THE EFFECTS OF PERIODIZED RESISTANCE TRAINING ON THE NEUROMUSCULAR PERFORMANCE, BODY COMPOSITION AND BALANCE CONTROL AMONG OLDER AND YOUNG ADULTS

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ABSTRACT

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Strength, power and muscle mass decline with age. These declines lead to poorer balance and increased risk for falls. Intervention studies using a periodized resistance training (RT) among the older are limited, despite its widespread applications in fitness and sports among young adults. In addition, the effects of periodized RT on balance control remain to be investigated. This study sought to examine the effects of a short term periodized RT on the neuromuscular performance, body composition and balance control among older and young adults.

A total of 31 untrained older (n=14, 8M & 6F; 69 ± 2 years) and young adult volunteers (n=17, 4M & 13F; 25 ± 3 years) completed 14-weeks of traditional periodized RT that included mesocycles targeted for hypertrophy, maximal strength, power and explosiveness. Measurements were conducted at two time-points: before and after RT. Neuromuscular performance tests included isometric unilateral plantar flexion (PF), isometric knee extension (KE), countermovement jump (CMJ) and one-repetition maximum (1RM) leg press. Electromyography (EMG) data was collected on all neuromuscular performance tests. In addition, body composition was measured using dual energy absorptiometry (DXA). Finally, center of pressure (COP) disturbance was assessed using a force platform for static balance, and an antero-posteriorly translating perturbation device for dynamic balance.

Neuromuscular performance results showed that both older and young adult groups increased KE maximal voluntary isometric contraction (MVIC) (both at $p<0.001$), 1RM leg press (both at $p<0.001$), and CMJ ($p<0.01$ & $p<0.001$ respectively). Only the young adults increased PF MVIC ($p<0.001$), PF rate of torque development (RTD) ($p<0.05$) and CMJ peak power ($p<0.01$), whereas both did not undergo a change in KE RTD. Body composition data revealed that only the older increased body mass ($p<0.05$), while only the young adults increased total lean mass ($p<0.05$) and total fat free mass ($p<0.01$). Static balance remained unchanged in both groups. Dynamic balance findings revealed that both older and young adult groups decreased COP disturbance during low intensity-anterior (Ant) ($p<0.01$) and averaged (Ave) posterior (Post) ($p<0.05$ & $p<0.01$) perturbations respectively. In addition, only the older decreased COP disturbance from high-Post perturbations ($p<0.05$), while only the young adults decreased from low Post ($p<0.05$), mid Ant ($p<0.001$) and Ave Ant ($p<0.001$) perturbations. Moreover, an age-related difference was revealed for CMJ height ($p<0.05$) and Ave Ant COP ($p<0.05$) data. Positive adaptations were incurred primarily through neural mechanisms among the older, while the young adults exhibited gains from both neural and muscular mechanisms. The current periodized RT program seem to be a viable design for optimizing adaptations in neuromuscular performance, body composition, and dynamic balance control on both older and young adults.

Keywords: age-related, perturbation, traditional periodization, resistance training

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LIST OF ABBREVIATIONS

RT - Resistance training
1RM – One repetition maximum
CMJ – Countermovement jump
COP – Center of pressure
EMG – Electromyography
PF - Plantar flexion
KE - Knee extension
MVIC – Maximal voluntary isometric contraction
COP – Center of Pressure
RFD – Rate of force development
RTD – Rate of torque development
LBM – Lean Body Mass

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1 INTRODUCTION

Peak neuromuscular performance occurs at age 20-29 years (Bemben et al., 1991; Larsson, Grimby, & Karlsson, 1979; Young, 1997). Thereafter, the neuromuscular system gradually degenerates, with losses in muscle mass and strength accelerating at around age sixty years (Häkkinen et al., 1995). Sarcopenia refers to the age-associated loss of muscle mass which is linked to several factors including changes in the nervous system, muscle atrophy and altered physical activity (Porter, Vandervoort, & Lexell, 1995). Additionally, Clark & Manini (2012) proposed the term dynapenia to specifically refer to the age-related losses in muscle strength and power that are not due to other neurologic or muscular illness. Both these age-related conditions have been shown to influence the functional capacity, independence (Reid et al., 2008) and risk for falls among the older (Benjumea et al., 2018; Mitchell et al., 2012; Neves et al., 2018).

