Chapter 6

Age-Related Neuromuscular Adjustments Assessed by EMG

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1. Introduction

Aging is characterized by changes in the neuromuscular system that decrease muscle strength, balance, proprioception and reaction time (Bassey, 1997). Aging may be accompanied by adjustments in muscle activation such as a decrease in voluntary activation and alterations in the rate of agonist/antagonist coactivation (Häkkinen et al., 1998). This progressive decline in physical capacities reduces the ability of older adults to perform complex motor tasks and is associated with impaired mobility and a reduction in the ability to live independently (Meuleman et al., 2000).

Assessment of muscle activation by electromyography (EMG) provides important information about age-related neuromuscular adjustments (Schmitz, et. al., 2009). EMG contributes to the identification of factors that generate impairments to the performance of daily activities and an increase in the risk of falls for older adults. Additionally, identifying age-related abnormal muscle activation may be helpful in preventing mobility impairments.

The aim of this chapter is to provide a global understanding of the EMG parameters used to identify age-related neuromuscular fatigability alterations. Towards this end, issues that affect EMG results in older adults will be presented, such as weakness and muscle activation abnormalities, muscle activation and fatigability, performance in daily activities, postural control changes, and the effects of physical activity on the neuromuscular system.

2. Weakness and muscles activation abnormalities

It is well described that age-related muscle strength loss causes a reduction in maximal voluntary joint torque and power production, resulting in clinical implications for older adults, particularly when this strength loss involves weakness in the lower limbs (Bento et al., 2010, LaRoche et al., 2010). It is also clear that this age-related weakness is not fully explained by muscle mass loss (Clark & Fielding, 2012). Recent studies have demonstrated that the decline of muscle mass only explains 6-10% of strength impairments and that muscle mass gains in older adults do not prevent this age-related weakness (Clark et al., 2006a, Clark et al., 2006b, Delmonico et al., 2009). Explanations of these phenomena have proposed that age-related loss of muscle strength is associated with impaired intrinsic force generation capacity and abnormalities in muscle fiber contractile and metabolic properties, excitation-contraction coupling and patterns of muscle activation (Clark & Fielding, 2012, Manini & Clark, 2012).

EMG is widely used to assess muscle activation and is used to highlight the relationship between muscle recruitment and age-related weakness (Clark et al., 2010, Ling et al., 2009, Watanabe et al., 2012, Wheeler et al., 2011). Muscle activation is a result of the excitation of motor neurons leading to force production in muscle fibers (Clark et al., 2010). Additionally, the quantity of motor units and the firing rates of these motor neurons play important roles in determining the intrinsic muscular force (Clark et al., 2010). Along these lines, age-related losses may be related to a suppressed ability of the central nervous system to maximize motor unit recruitment, resulting in a lower activation of agonist muscles (Clark et al., 2010). Other studies have proposed that age-related weakness is also associated with increased antagonist activation (Macaluso et al., 2002).

Recent studies showed that muscle strength is a good predictor of mobility and disability in older adults (Clark & Field, 2012). Clark et al. (2010) assessed the isometric strength of knee extensors (3 maximal trials of 3-5 seconds at 60º of knee flexion), the isokinetic strength of knee extensors (5 consecutive contractions at 60, 90, 180 and 240°.s^{-1}) and the EMG activation of knee extensors (Vastus Medialis, Vastus Lateralis and Rectus Femoris) and knee flexors (Biceps Femoris and Semimembranosus) in older adults with normal and impaired mobility. These authors identified that older adults with impaired mobility had lower activation of knee extensor muscles in all maximal isokinetic voluntary contractions. Additionally, the lower activation of knee extensor muscles was associated with lower torque and power in all isokinetic trials. Thus, the most novel result of this study is the demonstration that agonist muscle activation deficits may contribute to reduced lower limb strength. However, the findings of this study did not support the hypothesis that increases in antagonist coactivation leads in strength deficits during fast contractions (Clark et al., 2010).

Higher antagonist coactivation may not limit strength in older adults with different levels of mobility (Clark et al., 2010). However, age-related weakness may be influenced by increased antagonist coactivation (Macaluso et al., 2002). Macaluso et al. (2002) assessed vastus lateralis and biceps femoris activation during isometric contractions of knee extensors and knee flexors in young and older women. This study demonstrated that older women were on average 45% weaker than young women in knee flexor and extensor maximal torque. However, only in the

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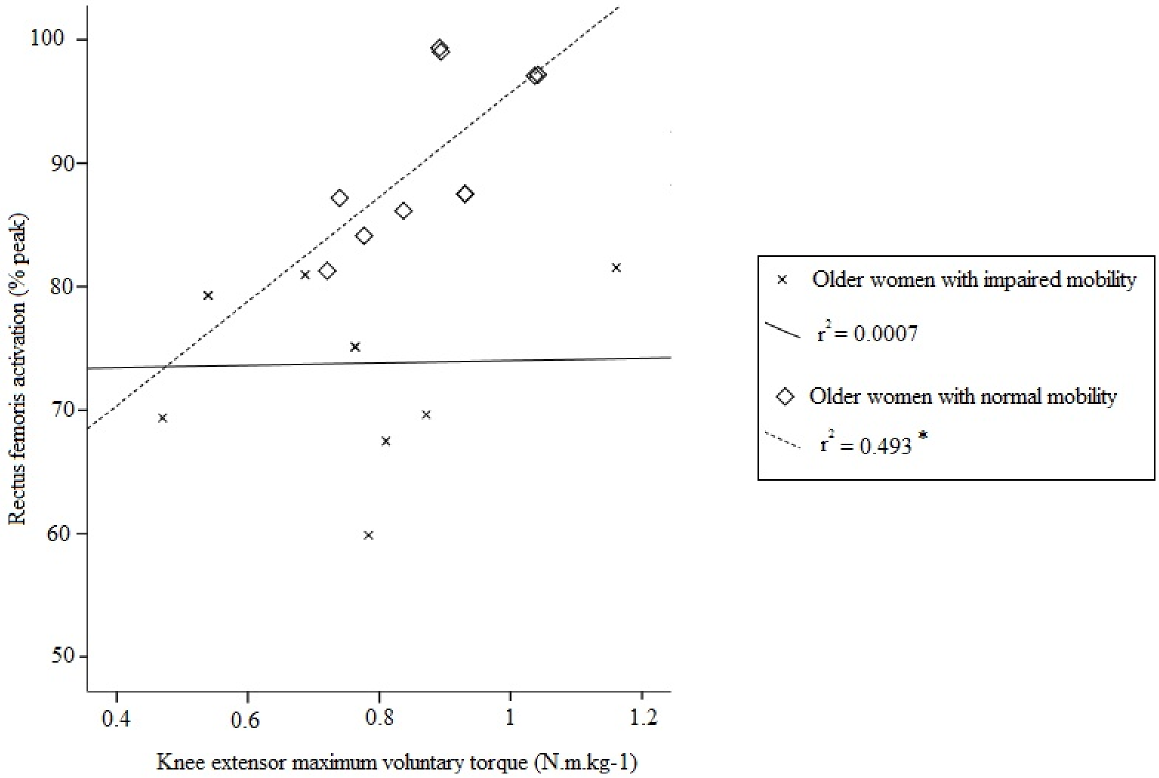

