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Electromyography Based Analysis of the Impact of Ageing on Muscle Activation Pattern during Static and Dynamic Balance Control Tasks: A Systematic Review

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ABSTRACT

The present systematic review was done, to examine the impact of aging on posture control mechanisms in terms of muscle activity and sway patterns. English language articles describing effects of aging on muscle activation pattern during balance control tasks using electromyography methods published from 2000 to 2019 were identified. Studies were compared with regards to study population, postural tasks, perturbations, muscle inclusion, and outcome measures. All the included studies (N-9) exhibited increased postural sway among elderly in contrast to young population. In contrast, inconsistency was observed in the muscle activation pattern, muscle dependency, and muscle co-contractions among the studies. Altogether, the findings of the review suggest that the aging causes alterations in muscle activity in order to maintain balance during challenging situations; however, the studies do not elucidate these changes across the ages.

Keywords: Aging, Muscle activation, Electromyography, Posture sway

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INTRODUCTION

The ability to maintain the body's center of mass over the base of support during the quiet stance, movement, and in response to balance threats is one of the main goals of postural control.[1] Therefore, it is considered as an imperative ability that plays a role in most daily activities, locomotion, social integration, etc. Although for an adolescent, these activities seem simpler, due to series of physiological changes associated with the aging, these simpler tasks often become challenging for elderly to the point that postural instability and balance disorders in the aging population are considered a major health concern. It is estimated that one-third to one-half of the population over 65 years presents some problems with balance control.[2]

The impaired balance control in aging population is attributed to diminished sensory information,[3-7] a decline in muscle force[8-11] and changes in the pattern of muscle activation.[12-15]

In order to maintain the balance, the postural control system has to integrate the sensory information on body oscillations and activate the muscles appropriately in terms of order and intensity.[16] Therefore, the analysis of muscular activation patterns constitutes an important component of the evaluation of neuromuscular control of balance. Few studies have investigated the influence of aging on electromyographic activities during static and dynamic balance control tasks. Amiridis *et al*.[12] revealed that increasing postural demands during quiet standing results in greater sway and active hip movement in the elderly that is compensated by increased hip muscle activity, a finding not noted in younger adults. The younger participants rather accommodated for the increased postural requirements by increasing the activity of ankle muscle only. Bugnariu and Fung[17] observed that in young adults, muscle recruitment generally followed a distal-to-proximal sequence, regardless of perturbation direction or sensory conflicts, whereas older adults exhibited a reverse order. The electromyography (EMG) data, in the study of Benjuya and associates[18] indicated that, unlike the younger group, the older group used co-contraction around the ankle in order to deal with changing conditions and sensory inputs.

Thus, prior studies have demonstrated that the older adults exhibit greater dependence on hip muscles along with insufficient ankle muscles activity, while performing the balance tasks of increasing difficulty. However, among ankle muscles, a whole lot of studies have focused on dorsiflexors and planterflexors but there appeared to be little consensus regarding the activation pattern of invertors and evertors while performing the balance tasks. Additionally, despite the important role played by trunk muscles in maintaining the stability[19-21] the activation pattern of trunk muscles with special reference to aging, has not been emphasized in earlier studies.

On the basis of above arguments, this systematic literature review has been conducted to synthesize the findings related to EMG based analysis of the trunk and lower extremity muscles, during static and dynamic balance tasks of increasing difficulty, with the main focus on different age groups, gender difference, postural sway, EMG protocol, muscle activation pattern, etc.

MATERIALS AND METHODS

Search Strategy

Systematic literature review for the studies published during 2000–2019, in the English language was done, with a search in the

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PUBMED, SCOPUS, Cochrane, and research gate databases. Search was performed using the keywords; Surface EMG (sEMG), Static equilibrium, Dynamic equilibrium, Aging, Balance Postural control, and Muscle activation pattern.

Selection Criteria and Quality Assessment

All prospective randomized controlled trials, parallel group designs, cross-over trials, and quasi-randomized clinical trials were eligible for inclusion. Papers reporting the effect of aging on posture control and muscle activation pattern using sEMG methods were only included in the study. The focus was on healthy young and old adult groups with the age range of 20–80 years, irrespective of the gender. Papers were excluded if they did not use EMG, were reviews, or descriptive.