The steady rate of global increase among people aged >65 years led to estimates that the 2010 older population will triple in 2050 (Suzman & Beard, 2011). Previous reports have shown that about 35% of older adults sustain at least one fall annually (Blake et al., 1988) and that 10–20% of these falls result to injury, hospitalization or death (Rubenstein, 2006). Several factors have been studied for their contributions to falling (Bruce et al., 2016), but the age-associated losses in strength, power and lean body mass seem to be among the primary contributors (Benjumea et al., 2018; Clark & Manini, 2010).

Resistance training (RT) has been shown as the most successful intervention to age-related neuromuscular degeneration (Häkkinen et al., 1998; Steele et al., 2017). One approach that has been shown to optimize the effects of RT is periodization which refers to a planned and systematic manipulation of acute RT variables (i.e. sets, repetitions, intensity, type, order and rest) to facilitate maximal gains (Fleck & Kraemer, 2014) at predetermined time points (Conlon et al., 2016). The adaptive mechanisms that periodized RT could possibly contribute on the most common age-related conditions (i.e., decreased neuromuscular performance, lean mass and balance control) remain unclear and warrant further investigation.

2 NEUROMUSCULAR CHANGES DURING AGING

2.1 Contributors to weakness in aging

Maximal strength, referring to the maximum force or torque that a group of muscles can produce, and muscular power, or the product of force and velocity of muscular contractions (Haff & Triplett, 2016, p.260) were found to undergo exponential declines by 20–40% during the seventh and eighth decade (Edwén et al., 2014; Himann et al., 1988). Different neural and muscular components seem to be altered with aging (Granacher et al., 2008; Reid et al., 2014). Motor unit, the functional component of the neuromuscular system that is composed of an alpha motor neuron and all muscle fibers it innervates (Fleck & Kraemer, 2014, p.93) was reported to undergo losses and remodeling in aging (Clark & Manini, 2012; Doherty et al., 1993) (figure 1). Increased sizes of slow motor units due to the reinnervation of slow motor units on some denervated fast motor units was shown to occur through a process called motor unit remodeling (Piasecki et al., 2016; Tudoraşcu et al., 2014). Since the ability of muscles to produce force is first initiated in the nervous system (Lambert & Evans, 2002), the weakness associated with aging have also been related several factors such as an impaired neural control, a decreased central drive, or a decreased ability to voluntarily activate muscles (Vandervoort, 2002; Roos et al., 1997).

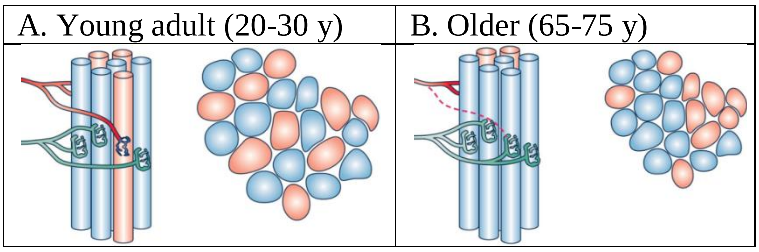

FIGURE 1. Morphological impact of motor unit alterations in aging muscle. Young adulthood (A) is characterized by an intermingling of fibres belonging to different motor units. Adulthood to old age (B) is characterized by repeating cycles of denervation–-reinnervation which results to fibres of the same type being beside one another (*In each box: L image = 3-dimentional morphology; R image = cross-sectional morphology*). (Adapted from Hepple & Rice, 2016).

In addition, decreases in the number and size of both slow twitch (type I) and fast twitch (type II) muscle fibers, with a preferential loss of fast twitch fibers also occur with aging (Lexell et al., 1988). An alteration of muscle architecture, such as decreased fibre fascicle length and decreased pennation angle in the plantar flexor muscles, has been shown in the older (Narici et al., 2003). For instance, Lexell et al. (1983) revealed through autopsy results that vastus lateralis (VL) muscle among their older participants (age 72 ± 1 years) were 18% smaller compared to young adults (age 30 ± 6 years). The authors noted that atrophy in older muscle coincided with the loss of approximately 110,000 muscle fibers due to aging, leaving the older muscle fibers 25% less than the amount found in young adults.

