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The Effects of Performance Fatigability on Postural Control and Rehabilitation in the Older Patient

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Abstract

Fatigue is common in older adults and has a significant effect on quality of life. Despite the high prevalence of fatigue in older individuals, several aspects are poorly understood. It is important to differentiate subjective fatigue complaints from fatigability of motor performance because the two are independent constructs with potentially distinct consequences on mobility. Performance fatigability is the magnitude of change in a performance criterion over a given time of task performance. Performance fatigability is a compulsory element of any strength training program, yet strength training is an important component of rehabilitation programs for older adults. The consequences of fatigability for older adults suggest that acute exercise of various types may result in acute impairments in postural control. The effects of performance fatigability on postural control in older adults are evaluated here to aid the rehabilitation clinician in making recommendations for evaluation of fall risks and exercise prescription.

Keywords

Fatigue; Fatigability; Performance fatigability; Older adults; Seniors; Geriatrics; Rehabilitation; Exercise; Posture; Postural control; Postural stability; Falls

Introduction

Fatigue is a commonly reported symptom in older adults. In a sample of 124 older adults in a primary care setting, approximately one third expressed concerns about fatigue [1]. Furthermore, 47 % of older adults in long-term care facilities report moderate or severe fatigue [2]. Despite the apparent epidemiologic importance of fatigue and the growing numbers of empirical studies investigating the construct, many fundamental questions remain unanswered. One of the most relevant discussions for older adults is how to define the various domains of fatigue effecting performance [3••]. In general, fatigue is a disabling symptom in which motor performance is constrained by interactions between perceptions of fatigue and the fatigability of the involved muscles.

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Perceptions of fatigue refer to an increasing sense of effort, subjective sensations of weariness, mismatch between effort expended and actual performance, or exhaustion [4, 5]. In contrast, performance fatigability is defined as the magnitude or rate of change in a performance criterion relative to a reference value over a given time of task performance (e.g., percent decline in maximal voluntary contraction during knee extension exercise) [6]. It is important to distinguish between subjective fatigue complaints and fatigability of motor performance because clear communication, scientific progress, and the development of effective interventions rely upon clear terminology and shared conceptual frameworks. This review will focus on fatigability involving decrements in motor performance in older adults.

Performance fatigability is commonly viewed as any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether the task can be sustained [7]. Fatigability is a compulsory element of any strength training program, but the consequences of fatigability for older adults suggest that acute exercise of various types may result in impairments in postural control [8•].

Postural control is a continuous process of monitoring and re-establishing balance. It is defined as the regulation of the body's position in space for the dual purposes of equilibrium and orientation [9]. Postural orientation involves interpreting various forms of sensory information in order to establish a representation of the body relative to its environment (e.g., visual, vestibular, and cutaneous sensorial afferent input during walking), as well as the ability to correct positioning of body segments relative to each other and the environment for a particular task [10]. Postural equilibrium is described as the ability to balance all the forces acting on the body such that it maintains a desired position or moves in a controlled way (e.g., maintaining upright after being nudged in a crowded room) [10]. Functionally, postural control serves to maintain the individual in an upright position in the face of gravity and/or in response to internal or external perturbations.

Rehabilitation clinicians implement exercise programs for older adults with the expectation of positive implications on postural control. Regardless of the framework in which muscular exercise is performed, classification systems define two types of interventions: one that mobilizes the whole body (general muscular exercise) and the other which focuses on a particular muscle or group of muscles (local muscular exercise). Most general muscular exercise engenders displacements of the whole body in space (e.g., walking and running) while most local muscular exercise generates segmental movements (e.g., knee extension, elbow flexion). A prior review has been devoted to the effects of these two types of fatiguing exercises on postural control, [11] but this commentary will focus on the local segmental movements which generate performance fatigability, as these comprise the main effect of resistance training interventions for older adults.