Abstraction of Data and Analysis

The review process was carried out by four authors. Two reviewers screened the title and abstract of the studies according to the inclusion criteria. Full paper review was performed by the other two reviewers for the studies fulfilling the inclusion criteria. The reviewer reported on study population, balance tasks for EMG muscle activation pattern, effects of aging on center of pressure (COP) displacement and Postural sway during balance control task, effect of aging on muscle activation pattern during balance control task, and gender differences.

RESULTS AND DISCUSSION

The present systematic review was done, to examine the impact of aging on muscle activation pattern, during various posture control mechanisms. A total of nine studies, published during 2000–2019, were examined for this purpose.

SEARCH RESULTS

Studies Identified

The database searching revealed 6340 studies through PubMed, Scopus, Cochrane, and research gate. In addition, 773 studies were detected through other sources. Out of these, 1273 duplicate studies were removed, thus leaving 5840 studies for further screening. 5722 studies, which didn't satisfy the inclusion criteria, were further removed, leaving 118 papers for abstract review. Following abstract review, 14 papers were excluded leaving 104 papers for a full review. Of these, nine research papers[12,16-18,22-26] which analyzed the impact of aging on muscle activation patterns, were selected for final inclusion after removing 96 papers.

Study Populations

Study populations, muscle groups, postural tasks, and outcome measures are summarized in Table1. Eight studies included a sample of both older and younger adults[12,17,18,22-26] whereas one study[16] was carried out on elderly population only. Mean age of the older people varied from 62.5 to 77.8 years, with a range across studies from 60 to 84 years. Mean age of the younger people varied from 20.1 to 26.7 years, with a range across studies from 20 to 34 years.

Balance tasks for EMG muscle activation pattern

Five studies[12,18,22,25,26] investigated balance control mechanisms only during steady state postural tasks. Study done by Donath *et al*.[26] investigated muscle activation patterns during five static balance tasks (Table 1). Study by Benjuya and his associates[18] measured four different conditions including upright standing with wide and narrow base (eyes open & eyes closed). Billot *et al*.[25] and Amiridis *et al*.[12] conducted three balance tasks of increasing difficulty in static stance (normal quite stance, tandem stance, and one limb stance). In contrast to these four studies, Asaka and Wang[22] added load (5% of the body weight) to static balance task of normal quiet standing. Only one of the nine studies,[16] had examined both static (upright standing with eye open and eye closed) and dynamic (sit to stand) postural control.

Two of the nine reviewed articles had undertaken external perturbations during quite stance. Kanekar and Aruin[23] included perturbations using pendulum impact paradigm, where subjects were required to receive the load attached to the pendulum. Bugnariu and Fung[17] exposed the subjects to visual perturbations through a moving virtual environment and surface perturbations consisting of ramp and hold tilt of 8°. One study[24] involved repeated hip flexion/extension movements during standing on the dominant leg.

Effects of aging on COP displacement and postural sway during balance control tasks

Almost all studies[12,17,18,22-26] suggested that both young and older adults demonstrated increase in the COP displacement with the increasing difficulty levels of balance control tasks. However, the displacements were markedly larger in older adults when exposed to similar postural disturbances. In addition, older adults took longer duration to return to the neutral positions.[17] In contrast to this, Gomes *et al*.[16] reported that women from the three age groups (60–64, 65–69, 70–74) exhibited similar displacement of COP during static as well as dynamic balance control tasks, suggesting that the decrease in postural control throughout the aging process does not occur on a linear basis. Nevertheless, further investigation is needed to endorse this statement, mainly due to a small interval (5 years) taken to divide the three age groups.

Effect of aging on muscle activation pattern during balance control tasks

While investigating muscle activation pattern during various balance tasks, five out of nine studies[12,16,18,24,25] focused on lower limb muscles, whereas four of them[17,22,23,26] have examined activation pattern of both trunks as well as lower limb muscles, among which, one study[17] included the neck muscles, too.

On the basis of EMG latencies, two studies examined whether the order of muscle activation during postural adjustments differed between young and older populations. One study[17] observed that the younger adults followed distal to proximal sequence of muscle recruitment, whereas, elderly demonstrated a reverse pattern of muscle activation, especially under sensory conflicts, where neck muscle activity preceded the lower limb muscle activity by 25–70 ms. Conversely, Kanekar and Aruin[23] recorded similar order of activation of muscles, i.e. distal to proximal, for both young and older adults, although the differences between the muscle latencies, in later group, were not statistically significant.