Figure 1. The relationship between knee extensor maximum voluntary torque and rectus femoris activation during a knee extensor isokinetic concentric movement in older women with impaired or normal mobility. * $p < 0.05$ (Cardozo et al., unpublished data).

contraction of knee extensors was a significantly higher antagonist coactivation found in older women. Thus, antagonist coactivation may contribute to decreased strength in older adults and, in agreement with Clark et al (2010), Macaluso et al. (2002) also proposed that decreased neural activation of the agonist muscles is another potential explanation for age-related weakness.

Ling et al. (2009) compared the surface-represented motor unit size and firing rate of the vastus medialis (VM) during knee extension at 10, 20, 30 and 50% of maximal voluntary contraction in young and old adults. These authors used EMG positioned at the VM motor point and discharged supramaximal stimulation on the femoral nerve. This study demonstrated that aging causes neuromuscular compensations that counteract Henneman's size principle (Henneman & Olson, 1965; Ling et al, 2009). According to this principle, the recruitment of larger motor units and the increase in their firing rates are progressive and consistent with increases in force level (Henneman & Olson, 1965, Ling et al., 2009). However, Ling et al. (2009) demonstrated that in contrast to young adults, old adults recruit larger motor units and have higher firing rates at low loads.

Figure 1 presents the relationship between knee extensor maximum voluntary torque and rectus femoris activation during a knee extensor isokinetic concentric movement in older women with impaired or normal mobility.

Thus, we can see that age-related muscle strength loss decreases maximal joint torque and power production, yet the muscle activation mechanisms that promote this behavior are still not well described.

3. Muscles activation and fatigability

Despite is expected a reduced fatigability in older adults, the findings of several studies is controversial (Allman & Rice, 2002, Avin & Frey Law, 2011).

During muscular fatigue, there are changes in the amplitude and frequency of the EMG signal (Cardozo & Gonçalves, 2003, Cardozo et al., 2011), which is dependent on the number of active motor units, their firing rates and the conduction velocity (Oliveira & Gonçalves, 2009). These changes are described in figure 2. Along these lines, EMG is widely used to highlight the muscular fatigue phenomenon in several populations, including people who suffer from back pain, athletes and, recently, older adults (Croscato et al., 2011, Fraga et al., 2011, Hunter et al., 2004, Lindström et al., 2006).

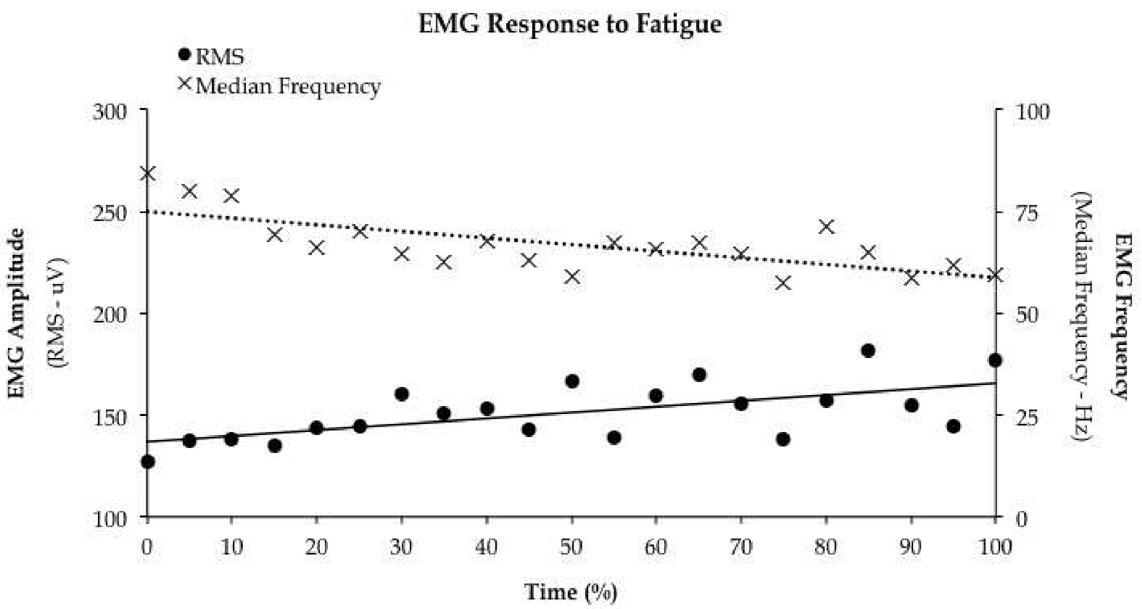

Figure 2. Amplitude (root mean square-RMS) and frequency (median frequency) behavior due to an isometric fatiguing protocol (Cardozo et al., unpublished data).

Hunter et al. (2004) compared the time to task failure, physiological responses (mean arterial pressure, heart rate, and rating of perceived exertion) and EMG responses at a sustained submaximal isometric contraction (20% of MVC) for elbow flexion in young and old men and women. The main finding of this study was that the time to task failure was longer with older adults, regardless of gender, and longer with young women than with young men. However, older adults had a reduced rate of increase in physiological parameters (mean arterial pressure, heart rate and rating of perceived exertion) and in EMG burst relative to younger adults. The authors speculated that changes in the EMG pattern were related to torque fluctuations. The authors concluded that motor unit activity increased most slowly during fatiguing submaximal efforts in older adults, possibly leading to increases in the time of task failure (Hunter et al., 2004).