A comprehensive and descriptive understanding of the role of fatigability on postural control is necessary because the extent of fatigability may be fundamental in determining whether older adults can perform and repeat requisite movements successfully. It is also important to identify whether specific post-exercise precautions should be considered following fatiguing exercise [12••]. These are important factors that relate ultimately to the ability of older adults to live meaningful and independent lives. Moreover, an understanding of the acute effects of

performance fatigability on postural control in older adults would enable potential risks of falls and injuries during rehabilitation sessions to be anticipated. Hence, the purpose of this review is to provide clinicians with a commentary on the effects of performance fatigability on postural control during localized muscular exercises commonly used in rehabilitation practice for older adults.

Performance Fatigability in Older Adults During Rehabilitation Practice

When deficits in muscle performance place a person at risk for injury or hinder function, the use of resistance exercise is a commonly used therapeutic intervention to improve strength, muscular endurance, and functional mobility. Resistance exercise is any form of active exercise in which dynamic or static muscle contraction is resisted by an outside force applied manually or mechanically [13]. Resistance exercise is a critical component of rehabilitation programs for older adults with impaired function and an integral feature of conditioning programs for individuals who wish to improve health and physical fitness, enhance motor skills, and reduce the risk of injury and disease [14, 15].

Numerous systems of resistance exercise have been developed over the past 50 years to improve muscle strength, power, and endurance in older adults. The basis for all forms of resistance training is the overload principle: muscle must be challenged to perform at a level greater than that to which it is accustomed [14]. The demands on the muscle must remain constant after the muscle has adapted; otherwise, muscle performance cannot be increased [16]. Clinical rehabilitation providers deliver a constant stress to the muscle by progressively loading the muscle and manipulating the intensity or volume of exercise. For older adults, who have decreased energetic reserves, [17] performance fatigability is a side effect of resistance training that must be monitored.

Performance fatigability can occur during static or dynamic muscle contractions. The decreased acute physiological response associated with fatigability is characterized by a steady deterioration of the force-generating capacity of the muscle, leading to a decrease in muscular strength [18]. Older adults may have difficulty continuing resistance training exercise in the face of declining strength. However, fatigability of muscle in older adults has been reported to be equivalent to that of young persons in various contraction types. For example, isometric or isokinetic voluntary contraction protocols involving the knee extensors, [19] elbow flexors, [20] and hand grip muscles have demonstrated no difference in fatigability of muscle between older adults and young subjects [21]. Other reports involving the same muscle groups with similar contraction protocols suggest that older adults are actually more resistant to fatigability than young persons [22–24]. The relative fatigability of muscle in older adults has been reviewed elsewhere [25, 26]. Rehabilitation interventions should focus on specific components of movement control [27]; therefore, we will describe the effect of performance fatigability on postural control when individual segmental muscles are employed.

Effects of Performance Fatigability on Postural Control in Older Adults

Systematic reviews have demonstrated significant effects of performance fatigability on postural control in older adults, [8•, 28•], but several new publications have shed more light on these effects. This study highlights recent evidence demonstrating the effects of performance fatigability on postural control for exercising seniors. Several resistance exercise protocols were used to induce performance fatigability in individual body segments including the trunk, hip, leg, and ankle musculature. Fatigability protocols can be seen in Table 1.

Effect of Fatigability on Quadriceps and Hip Extensors

Papa et al. analyzed the effects of age and performance fatigability of the quadriceps and hip extensors on reactive postural control in healthy older adults [12••]. Participants resisted a motorized foot pedal as it moved toward them during seated exercise, thereby experiencing eccentric muscle contractions about the hip and knee extensors. Fatigability was determined by a 30 % decline in baseline maximal voluntary contraction (MVC). MVC was established with the average of four maximal effort pedal strokes prior to beginning exercise. Outcome measures included step velocity, knee and ankle angular displacements, and center of pressure-center of mass difference (COP-COM difference). Participants' postural control was assessed during a reproducible fall [29] before muscle fatiguing exercise, immediately after exercise, and after 15 and 30 min of rest. Results indicated significant differences between the time frames for several components of postural control including COP-COM difference, step velocity, and both knee and ankle angular displacement of the stepping limb during the support (landing) phase of the fall. The authors noted that outcomes altered by performance fatigability returned to baseline within 15 min of rest. These results provide important insight for rehabilitation providers, suggesting that it may be prudent to encourage highly fatigued older patients to rest up to 15 min before leaving clinical exercise settings.