Table 1: Study population, Muscle Groups, postural tasks and outcome measures of the included studies

Study	*Methods: Study Population, Side, Muscles, and Postural Tasks*	*Outcome Measures*
Asaka & Wang (2008)[1]	09 young adults, males/females (22.3 ± 1.2) 09 old adults, males/females (66.4 ± 3.5) Left side, 6 muscles of lower limb Load release task (load of 5% body weight suspended behind the body through pulley system	COP displacement in AP direction EMG Time lag at the moment of peak (ms), R Peak, M-mode. Reciprocal co-contraction
Bugnariu & Fung (2007)[2]	10 young adults, males/females (26 ± 5.1) 10 old adults, males/females (72 ± 3.3) Bilateral Side, five muscles of the lower limb, one trunk muscle, and two neck muscles Quiet stance with random visual, surface, discordant, and concordant perturbations	COP in vertical, anterior posterior, and Mediolateral moments COM peak to peak excursion Average EMG Latencies
Kanekar & Aruin (2014)[3]	13 young adults, males/females (26.69 ± 3.72) 10 old adults, males/females (69.9 ± 4.04) Right Side, 10 muscles of lower limb and 3 trunk muscles Pendulum impact Paradigm used as perturbation during upright stance	Peak displacement of COP and COM in AP direction. EMG latency Integrals of Compensatory and anticipatory EMG activity within 4 time windows
Gomes *et al*. (2013)[4]	57 elderly women (62.5 ±1.3 – 73.8 ± 2.3) Right side, 4 muscles of lower limb Eyes open(EO) and Eyes closed (EC) Normal Quiet Standing (NQS), Sit to stand and stand to sit	Average velocity of COP trajectory in ML & AP directions RMS value
Amridis *et al*. (2003)[5]	19 old male adults (70.1±4.3) 20 young male adults (20.1± 2.4) Dominant leg(irrespective of side), four muscles of lower limb Normal Quiet Standing, Tandem Romberg stance, One Leg Stance	Peak to peak amplitude and variance of COP along AP & ML axis. EMG Amplitude expressed as normalized EMG activity
Hatzitaki *et al*. (2005)[6]	09 young adults, Males/Females (20.1 ± 2.4) 11 old adults, males/females (70.1 ± 4.3) Dominant Side, 4 muscles of lower limb Single leg stance with flexion & extension of the swinging limb	COG and COP in forward and Backward directions, EMG Amplitude of muscle activity
Billot *et al*. (2010)[7]	07 young adults, males/females (22.7 ± 2.6) 07 old adults, males/females (80.7 ± 3.9) Right Side, 4 muscles of lower limb Normal Quiet Standing, Romberg stance, One Limb Stance	COP pathway Relative EMG-RMS (%) Relative torque (%)
Benjuya *et al*. (2004)[8]	20 young adults, males/females (26.6 ± 3.2) 32 old adults, males/females (77.8 ± 2.1) Dominant Side, four muscles of lower limb Upright standing with wide base & narrow base (Eyes open & Eyes closed)	COP, sway in AP & ML directions, mean COP velocities Averaged EMG amplitude from Maximum Voluntary Isometric Contraction (MVIC)
Donath *et al*. (2016)[9]	20 young adults, males/females (24 ± 2) 20 old adults, males/females (73 ± 6) Non-Dominant Leg, eight muscles of lower limb and two trunk muscles Double limb stance on foam surface with eye open and on firm surface with eye closed, Double limb stance feet in step position on foam surface with eye open and on firm surface with eye closed, Single limb stance on firm ground with eye closed	COP path length displacement from AP & ML sway Relative muscle activity (%MVC, respective reference contraction) Amplitude ratios (AR - % of muscle activity contribution of each muscle to overall muscle activity) Co-activation index (CAI = less active muscle/ more active muscle)

Three studies demonstrated an increased EMG activity of hip muscles in older adults as compared to their younger counterparts. Amiridis *et al*.[12] demonstrated that older adults employed significantly greater rectus femoris (RF) and semitendinous (ST) activity than younger adults in order to balance in RS and Ordinary Least Squares tasks with no significant, between group differences, in the ankle muscles. On the other hand, Hatzitaki *et al*.[24] revealed that young adults produced significantly greater ankle muscle activity compared to old participants in order to maintain the stance limb fixed to the ground during the performance of single-limb oscillations. At the hip, however, old participants exhibited significantly greater ST amplitude than young individuals with no significant, between group difference, in RF's activation level. Similar findings have been reported by Benjuya *et al*.[18] for maintaining static postural stability, as they noted that ST was used by the older group significantly more than the younger group while RF and ST activity ratios remained unchanged in both groups. Taken together, these studies suggest greater hip dependence in elderly, while performing the static and dynamic balance tasks of increasing difficulty, which is in contrast with younger people. A whole lot of studies support and consequently explain this finding of the present review.[12,27,28]