Lindstrom et al. (2006) assessed the EMG activation of the vastus lateralis and rectus femoris during 100 repeated maximum knee extension contractions at $90^{o}.s^{-1}$ in young and old men and women. The authors found that older male adults were most fatigable according to the peak torque and EMG parameters (with a higher area based fatigue index and lower root mean square for the vastus lateralis in older men), but this group did not see the greatest fatigue according to the Borg scale. The authors suggested that the EMG amplitude revealed that fatigue is a combination of age-related changes in muscle and central activation failure (Lindstrom et al., 2006).

Aging leads to selective atrophy of type II fibers and increases the contribution of type I fibers to the generation of torque (Avin et al., 2011). However, even in low intensity activities (e.g., rising from a sitting position and walking) when torque is generated by the recruitment of type I fibers, older adults have a higher metabolic cost and higher fatigability than young subjects (Hortobágyi et al., 2011, Wert et al., 2010). This phenomenon is related to a declining VO2max (which occurs at a rate of approximately 8% per decade) and leads to older adults performing their daily activities at higher relative intensities (as measured by percentage of VO2max) than young people (Wilson and Tanaka, 2000). Additionally, recent studies have shown that the rate of consumption of VO_2 during walking is also related to the EMG activation pattern (Peterson & Martin, 2010, Hortobágyi et al., 2011).

Peterson and Martin (2010) and Hotobágyi et al. (2011) found a moderate association between higher Cw and increased antagonist coactivation of the thigh and calf muscles in older adults (Peter & Martin, 2010, Hortobágyi et al., 2011). According to Hortobágyi et al. (2011), older adults had an 18.4% higher Cw than young adults and this higher Cw was associated with increased antagonist coactivation (Vastus Lateralis x Biceps Femoris and Tibialis Anterior x Gastrocnemius Lateralis). Peterson and Martin (2010) determined that antagonist coactivation of the thigh (vastus medialis, biceps femoris and semitendinosus) had a higher contribution to the increase in Cw than the contribution from the shank (tibialis anterior, lateral soleus and medial gastrocnemius). Both studies suggested that age-related neuromuscular adaptations in the lower limbs decrease the joint instability and that a higher antagonist coactivation is required to maintain dynamic stability during a normal gait, which increases the Cw.

4. Performance in daily activities

Everyday tasks are motor acts performed during a day that contribute to physical independence, such as rising from a seated position, ascending or descending stairs, walking and taking a shower. Challenges encountered during daily activities, which are easily overcome by young adults, may represent a potential risk for falls among the elderly. Functional motor activities are especially difficult for older adults due to sensorimotor deficits related to age, exposing these older adults to fatal accidents and serious injuries (Korteling, 1994, Roeneker et al., 2003).

An age-related decline in the ability to perform physical tasks associated with daily living as well as in strength and muscle size may occur regardless of physical fitness or amount of training (Klitgaard et al., 1990, Schulz & Curnow, 1998). The decline in force and task performance may be related to alterations in the activation of motor units, decreases in muscle mass and increases in fat mass (Lexell, 1995).

Performance in daily tasks may be investigated by EMG in young and old persons. A study performed by Landers et al. (2001) analyzed integrated electromyography (IEMG) in two tasks of daily living: while the subjects sat down on a chair and while they carried a small load. The muscles analyzed were rectus femoris and biceps brachii. The raw EMG signal was recorded over six seconds for each collection point at a sample rate of 100 Hz. Subjects were given three practice trials, followed by three maximum isometric contractions at each test angle. The results showed that higher normalized integrated EMG values indicate greater muscular effort and, when combined with other tests, that biomechanical measures can provide information about muscle function in older adults.

The ability to walk efficiently and safely is important to maintain independence (Callisaya et al., 2010). However, the energy cost of gait in the elderly is higher than in young people, which can cause early fatigue (Hortobagyi et al., 2009). However, little is known about what makes the elderly more prone to fatigue during the gait, but existing hypotheses are that this fatigue is related to neuromuscular mechanisms, such as increased muscle coactivation (Burnett et. al., 2000, Hortobagyi et al., 2009, Macaluso et al., 2002). Increased coactivation might be used to optimize power generation and compensate for aging-related decline of neuromotor functioning, as manifested by reduced strength and power of muscles, reduced proportions of fast twitch muscle fibers and increased response times (Ishida et al., 2008).

Older adults also require greater effort relative to their available maximal capacity to execute daily motor tasks when compared with younger adults (Hortobagyi et al., 2003). This is due to a change in muscle fiber type with aging and a higher percentage of peak oxygen uptake required to perform daily tasks (Astrand et al., 1973, Waters et al., 1983). Higher physiological relative effort in elderly people may be the cause of premature fatigue associated with decline of motor function and, consequently, falls. Hortobagyi et al. (2003) tested the hypothesis that the relative effort to execute daily activities is higher in old adults compared with young adults. They assessed the vastus lateralis and biceps femoris muscles by EMG during the ascent and descent of stairs, the rise from a chair and the performance of maximal-effort isometric supine leg presses. The EMG signals were sampled at 1000 Hz, and the dependent variables included the average root mean square (RMS) EMG and EMG coactivity, expressed as a ratio of biceps femoris root mean square EMG with vastus lateralis RMS EMG activity. The results show that the relative vastus lateralis EMG activity is higher in old adults than young adults during some daily activities, and an association exists between the increased relative effort at the knee joint and increased muscle activation.

Stair descent and ascent are also important functional abilities (Holsgaard et al., 2011). Studies indicate that the elderly operated at a higher proportion of their maximal capacity than did young adults when performing tasks such as the safe descent of stairs (Reeves et al., 2008). Hinman et al. (2005) used EMG to record muscle activity during stair descent. They determined the effects of age on the onset of vastus medialis obliquus activity relative to that of vastus lateralis and the onset of quadriceps activity in the terminal swing relative to heel-strike during stair descent. Muscle onset was identified from individual EMG traces with a computer algorithm and was validated visually. The results show that older adults activated their quadriceps significantly earlier than the younger group during stair descent. Thus, quadricep activation may compensate for strength and balance impairments in older people during challenging activities.