A study by Toebes et al. analyzed the effects of unilateral quadriceps and hip extensor fatigue on postural control in perturbed and unperturbed gait during specific phases of gait in healthy older adults [30]. Ten older subjects were recruited to perform the perturbed and unperturbed gait before and after fatiguing exercise. Performance fatigability was produced by repetitive single-leg squats using a maximal voluntary isometric knee extension moment at a knee angle of 120° with a custom-made dynamometer. The authors observed an interaction between condition (fatigued/unfatigued) and gait phase (stance/swing); less force was required to perturb the subjects in the fatigued condition during the stance phase. The authors also found that the deviation of the trunk from unperturbed walking at first heel contact after the perturbation was smaller in the fatigued than in the unfatigued condition. The results of this study affirm that the force-producing capacity of leg muscles may limit the ability of quadriceps and hip extensor muscles to resist mild gait perturbations. However, the authors noted that leg muscle fatigability did not reduce postural control in steady-state gait. Therefore, while older adults may ambulate in a steady state without bio-mechanical deficits after exercise, clinical exercise specialists may consider monitoring fatigued individuals in the event of a trip or slip, in order to prevent iatrogenic falls.

Effect of Fatigability on Plantarflexors

Nam et al. recruited twenty-four healthy older adults who were fatigued by performing maximal voluntary contractions of the gastrocnemius muscle [31]. Fatigue was determined when 40 % maximal voluntary contraction declined by 5 %. Postural control assessments were performed using single-limb posturography. Their results indicated a significant difference between the pre- and post-fatiguing exercise in mediolateral COP deviation, but there was no significant difference found for anteroposterior deviation. In addition, the occupied area of COP with the indices of envelope area and root mean square area also increasing after fatiguing exercise. Moreover, the length of COP movement in both mediolateral and anteroposterior directions was increased after fatiguing exercise. These findings indicate performance fatigability involving the plantarflexor muscles reduces postural control in mediolateral directions and increases movement variability during single-limb stance. These changes may predispose fatigued older adults to increased fall risks during clinical exercise sessions because habitual plantarflexion activity occurs during ambulation in addition to the fatigued muscle group.

The effect of ankle muscular fatigue on postural control was also analyzed by Bisson et al. [32]. Using firm and compliant surfaces, the investigators examined 13 older men under two different conditions: quiet standing and while performing a secondary task. The dual task involved a choice reaction time task. Subjects were fatigued by performing maximal isometric voluntary contractions of the plantarflexor muscles using a Biodex isokinetic dynamometer. The presence of fatigability was determined if the subjects were unable to hold 50 % maximal voluntary contractions for five consecutive seconds. Results indicated an interaction between fatigability and surface for COP sway area. COP sway area was greater on the compliant surface compared with the firm surface in the post-fatigue condition. In addition, reaction time increased significantly after fatiguing exercise while standing on the compliant surface. Furthermore, the fall risk increased when the COP sway area increased by 78 %. These findings indicate that the effects of performance fatigability on postural control are more dangerous when proprioceptive information at the ankle is altered. Clinicians should caution performance-fatigued older adults to be aware of living conditions that may alter proprioception such as thick carpets and anti-fatigue standing mats.