Four studies[18,22,25,26] demonstrated EMG co-activation in elderly with Billot and his associates[25] examining only ankle muscles, Benjuya *et al*.[18] both hip and ankle muscles, whereas Asaka and Wang[22] and Donath *et al*.[26] examining trunk and hip muscles in addition to ankle muscles. All of them showed increased levels of EMG co-activation of ankle muscles in elderly, in order to control body sway under disturbed postural conditions, as evidenced by simultaneous recording of EMG activity on TS and TA;[25] Sol/TA normalized EMG ratios;[18] computing co-activation index[26] and co-contraction Muscle-modes.[22] Nevertheless, with reference to proximal muscles, the outcome varies between these four studies.[18] Reported no co-activation at the hip joint with ST used by the older group significantly more than the younger group and no significant between group differences, in the EMG activity of RF during upright standing, suggesting that, unlike younger group, the older group used co-contraction around distal joints. Conversely,[22] observed more frequent co-contractions at the hip and knee joints than those at the ankle joint among elderly, thus indicating that the proximal group of muscles in older might tend to change into co-activation pattern under the disturbed postural conditions, comparing to those of younger group. Donath *et al*.[26] noticed inverse muscle activity patterns at the ankle and trunk with significantly higher level of co-activation for the ankle muscles in older adults and for the trunk muscles in younger adults. This might reflect a greater use of hip strategy by stiffening the ankle joint in elderly population. On the other hand, young seem to stiffen the trunk for maintenance of upright posture using ankle strategy. To sum up, all four studies have shown the mechanical stiffening of the joints, among elderly and differences in regulation of agonist and antagonist between young and elderly.

The observation from the above review indicates a wide variation in the muscle activation pattern among young and old adults. Nonetheless, none of the studies have investigated changes in muscle activation pattern across the ages. Most of the studies compared between two wide groups i.e. young and old adults. Only one study[16] compared EMG activity of lower limb muscles, for the elderly women of different age groups. The study reported no noticeable change in the pattern of muscle activation among the different age groups of elderly women. The ability to coordinate multiple muscles into postural muscle synergies is a critical aspect of the maintenance of balance control. Therefore, in order to better understand its mechanism, it is important to investigate adjustments in postural control in terms of changes in the muscle activation patterns across the ages. This would elucidate age-range identification with reference to the onset of the deterioration in balance control which in turn could help in evaluating balance as well as implementing the falls preventive strategies amongst the population of an appropriate age range.

Gender Differences

In context to the gender differences in muscle activation patterns, none of the studies examined impact of gender on muscle activation patterns during various postural tasks. As the literature on fall risk shows a controversial gender-based differences in balance performance, it is important to find the changes in the muscle activity pattern with aging from the perspectives of gender. While some studies suggest that gender differences appeared in older subjects with women significantly less stable than men[29,30] many studies failed to find any significant difference in relation to gender.[31,32] Thus, the impact of gender differences on muscle activity performances still remains unclear. Therefore, further research is required to draw conclusions on gender, in the effects of aging on muscle activation during balance and functional tasks.

CONCLUSION

Regardless of variations in study population, postural tasks, perturbations, muscle inclusion, and outcome measures, findings of the present review were reasonably consistent in relation to increase in COP displacement among both young and older adults in response to the increasing difficulty levels of posture control tasks, with significantly larger displacements in older adults. This suggests that there is definitely a decline in balance control with aging. However, further research is required to decide whether this decline is on linear basis or not. In addition to this, the present review has observed contradicting findings in regard with the muscle activation pattern during static and dynamic balance tasks, indicating that future studies, having a more integrated approach that incorporates trunk and leg muscles, should be carried out so as to suggest the interventional strategies that could reduce electromechanical cost for a given balance task in older adults.

Taken together, the findings do not indicate the age range when the healthy adults initially demonstrated alterations in muscle activation pattern during either static or dynamic balance control. Thus, further investigation is needed to identify a more appropriate age range for the assessment of balance as well as the implementation of falls prevention strategies.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to research, authorship, and/or publication of this article.

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