2.2 Consequences of aging

2.2.1 Isometric and dynamic strength declines

Muscular strength has been usually examined in both isometric and dynamic contractions (Roig et al., 2010). Maximum voluntary isometric contraction (MVIC), a common measure of isometric strength, peaks at about age 20–30 years (Bemben et al., 1991; Larsson, Grimby, & Karlsson, 1979) and remain unchanged for a span of time until age-related declines eventually appear after the sixth decade (Stoll et al., 2000). In a mathematical model comparing the isometric muscle strength among healthy individuals aged 20-80 years, Danneskiold-Samsøe et al. (2009) provided a set of normal MVIC values on major joint movements of the body according to age groups (figure 2). They found that the age-dependency of isometric strength varied depending on the type of movement, although in general, MVIC decreased linearly with age after the 20-29 year group. Moreover, other studies have also noted that force steadiness during submaximal isometric contractions is decreased among the older (Enoka et al., 2003; Carville et al., 2007). Among the primary contributory mechanisms to explain these findings include an age-related loss of motor units in different muscles, prominently in distal regions of the body, in addition to a greater motor unit firing variability (Enoka et al., 2003).

Dynamic strength on the other hand has been shown to decrease at a similar rate with isometric strength. Larsson, Grimby, & Karlsson (1979) in a study with healthy subjects aged 11-70 years showed coherent findings that knee extension dynamic strength increased steeply in the 20-29 year group, plateaued in the 40-49 year group, and then declined in the 50-59 year group. The authors examined muscular mechanisms through histochemical analysis from vastus lateralis muscle biopsy samples and revealed that the older participants experienced decreased proportions and selective atrophy of type II fibers.

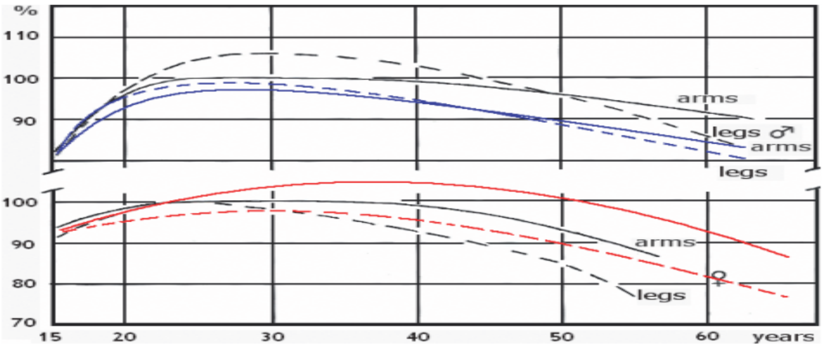

FIGURE 2. Percentage isometric strength for muscle groups of arms and legs in relation to age. Data in dark lines are from 1961 while data in blue (for men) and red (for women) are from 2009. (Adapted from Danneskiold-Samsøe et al., 2009).

Dynamic actions have been commonly assessed in its concentric (muscle shortening), and eccentric (active lengthening) phases (Roig et al., 2010). Studies have shown that while both isometric and concentric muscle strength decline with aging (Hortobágyi et al., 1995), eccentric strength is notably preserved even among the older (LaStayo et al., 2000; Hortobágyi et al., 1995; Melo et al., 2016; Pousson, Lepers, & Van Hoecke, 2001) due to the mechanisms within the musculotendon complex (Klass, Baudry, & Duchateau, 2005). Aging has also been reported to induce increased antagonist muscle coactivation (Arnold & Bautmans, 2014) in both isometric and dynamic actions (Häkkinen et al., 1998a). Coactivation is usually computed by expressing the EMG activity of antagonist EMG as a percentage of agonist muscle EMG contraction (Kellis, 1998). While antagonist coactivation can be useful in stabilizing joints to compensate for older strength declines, disproportional rates of coactivation could lead to further decreases in agonist net force production and voluntary activation (Arnold & Bautmans, 2014; Hortobagyi & Devita, 2006). In relation, although coactivation has been reported to reduce isometric and concentric strength, it was shown to have minimal effects on eccentric strength due to a relatively minor influence of agonist and antagonist muscles during eccentric force generation (Duchateau & Enoka, 2008; Klass & Duchateau, 2007).