Effect of Fatigability on Hip Abductors

A study by Arvin et al. investigated the effect of unilateral hip abductor fatigue on postural control during gait with 17 healthy older adults [33]. Participants were fatigued by repetitive hip abduction. A fixed target (30° hip abduction and 20 lifts per minute) was set for each subject during hip abduction exercise. Subjects were considered fatigued if they were unable to reach the set target. Several important findings were noted: (1) stride time variability was increased significantly after fatiguing exercise; (2) fatigability reduced overall trunk movement, causing subjects to increase variability in their stride time; (3) performance fatigability decreased mediolateral step-to-step symmetry and mediolateral peak trunk velocity; (4) errors in hip position sense were increased following fatiguing exercise. These findings indicate the importance of hip abductor muscles for control of posture during gait. Rehabilitation programs that feature hip abductor fatiguing exercises such as side-lying hip

abduction or “clamshells” should be aware of their acute negative effects on gait control and stability.

Effect of Fatigability on Trunk Extensors

Performance fatigability of trunk extensor muscles can also play an important role in postural control. Parreira et al. evaluated the effects of fatigability of trunk extensor muscles on postural control during a single-leg balance task [34••]. Participants were fatigued by repeatedly flexing and extending the trunk from 45° to 0° relative to the horizontal line on a Roman chair. The subject was considered fatigued when they were unable to continue the exercise, or no longer maintained the required movement velocity as paced by a metronome at 60 bpm. Postural control was assessed before the fatigability protocol, immediately after the protocol, and following 5, 10, and 20 min of recovery. Older adults demonstrated increased COP velocity in the mediolateral and anteroposterior sway directions after fatiguing exercise. These postural stability changes returned to baseline within 10 and 20 min of rest, respectively. These findings corroborate the results of Papa et al., suggesting that acute negative effects of fatigue on postural control are attenuated by rest.

Clinical Implications

Ecologically Valid Fall Risk Examinations

Standard of care clinical rehabilitation practice dictates that thorough fall risk examinations be performed for older adults at risk for falls. The data presently reviewed suggest that performance fatigability in older adults induces alterations in postural control. At a minimum, this suggests that fatigability has a measurable clinical effect on stability and potentially on fall risk. Despite this evidence, fall risk examinations are not performed following therapeutic exercise (in a fatigued state). This review emphasizes the need to conduct fall risk examinations in a more ecologically valid scenario, with both pre- and post-fatigue assessments. Further research is needed to validate the effect of performance fatigability on fall incidence in older adults.

Utility of a Valid Clinical Fatigability Scale

The most frequently cited causes of falls in older adults are accidental or environment-related falls, followed closely by postural instability and/or gait problems [35]. When performance fatigability is added to these factors, older individuals may become increasingly susceptible to falls [36–38]. We propose that fatigability has the potential to be used as a new remediable risk factor for falls in clinical rehabilitation practice. Given that clinical balance tests combined with health and demographic factors have not been successful at predicting falls in clinical settings, [39] clinicians are in need of valid and reliable clinical tests that have strong predictive properties to prevent future falls. While a previous fall is the most potent predictor of fall risk in older adults, [40] it does not provide information to guide assessment and intervention strategies for preventing subsequent falls. The development of a clinical fatigability scale would serve to guide safe therapeutic exercise for rehabilitation clinicians.

Post-Exercise Precautions

Post-exercise recovery time is an important element of rehabilitation practice for older patients. Rehabilitation clinicians should be cognizant of the potential for fatigability-induced iatrogenic falls and should organize training conditions so as to minimize the impact of fatigability on older persons. Adequately designed training programs with cardiovascular monitoring, and proper hydration and nutrition, should be incorporated into safe clinical exercise practice.