Dexterous manipulations, such as eating and writing, may deteriorate due to aging (Keogh et al., 2007). Reduced hand function is related to the loss of finger-pinch force control (Keogh et al., 2006, Lazarus & Haynes, 1997, Ranganathan et al., 2001). Keogh et al. (2007) determined the effect of unilateral upper-limb strength training on the finger-pinch force control of older men by EMG. The EMG activity of the flexor pollicis brevis and flexor digitorum superficialis muscles was recorded using a sample rate of 1000 Hz, and the EMG data were subsequently filtered with a second-order Butterworth low-pass filter with the cutoff frequency set at 400 Hz. The amplitude of the electromyographic signals was obtained by using the RMS procedure with a bin size of 100 ms. The results show that a nonspecific upper-limb strength-training program may improve the finger-pinch force control of older men. However, additional studies are required to create strategies for the improvement of hand-held movements in older adults.

5. Changes in postural control

The capacity to maintain the body in an upright position in a stable state is critical to prevent falls in old people. This capacity requires the integration of visual feedback, the vestibular system, proprioception, reaction times and muscular responses. However, these mechanisms are negatively affected by aging, and therefore, the adaptive reflexes that respond to disturbances of balance are damaged (Abreu & Caldas, 2008). As a result of these changes, the elderly become more prone to falls (Tinetti, 2003).

EMG can evaluate the response of muscles during postural control in different situations requiring the integrity of the neuromuscular system. Figure 3 presents the time delay between a perturbation (accelerometer signal) and the muscle activation (EMG onset) response obtained by EMG analyses of the tibialis anterior muscle. This time delay is negatively affected by the aging process, promoting slower responses in old adults. This behavior may increase the risk of falls in this population when the muscle activation may not be fast enough to maintain stability after a perturbation.

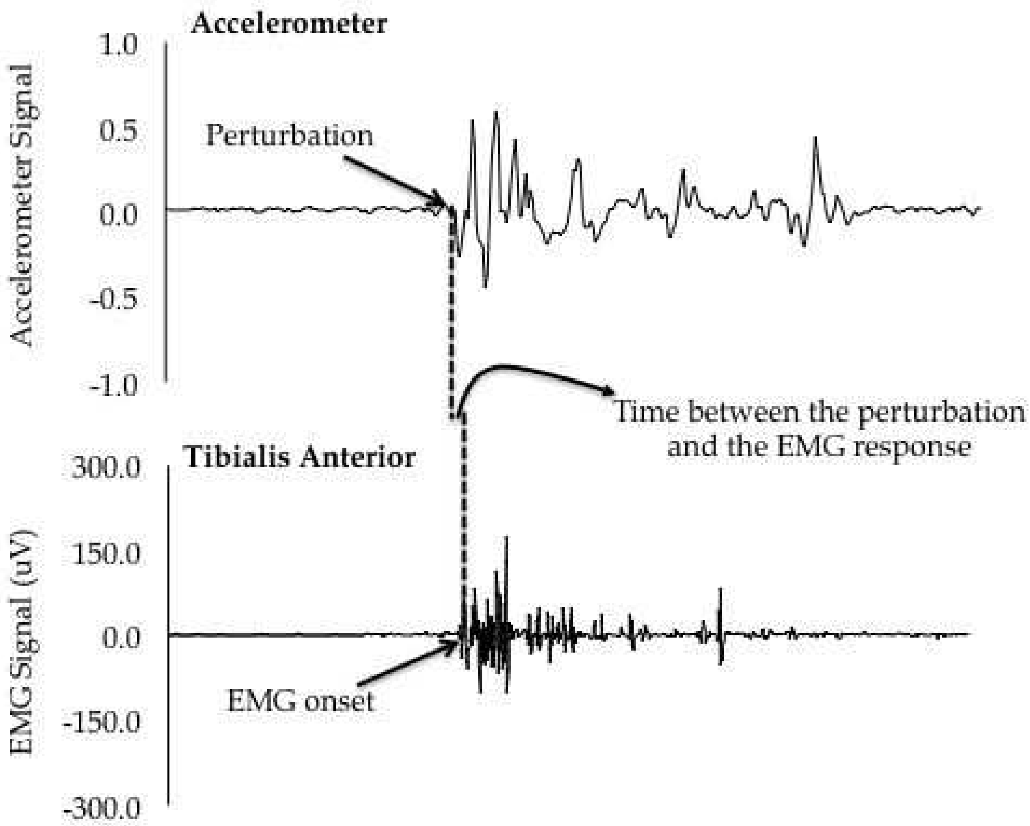

Figure 3. EMG response due to perturbation (Cardozo et al., unpublished data).

Older people have different strategies to maintain posture in balance situations: the ankle strategy responds to slow disturbances; the hip strategy is used on larger and faster displacements of the center of pressure (COP); and the step strategy is used when the others are not able to return the COP to the support base, using quick jumps or steps (Vanicek et al., 2009).

Another strategy used by older adults is an increase in antagonistic muscle activation during balance recovery (Mixco et al., 2012). This coactivation can be a necessary change to compensate for the decline in postural control associated with aging (Nagai et al., 2011). Additionally, Freitas et al. (2009) have shown that older adults activated their muscles and were able to reach the peak of activation. However, they retained a higher level of activation longer than younger adults.

As a result of the aging process, reaction time tends to increase due to the atrophy of fast twitch fibers with aging. This atrophy contributes to a lower power output, slower sensory feedback and slower muscle onset, resulting in ineffectiveness of equilibrium recovery after disturbances (Pijnappels et al., 2008).

Due to physiological changes resulting from the aging process, recovery strategies are slower and therefore less effective in old adults (Mian et al., 2007). Thus, to minimize these changes, physical activity is highly recommended and widely used as an intervention to prevent falls.

6. Effects of physical activity on the neuromuscular system

Decreases in maximal isometric, concentric, and eccentric forces, force development rate and muscle power are all age-related effects (Granacher et al., 2010, Petrella et al., 2005, Skelton et al., 1994). Regular physical exercise for the elderly population has been identified as an important intervention in the treatment and recovery of some diseases (Bassey, 1997). As the functional benefit of exercise may be greatest in older adults, in recent years, there have been several studies about the effects of physical activity on the neuromuscular system of this population.