2.2.2 Explosive strength declines

Another consequence of aging is a decline in explosiveness during muscular contractions (Häkkinen & Häkkinen, 1991). Explosiveness, or the capacity to quickly increase force or torque during a rapid voluntary contraction starting from rest (Maffiuletti et al., 2016) decreases at a faster rate than maximal strength during concentric, isometric (Häkkinen & Häkkinen, 1991; Häkkinen et al., 1995), and stretch-shortening cycle (SSC) actions (i.e., jumping, running) (Bosco & Komi, 1980; Larsson et al., 1979). For instance, Häkkinen et al. (1995) reported a diminished explosive force production capacity of the leg extensor muscles among three age groups of participants in their study (i.e., 30-, 50-, & 70-year groups), as illustrated by the changes in their force–time curves (figure 3). The authors also noted that their older participants experienced decreases in their capacity for maximal voluntary neural activation in the agonist muscles.

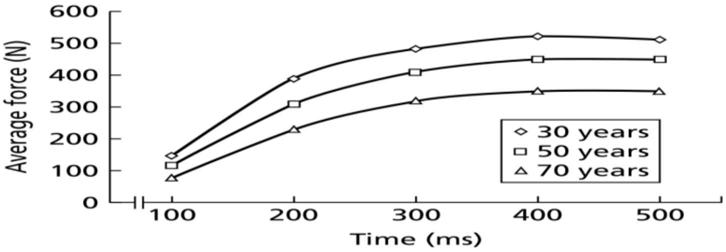

FIGURE 3. Average force–time curves of isometric bilateral leg extension action in men of three different age groups. (Modified from Häkkinen et al. 1995).

Explosiveness is usually assessed as the rate of torque development (RTD) from the torque-time curves (Aagaard et al., 2002) during isometric and dynamic voluntary contractions (Haff et al., 2005). Compared with measures of maximal force production capacity, the distinct physiological mechanisms that regulate RTD (i.e. neural, contractile) (Andersen & Aagaard, 2006) highlights its superiority in detecting acute and chronic neuromuscular changes (Jenkins et al., 2014) and at comparing age-related performance differences (Maffiuletti et al., 2016). Furthermore, RTD have been assessed in both "early" (less than 50ms) and "late" (150-250 ms) phases (Aagaard et al., 2002). Distinguishing the two may reveal distinct neuromuscular qualities (Andersen et al., 2010; Oliveira et al., 2013), with the early phase indicative of the neural components (Folland, Buckthorpe, & Hannah, 2014) and the late phase showing the twitch contractile skeletal muscle properties and maximal strength (Andersen & Aagaard, 2006).

Although the magnitude of age-related decreases in maximal and explosive strength are varied for each muscle, studies have consistently shown more rapid declines in the lower extremities (Candow & Chilibeck, 2005; Mitchell et al., 2012; Runnels et al., 2005; Viitasalo et al, 1985). This can be detrimental since explosiveness in the lower extremities is vital for daily living such as in performing functional tasks like stair climbing or walking (Bassey et al., 1992; Thompson et al., 2013).

2.2.3 Power declines

Power is lost more rapidly than strength in aging (Skelton et al., 1994; Candow & Chilibeck, 2005; Harridge & Young, 1997). Power refers to the capacity to do mechanical work, or when an applied force displaces the object acted upon (Moir, 2016, p.210). Since power is the product of muscle force and action velocity, the two most significant factors that can affect power production is the capacity to generate (1) maximal force at (2) high contraction velocities (Kawamori & Haff, 2004). A cross-sectional study by Skelton et al. (1994) among healthy adults aged 65-89 years reported that leg extensor power decreased at a faster rate of 3.5% per annum compared to decreases in knee extensor strength at 1.5%. Furthermore, Candow & Chilibeck (2005) showed that muscle thickness, torque and power in the lower extremity muscles among older adults (*age 59-76 years*) were significantly less compared to young adults (age 18-31 years) especially during a fast velocity contraction (*3.14 rad/s*). The authors discussed that a decreased content in myosin heavy chain IIB with aging could be a contributory muscular mechanism.