One of the fundamental goals of exercise in older adults is to improve strength and reduce fall risk. Unfortunately, rehabilitation clinicians have given little thought to the potential for falls during acute exercise settings. Adequate recovery time is not only essential for long-term improvements in muscle performance (strength, power, endurance) [41, 42] but also for acute recovery of mobility and postural control function. Independent of age, previous studies examining performance fatigability have shown that postural control returns to baseline across all age groups between 75 s [43] and 20 min [44]. The more recent studies reviewed here suggest alterations in postural control return to baseline values between 10 and 20 min in older adults. Postural control is also diminished by fatigability in older adults with co-morbid conditions such as stroke and Parkinson's disease [45, 46], but the recovery from fatigability has not been investigated in these persons. A consensus on post-fatigue recovery in older adults is complicated by neurologic conditions, [6] as well as differences across study designs in sex, [47] muscle group, [48] contraction type [49], and task intensity [50]. In general, there is a need for a greater preponderance of evidence and a degree of consistency across study designs before stronger conclusions can be drawn relative to recovery time for performance-fatigued older adults.

Exercise as a Therapeutic Target for Fatigability Resistance

The acute decline in postural control induced by fatiguing exercise would appear to reveal a potential target for intervention. If clinical rehabilitation exercise programs were designed to make muscle more resistant to fatigability, older individuals might derive postural control benefits. It is our opinion that clinical rehabilitation practice is most effective when aimed at specific physiologic or movement system deficits. For example, the present review suggests that lower extremity joint angular displacements are altered by fatiguing exercise in older adults. Therefore, if rehabilitation practice were directed to increase neuromuscular endurance in those targeted areas, clinicians might reduce the burden of fatigability during body weight support of postural tasks. Controlled trials are needed to demonstrate the efficacy of rehabilitation programs aimed at improving fatigability resistance through chronic muscle endurance training.

Conclusions

Clinical rehabilitation providers diagnose and manage postural control dysfunction; restore, maintain, and promote optimal postural control; and foster the prevention of impairments and functional limitations that lead to decreased postural control in older adults. Resistance training is a common exercise intervention used by physical therapists and rehabilitation providers. However, just as in pharmacologic interventions, exercise interventions have their

intended consequences and an unintended side effect profile. Fatigability is a natural consequence of resistance exercise and may result in undesirable or adverse side effects, such as decreased postural control during functional tasks. Inherent in the art of clinical practice is the ability to determine the relative trade-off between the development of muscle strength, which requires a sufficient stimulus, with the negative effects of performance fatigability on postural control. This review was developed to assist the clinician with awareness of these effects in order to make appropriate recommendations for safe and effective clinical rehabilitation practice.

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Table 1

Summary of performance fatigability protocols and statistically significant effects on postural control in recent research

References	Number of subjects	Age (years) mean (SD)	Method of performance fatigability	Functional task	Effect on postural control	Interaction effect (age by fatigability)
Parreira, et al., 2013 [34••]	36 (18 young and 18 older)	Older: 69.8 (4.9), Young: 26.3 (5.8)	Trunk extension and flexion	One-leg balance test	Yes	Yes
Papa, et al., 2015 [12••]	16 (8 young and 8 older)	Older: 58.5 (4.6), Young: 26.8 (3.7)	Eccentric resistance exercise of quadriceps and hip extensors	Tether-release task	Yes	No
Toebes, et al., 2014 [30]	10 (6 female, 4 male)	Older: 63.4 (5.5)	Repetitive single-leg squat of hip extensors and quadriceps	Walking on a treadmill	Yes	NA
Bisson, et al., 2014 [32]	24 (11 Young and 13 Older)	Older: 65 (4), Young: 24 (4)	Maximal isometric voluntary contractions of plantar flexors	Standing under four conditions: 1. Quiet standing, 2.Secondary task, 3. Firm surface, 4. Compliant surface	Yes	Yes
Nam, et al., 2013 [31]	24 (17 female and 7 male)	Older >65 (SD not reported)	Submaximal isometric voluntary contraction of the plantar flexor	One-leg balance test	Yes	NA
Arvin, et al., 2015 [33]	17 (12 female and 5 male)	Older: 73.2 (7.7)	Repetitive hip abduction	Walking on a treadmill	Yes	NA