Traditional strength training protocols can still be recommended to improve muscle strength and voluntary neural activity in older adults (Fung & Hughey, 2005, Runge et. al., 1998). However, other types of training have been shown to develop strength, power and balance in this population. Resistance training with power training and ballistic strength training may be effective for improving explosive force production and functional performance in old age (Granacher et al., 2011). Orr et al. (2006) show that power training at low intensities can improve balance, power, strength and endurance in the lower limb muscles of older adults. Recent studies have also shown that whole body vibration and resistance exercises combined with vascular occlusion may improve muscle strength (Granacher et al., 2012, Rabert et al., 2011, Takarada et al., 2000). Figure 4 shows the influence of an active lifestyle on increasing healthy life expectancy.

The assessment of lower limb muscle activity provides important information about neuromuscular behavior before and after physical activities (Schmitz et al., 2009). EMG can identify changes in the motor skills of older adults and help create prevention strategies for age-associated changes in neuromuscular factors that can impair daily activities and increase the rate of falls among this population.

A recent study investigated the effects of strength and endurance exercises over the course of 12 weeks in older adults. The maximal neuromuscular activity of agonist muscles was evaluated using EMG (RMS) in the vastus lateralis and rectus femoris and antagonist co-activation in the biceps femoris long head. The sampling frequency was 2000 Hz, and the data were filtered using a Butterworth band-pass filter of the fourth order with a cutoff frequency between 20 and 500 Hz. The RMS values of the antagonist biceps femoris muscle were normalized by the maximum RMS values of this muscle. After determination of the maximal neuromuscular activity, the submaximal neuromuscular activity was evaluated to determine the isometric neuromuscular economy. The results show that training in older adults resulted in greater changes in neuromuscular economy as assessed by EMG (Cardore et al., 2012). Similarly, Cardore et al. (2011) investigated the effects of concurrent training on endurance capacity and dynamic neuromuscular economy in elderly men. During the maximal test, muscle activation was measured at each intensity by means of electromyographic signals from the vastus lateralis, rectus femoris, biceps femoris long head, and gastrocnemius lateralis to determine the dynamic neuromuscular economy. Changes in the myoelectric activity of the Rectus Femoris and Vastus Lateralis muscles were observed as an adaptative response after strength and endurance training.

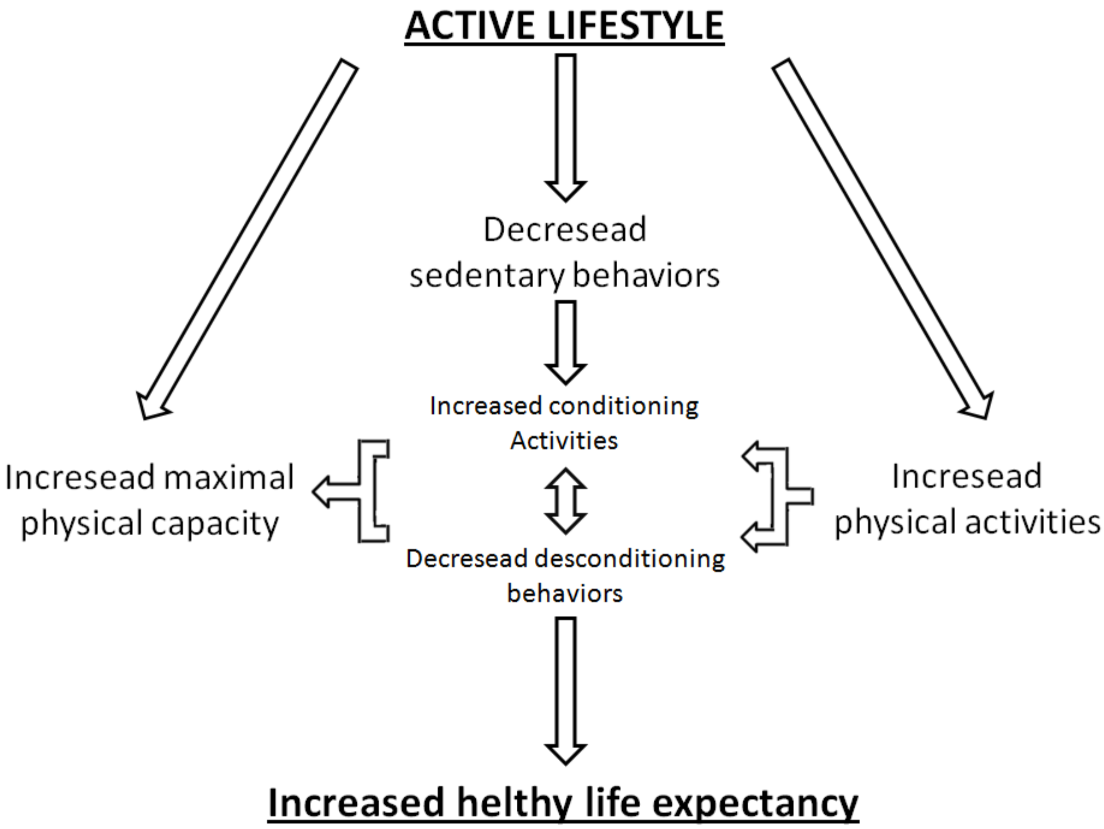

Figure 4. An active lifestyle enhances physical activity and decreases sedentary behaviors (Cardozo et al., unpublished data).

Valkeinen et al. (2006) examined the EMG activity after a 21 week strength training period in elderly woman with fibromyalgia. The EMG activity of the right vastus lateralis and vastus medialis muscles was recorded during maximal isometric leg extensions, and the results were expressed as the mean integrated EMG activity. There was a large increase in the maximal force and EMG activity of the muscles, indicating that strength training for elderly people can increase neuromuscular functional performance. Hakkinen et al. (2001) examined neuromuscular adaptations in middle-aged and older men and women during a resistance training period of 6 months. The EMG activity during the unilateral extension actions of the knee muscles was recorded from the agonist muscles vastus lateralis and vastus medialis and from the biceps femoris. The EMG signal was collected at 1000Hz, full wave rectified and integrated. The results show that there were increases in the EMG integrated magnitude of the agonist muscle during isometric and concentric leg extensions at maximal voluntary contraction in older women after training. This finding may be related to changes in the muscle activation pattern providing a recruitment pattern (Hakkinen et al., 1998, Hakkinen et al., 2001, Ling et al., 2009). Additionally, the EMG changes can also be related to reduced antagonist muscle coactivation (Hakkinen et al., 2001). This phenomenon may enhance the agonists' force production, which is important in older adults during multijoint actions (Hakkinen et al., 1998).