One common assessment of power is a vertical jump (VJ) (Buehring, Krueger & Binkley, 2010; de Vito et al., 1998). Laboratory assessments of VJ is usually performed on a force platform, where the resultant jump height is used to calculate lower limb power (Linthorne, 2001). Countermovement jump (CMJ) is one of the VJ variations that is commonly used in research to reveal age-related differences (Bosco & Komi, 1980; Moran et al., 2016). CMJ exemplifies a stretch–shortening cycle (SSC) action wherein an eccentric contraction occurs before a concentric muscle action (Larsson et al., 1979). The pre-stretch resulting from a combined use of stretch reflex and elastic energy potentiates leg extension further during a CMJ (Bosco et al., 1982). Investigating among young adults, Patterson & Peterson (2004) revealed that vertical jump and leg power norms for young adults were not different between young adults aged 21–25 and 26–30 years. On the other hand, a classic study by Bosco & Komi (1980) showed that while peak CMJ variables were attained in the 20-30 year group, a linear reduction became evident for the succeeding age groups (figure 4). The age-related decreases in reflex potentiation and elastic behavior of lower extremity muscles were among those suggested by the authors to explain their findings.

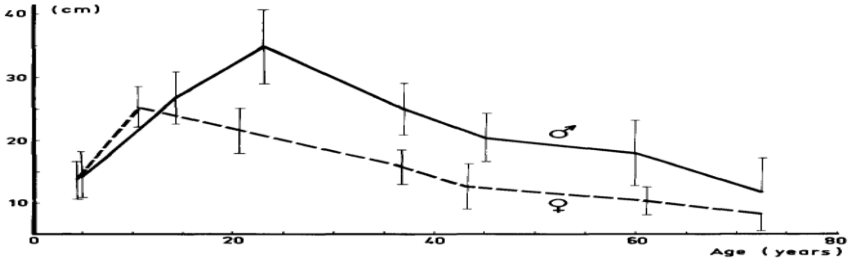

FIGURE 4. Mean (± SD) heights of rise in the countermovement jump in men (bold line) and women (broken line) of different age groups (Bosco & Komi 1980).

Furthermore, Reid et al. (2014) added that the stiffening caused by the changes in ligament, fascia, and tendon could also explain power reductions in aging, whereas Häkkinen (2003) stressed that age-related declines in jump performance seem to be caused not only by a reduced capacity for explosive force production, but also because of a lower absolute maximal strength in the lower extremities. Finally, another important factor that may significantly affect both jump performance and daily functions among the older is coordination (Haguenauer et al., 2005). de Vito et al. (1998) reasoned that a diminished coordination caused a lesser vertical velocity, and eventually the over-all jump peak power among older participants aged 50-75 years in their study.

2.2.4 Body composition changes

Another consequence of aging that has been attributed as a major cause of strength and power declines with aging is the loss of muscle mass (Frontera et al., 2000; Klein, Rice, & Marsh, 2001). In a classic study which aimed to study the effects of aging on the human skeletal muscle, Lexell, Taylor, and Sjöström (1988) examined autopsy data from the vastus lateralis muscle among 43 previously physically active adults aged 15-83 years. Their results revealed muscle atrophy at an early age of 25 years, which seemed to occur at an accelerated rate thereafter. They also found that 10% of the original muscle mass was already lost by age 50 and that by age 80, only about half of a person's original muscle mass was left due primarily to muscle fiber losses and due partly to decreases in type II fiber sizes.

In addition, Lexell, Taylor, & Sjöström (1988) reported that although reinnervation could still occur even with increased age, the older muscle fibers seem to undergo a denervation process that triggers muscle replacements by fat and fibrous tissue. All these consequent led to decreases in older muscle tissue proportions. The infiltration by fat and connective tissue have been found to represent 15% of the total muscle cross-sectional area (CSA) in sedentary adults and have led to further lessening of the net muscle contractile tissue CSA (Taaffe et al., 2009). These results are in agreement with the findings of Jackson et al. (2012) which showed that while fat-free mass increased between age 20 to 47 years, an age-related non-linear rate of fat-free mass decreases occur thereafter as observed among their 7,265 healthy adult participants. Moreover, in a 5-year longitudinal study among 1,678 participants, Delmonico et al. (2009) revealed age-related increases in intermuscular fat assessed using computed tomography (CT) in the mid-thigh skeletal muscle. The authors found concomitant intermuscular fat increases over 5 years, irrespective of the changes in weight or subcutaneous thigh adipose tissue among their participants. Their team also showed that maintenance of muscle mass does not prevent strength loss.

2.2.5 Balance control changes

The neuromuscular system has been found to undergo age-related structural and functional changes that may damage the motor output necessary for balance control

(Abrahamová & Hlavacka, 2008; Papegaaij et al., 2014). Balance control refers to the maintenance of the center of mass within the base of support (Yim-Chiplis & Talbot, 2000). Age-related differences in balance control systems have been examined under static and dynamic conditions (Prioli et al., 2005; Richerson et al., 2003).

