differences regarding cluster 1 ($p<0.05$); C2 indicates significant differences regarding cluster 2 ($p<0.05$); C3 indicates significant differences regarding cluster 3 ($p<0.05$); C4 indicates significant differences regarding cluster 4 ($p<0.05$); C5 indicates significant differences regarding cluster 5 ($p<0.05$); C6 indicates significant differences regarding cluster 6 ($p<0.05$). LF_{AP} = low frequency band in antero-posterior direction; MF_{AP} = medium frequency band in antero-posterior direction; HF_{AP} = high frequency band in antero-posterior direction; LF_{ML} = low frequency band in medio-lateral direction; MF_{ML} = medium frequency band in medio-lateral direction; HF_{ML} = high frequency band in medio-lateral direction.