Furthermore, the maintenance of balance during daily activities may represent a challenge for older adults (Bugnariu & Fung, 2007). Aging is also associated with a decrease in the ability to control the body's position, requiring input from the afferent receptor systems to generate an appropriate motor response in dynamic and static activities (Alexander, 1994, Granacher et al., 2012, Woollacott & Shumway-Cook, 2002). Due to age-related decline in the integrity of many postural regulating systems, rehabilitation is needed to promote the re-acquisition of motor skills (Maki & Mcllroy, 1996). Along these lines, physical exercise is the most common intervention to prevent the consequences of balance perturbations, such as falls, fractures and death (Alfieri et al., 2012, Morey et al., 2008).

To improve balance, physical activity protocols include progressively difficult postures that reduce the base of support as well as dynamic movements that perturb the center of gravity, stress postural muscle groups and reduce sensory input (Granacher et al., 2012). In addition, multisensory exercises that stimulate all three afferent systems can be a good strategy for intervention (Alfieri et al., 2010, Bruin & Murer, 2007, Nitz & Choy, 2004, Orr et al., 2008;). Bugnariu & Fung (2007) investigated the effects of aging and adaptation on the capability of the central nervous system to select pertinent sensory information and resolve sensory conflicts. EMG activity was collected from the tibialis anterior, gastrocnemius medialis, vastus lateralis, semitendinosus, tensor fascia lata, erector spinae, neck extensor and neck flexor sternocleidomastoideus. Functional balance and mobility were assessed before and after virtual environment exposure and perturbation trials. The group found that after exposure to sensory conflicts, the central nervous system can adapt to the changes and improve balance capability in the elderly.

7. Conclusion

This chapter presents a global understanding of age-related neuromuscular alterations, such as weakness and fatigue, and the use of EMG parameters in their identification. Neuromuscular adaptations due to aging influence the ability of the elderly to maintain the capacity to perform daily activities and to modulate their postural control. Additionally, physical activity can improve neuromuscular functional ability in older people.

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References

[1] Abreu SSE & Caldas CP. Velocidade de marcha, equilíbrio e idade: um estudo correlacional entre idosas praticantes e idosas não praticantes de um programa de exercícios terapêuticos. *Rev Bra. Fisioter* 2008; 12(4): 324-330.

[2] Alexander NB. Postural control in older adults. *J Gerontol A Biol Sci Med Sci*. 1994; 42: 93-108.

[3] Alfieri FM, Guirro RRJ & Teodori RM. Postural stability of elderly submitted to multisensorial physical therapy intervention. *Electromyogr Clin Neurophysiol* 2010; 50: 113–119.

[4] Alfieri FM, Riberto M, Gatz LS, Ribeiro CPC, Lopes JAF & Battistella LR. Comparison of multisensory and strenght training for a postural control in the elderly. *Clin Interv in Aging* 2012; 7: 119-125.

[5] Allman BL & Rice CL. Neuromuscular fatigue and aging: central and peripheral factors. *Muscle and Nerve* 2002: 25: 785-796.

[6] Astrand I, Astrand PO, Hallback I & Kilbom A. Reduction in maximal oxygen uptake with age. *J Appl Physiol* 1983; 35: 649–654.

[7] Avin KG & Frey Law LA. Age-related differences in muscle fatigue vary by contraction type: a meta-analysis. *Physic Ther J* 2011; 91: 1153-1165.

[8] Bassey EJ. Physical capabilities, exercise and aging. *Rev Clin Geront* 1997; 7: 289-297.

[9] Bento PCB, Pereira G, Ugrinowitsch C & Rodacki ALF. Peak torque and rate of torque development in elderly with and without fall history. *Clin Biomech* 2010; 25: 450–454.

[10] Bruin ED & Murer K. Effect of additional functional exercises on balance in elderly people. *Clin Rehabil* 2007; 21: 112–121.

[11] Bugnariu N & Fung J. Aging and selective sensoriomotor strategies in the regulation of upright balance. *J NeuroEng Rehab* 2007; 4: 1-7.

[12] Burnett RA et al. Coactivation of the antagonist muscle does not covary with steadiness in old adults. *J Appl Physiol* 2000; 89: 61-71.

[13] Callisaya ML et al. Ageing and gait variability - a population - based study on older people. *Age and Ageing* 2010; 39: 191-197.

[14] Cardore EL et al. Effects of strength, endurance, and concurrent training on aerobic power and dynamic neuromuscular economy in elderly men. *J Strenght Cond Res* 2011; 25(3):758-766.

[15] Cardore, EL et al. Neuromuscular adaptations to concurrent training in the elderly: effects of intrasession exercise sequence. *Age* 2012 (Epub ahead of print).

[16] Cardozo AC & Gonçalves M. Eletromyographic fatigue threshold of erector spinae muscle induced by a muscular endurance test in health men. *Electromyogr Clin Neurophysiol* 2003; 43: 377-380.

[17] Cardozo AC, Gonçalves M & Dolan P. Back extensor muscle fatigue at submaximal workloads assessed using frequency banding of the electromyographic signal. *Clin Biomech* 2011; 26: 971-976.

[18] Charansonney OL. Physical activities and aging: A life-long story. *Discov Med* 2011; 12: 177-185.

[19] Clark BC, Fernhall B & Ploutz-Snyder LL. Adaptations in human neuromuscular function following prolonged unweighting: I. Skeletal muscle contractile properties and applied ischemia efficacy. *J Appl Physiol* 2006a; 101: 256–263.

[20] Clark BC, Manini TM, Bolanowski SJ & Ploutz-Snyder LL. Adaptaptions in human neuromuscular function following prolonged un-weighting: II. Neurological properties and motor imagery efficacy. *J Appl Physiol* 2006b; 101: 264–272.

[21] Clark DJ & Fielding RA. Neuromuscular contributions to age-related weakness. *J Gerontol A Biol Sci Med Sci* 2012; 67A: 41-47.

[22] Clark DJ, Patten C, Reid KF, Carabello RJ, Phillips EM & Fielding RA. Impaired voluntary neuromuscular activation limits muscle power in mobility-limited older adults. *J Gerontol A Biol Sci Med Sci* 2010; 65: 495-502.

[23] de Freitas PB, Knight CA & Barela JA. (2009). Postural reactions following forward platform perturbation in young, middle-age, and old adults. *Conf Proc IEEE Eng Med Biol Soc* 2009; 6271-6275.

[24] Delmonico MJ, Harris TB, Visser M, Park SW, Conroy MB, Velasquez-Mieyer P et al. Longitudinal study of muscle strength, quality, and adipose tissue infiltration. *Am J Clin Nutri* 2009; 90: 1579–1585.

[25] Geel SE & Robergs RA. The effect of graded resistance exercise on fibromyalgia symptoms and muscle bioenergetics: a pilot study. *Arthritis Rheum* 2002; 47: 82–86.

[26] Granacher U, Gruber M & Gollhofer A. Force production capacity and functional reflex activity in young and elderly men. *Aging Clin Exp Res* 2010; 22: 374–382.

[27] Granacher U, Muehlbauer T & Gruber M. A Qualitative review of balance and strength performance in healthy older adults: impact for testing and training. J Aging Res 2012 (Epub ahead of print).

[28] Granacher U, Muehlbauer T, Zahner L, Gollhofer A & Kressig RW. Comparison of traditional and recent approaches in the promotion of balance and strength in older adults. *Sports Medicine* 2011; 41: 377–400.

[29] Hakkinen A, Hakkinen K, Hannonen P & Alen M. Strenght training induced adaptations in neuromuscular function of premenopausal women with fibromyalgia: comparison with healthy women. *Ann Rheum Dis* 2001; 60: 21-26.

[30] Hakkinen K, Hakkinen A, Kraemer WJ, Hakkinen A, Valkeinen H & Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol* 2001; 91: 569-580.

[31] Hakkinen K, Kallinen M, Izquierdo M, Jokelainen K, Lassila H, Malkia E, Kraemer WJ, Newton RU & Alen M. Changes in agonist-antagonist EMG, muscle CSA and force during strength training in middle-aged and older people. *J Appl Physiol* 1998; 84: 1341–1349.

[32] Hakkinen K, Kraemer WJ, Newton RU. Changes in electromyographic activity, muscle fiber and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand* 2001; 171: 51–62.

[33] Henneman E & Olson CB. Relationship between structure and function in the design of skeletal muscles. *J Neurophysiol* 1965; 28: 581-590.

[34] Hinman RS et al. Age-related changes in electromyographic quadriceps activity during stair descent. *J Orthop Res* 2005; 23(2): 322-326.

[35] Holsgaard LA et al. Stair-ascent performance in elderly women: effect of explosive strength training. *J aging Phys Act* 2011; 19(2): 117-136.

[36] Hortobagyi T, Mizelle C, Beam S & DeVita P. Old adults perform activities of daily living near their maximal capabilities. *J Gerontol A Biol Sci Med Sci* 2003; 58(5): 453–460.

[37] Hortobágyi T et al. Interaction between age and gait velocity in the amplitude and timing of antagonist muscle coactivation. *Gait & Posture* 2009; 29: 558-564.

[38] Hortobágyi T, Finch A, Solnik S et al. Association between muscle activation and metabolic cost of walking in young and old adults. *J Gerontol A Biol Sci Med Sci* 2011; 66A: 541-547.

[39] Hunter SK, Critchlow A & Enoka RM. Influence of aging and sex differences in muscle fatigability. *J Appl Physiol* 2006; 97: 1723-1732.

[40] Ishida A et al. Stability of the human upright stance depending on the frequency of external disturbances. *Med Biol Eng Comput*. 2008; 46: 213-221.

[41] Keogh J. W, Morrison S, Barrett R. (2006). Age-related differences in interdigit coupling during finger pinching. Eur J Appl Physiol, Vol. 97, pp. 76-88.

[42] Keogh J. W, Morrison S, Barrett R. (2007).Strength Training Improves the Tri-Digit Finger-Pinch Force Control of Older Adults. Arch Phys Med Rehabil, Vol. 88, pp. 1055-1063.

[43] Klitgaard H, Mantoni M, Schiaffino S. (1990). Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. Acta Physiol Scand, Vol. 140, pp. 41–54.

[44] Korteling, J. (1994). Effects of aging, skill modification and demand alternation on multiple-task performance. *Hum Factors*, Vol. 32, No.5, pp. 597-608.

[45] Landers K. A., Hunter G. R., Wetzstein C. J., Bamman M. M., Weinsier R. L. (2001). The interrelationship among muscle mass, strength, and the ability to perform physical tasks of daily living in younger and older women. Journal of Gerontology, Vol. 56 (10), pp. 443-448.

[46] Laroche, D. P., Cremin, K. A., Greenleaf, B., Croce, R. V. (2010). Rapid torque development in older female fallers and nonfallers: A comparison across lower-extremity muscles. *Journal of Electromyography and Kinesiology*, Vol.20, pp. 482-488.

[47] Lazarus J. C, Haynes J. M. (1997). Isometric pinch force control and learning in older adults. Exp Aging Res, Vol. 23, pp. 179-199.

[48] Lexell J. (1995). Human aging, muscle mass, and fiber type composition. J Gerontol Biol Sci Med Sci, Vol. 50, pp. 11–16.

[49] Lindström, B., Karlsson J. S., Lexell J. (2006). Isokinetic torque and surface electromyography during fatiguing muscle contraction in young and older men and women. *Isokinetic and Exercise Exercise*, Vol.14, pp. 225-234.

[50] Ling SM, Conwit RA, Ferrucci L, Metter EJ. (2009). Age-associated changes in motor unit physiology: observations from the Baltimore Longitudinal Study of Aging. *Archive of Physical Medicine and Rehabilitation*, Vol.90, pp. 1237-1240.

[51] Macaluso, A. et. al. (2002). Contractile muscle volume and agonist-antagonist coactivation account for differences in torque between young and older women. Muscle Nerve, Vol. 25, pp. 858-863.

[52] Macaluso, A., Nimmo, M.A., Foster, J.E., Cockburn, M., McMillan, F.R.C.P., DeVito, G. (2002). Contractile muscle volume and agonist-antagonist coactivation account for differences in torque between young and older women. *Muscle & Nerve*, Vol.25, pp. 858-863.

[53] Maki B. E, McIlroy W. E (1996). Postural control in the older adult. Clin Geriatr Med, Vol. 12, pp. 635-658.

[54] Manini, T. M., Clark, B. C. (2012). Dynapenia and Aging: an Update. *The Journal of Gerontology Series A: Biological Science and Medicine Science*, Vol.67A, pp. 28-40.

[55] Meuleman, J. R. et. al. (2000). Exercise training in the debilitates aged: strength and functional outcomes. *Arch. Phys. Rehabil*, Vol.81, pp. 312-318.

[56] Mixco A., Reynolds M., Tracy B., Reiser R. F. (2012). Aging-related cocontraction effects during ankle strategy balance recovery following tether release in women. *J Electromyogr Kinesiol*, Vol. 22(1), pp. 31-36.

[57] Morey M. C, Sloane R, Pieper C. F. (2008). Effect of physical activity guidelines on physical function in older adults. J Am Geriatr Soc, Vol. 4, pp. 1873-1878.

[58] Nagai K., Yamada M., Uemura K., Yamada Y., Ichihashi N., Tsuboyama T. (2011). Differences in muscle coactivation during postural control between healthy older and young adults. *Age*, Vol. 33(3), pp. 393-407.

[59] Nitz J. C, Choy N. L. (2004). The efficacy of a specific balance-strategy training program for preventing falls among older people: a pilot randomized controlled trial. Age Agein, Vol. 33, pp. 52–58.

[60] Orr R, Raymond J, Sigh M. F. (2008). Efficacy of progressive resistance training on balance performance in older adults. Sports Med, Vol. 38, pp. 317–343.

[61] Orr R, Vos N. J, Singh N. A, Ross D. A, Stavrinos T. M, Fiatarone-Singh M. A. (2006). Power training improves balance in healthy older adults. The Journals of Gerontology, Vol. 61, pp. 78–85.

[62] Peterson, D. S., Martin, P. E. (2011). Effects of age and walking speed on coactivation and cost of walking in healthy adults. *Gait and Posture*, Vol.31, pp. 355-359.

[63] Petrella J. K, Kim J. S, Tuggle S. C, Hall S. R, Bamman M. M. (2005). Age differences in knee extension power, contractile velocity, and fatigability. Journal of Applied Physiology, Vol. 98, pp. 211–220.

[64] Pijnappels M, Reeves ND, Maganaris CN, Van Dieen JH. (2008). Tripping without falling; lower limb strength, a limitation for balance recovery and a target for training in the elderly. J. Electromyogr. Kinesiol. Vol. 18(12), p. 188-196.

[65] Rabert M. S, Zapata M. J. M, Vanmeerhaeghe A. F, Abella F. R, Rodríguez D. R, Bonfill X. (2011). Whole body vibration for older persons: an open randomized, multicentre, parallel, clinical trial. BMC Geriatrics, Vol. 11, pp. 1-6.

[66] Ranganathan V. K, Siemionow V, Saghal V, Yue G. (2001). Effects of aging on hand function. J Am Geriatr Soc 2001;49:1478-84. 3. Carmeli E, Patish H, Coleman R. The aging hand. J Gerontol A Biol Sci Med Sci, Vol. 58, pp. 146-152.

[67] Reeves, N. D. et. al. (2008). The demands of stair descent relative to maximum capacities in elderly and young adults. *J Electromyogr Kinesiol*, Vol. 12, No. 2, pp. 218-227.

[68] Roeneker D. et al. (2003). Speedof-processing and driving simulator training result in improved driving performance. *Hum Factors*, Vol. 45, No.2, pp. 218-234.

[69] Russ, D.W., Kent-Braun, J.A. (2003). Sex difference in human skeletal muscle fatigue are eliminate under ischemic condition. *Journal of Applied Physiology*, Vol.94, pp. 2412-2422.

[70] Schmitz, A. et. al. (2009). Differences in lower-extremity muscular activation during walking between healthy older and young adults. Journal of Electromyography and Kinesiology, Vol. 19, pp. 1085-1091.

[71] Schulz R, Curnow C. (1998). Peak performance and age among superathletes: track and field, swimming, baseball, tennis, and golf. J Gerontol, Vol. 43, pp. 113–120.

[72] Skelton D. A, Greig C. A, Davies J. M., Young A. (1994). Strength, power and related functional ability of healthy people aged 65–89 years. Age & Ageing, Vol. 23, pp. 371–377.

[73] Takarada Y, Takazawa H, Sato Y, Takebayashi S, Tanaka Y, Ishii N. (2000). Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. J Appl Physiol, Vol. 88, PP. 2097–2106.

[74] Tinetti M. (2003) Preventing falls in elderly persons. N. Eng. J. Med. Vol. 348(1), pp. 42-49.

[75] Valkeinen H, Alen M, Hannonen P, Hakkinen A, Airaksinen O, Hakkinen K. (2004). Changes in knee extension and flexion force, EMG and functional capacity during strength training in older females with fibromyalgia and healthy controls. Rheumatology (Oxford), Vol. 43, pp. 225–228.

[76] Valkeinen H, Hakkinen A, Hannonen P, Hakkinen K, Alen M (2006). Acute heavy-resistance exercise induced pain and neuromuscular fatigue in elderly women with fibromyalgia and healthy controls: effects of strength training. Arthritis & Rheumatism, Vol. 54, pp. 1334-1339.

[77] Vanicek N, Strike S, McNaughton L, Polman R. (2009). Postural responses to dynamic perturbations in amputee fallers versus nonfallers: a comparative study with able-bodied subjects. Arch. Phys. Med. Rehabil. Vol. 90(6), pp. 1018-1025.

[78] Watanabe, K., Kouzaki, M., Merletti, R., Fujibayashi, M., Moritani, T. (2012). Spatial EMG potential distribution pattern of vastus lateralis muscle during isometric knee extension in young and elderly men. *Journal of Electromyography and Kinesiology*, Vol.22, pp. 74-79.

[79] Waters R. L., Hislop H. J., Perry J, Thomas L, Campbell J. (1983). Comparative cost of walking in young and old adults. J Orthop Res, Vol. 1, pp. 73–76.

[80] Wheeler, K. A., Kumar, D. K., Shimada, H., Arjunan, S. P., Kalra, C. (2011). Surface EMG model of the bicep during aging: a preliminary study. *Conference Procedures of IEEE Engenering in Medicine and Biological Society*. 2011;2011:7127-30.

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

[82] Mian, OS, Baltzopoulos V, Minetti AE, Narici MV. The impact of physical training on locomotor function in older people. Sports Med.2007; 37(8):683-701.