2.2.5.1 Static balance control

Static balance refers to the capacity to minimize upright postural sway (Woollacott & Tang, 1997). Winter (1995) proposed that postural control in minimizing body sway during standing follows an inverted pendulum model, whereby appropriate mechanisms are integrated for the primary goal which is to stabilize the pendulum from its base (Loram & Lakie, 2002). Across age groups, strategies for postural control varies depending on the sway direction (i.e. ankle strategy in the anteroposterior (AP) direction; hip load or unload strategy in the mediolateral (ML) direction) (Winter, 1995). In standing upright, the central nervous system has to efficiently integrate the information coming from various sensory systems (i.e., visual, vestibular, and somatosensory systems) in order to produce an appropriate postural response through the motor system (Gaerlan et al., 2012; Horak et al., 1989). The declines in the musculoskeletal and sensory systems along with changes in the brain structure and cognitive status with aging (Sullivan et al., 2009) lead to deteriorations in postural control (Isles et al., 2004).

In a study among 81 healthy subjects age 20-82 years, Abrahamová & Hlavacka (2008) found that center of pressure (COP) parameters including root mean square (RMS), amplitude and velocity increased in the anteroposterior (AP) direction at age 60 years, which implies a reduced postural control with aging. Their data showed that COP parameters in all three age groups (i.e., young, mid, & older) increased during eyes closed condition, and that there were clear differences in the RMS between young ($\bar{X}$ = 24.8 years) and older ($\bar{X}$ = 70.7 years) groups, which were likely due to combined sensory deficits (i.e., visual, somatosensory or both) in aging. Their study determined that RMS, COP amplitude, and velocity in AP direction were the most sensitive data in determining static balance control. In addition, Prioli et al. (2005) in their study which compared static balance control on moving room condition, found that sedentary older adults had longer latencies or higher thresholds in generating appropriate motor response for decreasing body sway or oscillations as compared with the active older and young adult groups. Their study proposed that static balance is dependent on the coupling between sensory information and motor response, and that sedentary adults had greater difficulty in discriminating and integrating sensory stimulus.

Older adults were reported to use proprioception more than visual and vestibular cues for postural control (Wiesmeier, Dalin, & Maurer, 2015) while young adults on the other hand predominantly use the visual system more than the vestibular and somatosensory systems (Gaerlan et al., 2012) Nevertheless, some studies argued that static balance studies are generally limited at revealing balance mechanisms (Winter, 1995) and that they do not clearly reveal balance disorders or age-related differences as dynamic balance assessments would (Baloh et al., 1994).

2.2.5.2 Dynamic balance control

Dynamic balance control refers to the capacity to minimize upright postural sway while the body is in motion, or in response to postural perturbations (Hughes et al., 1995; Winter, 1995). Compared to young adults, a dynamic balance control response in older adults is characterized by larger latencies in voluntary or postural muscle response resulting to slower feed-forward activation during a stabilizing movement (Woollacott, Inglin, & Manchester, 1988). Dynamic balance control is accomplished through (a) detection of sensory information regarding motion and orientation, (b) selection of appropriate postural responses, and (c) activation of muscles to overcome balance disturbance (Enoka, 2008, p.273). Several systems (i.e., nervous, sensory, and motor systems) have to coordinate in generating postural responses that are appropriate for the specific type of balance disturbance (Chen et al., 2014; Shumway-Cook & Woollacott, 2001). Specifically, the muscles and tendons are crucial for the motor system (Riemann & Lephart, 2002) since they are needed during the execution of primary motor control strategies for dynamic balance (i.e., ankle, hip, mixture of ankle & hip, or step strategies) (Horak et al., 1989; Winter, 1995).

Postural perturbations, or the sudden externally induced conditions aimed at displacing the body from equilibrium have been studied to examine reactive postural responses (Chen et al., 2014). Postural perturbation response have two phases, namely 1) postural disturbance phase and 2) postural response phase (Szturm & Fallang, 1998). Nashner & Cordo (1981) early on described the order of muscular response following a perturbation to begin with a stretch reflex (latency 40–50 ms), followed by automatic postural responses (latency 70–150 ms), before finally producing voluntary/cognitive responses (180– 250 ms). The recent technological advances in bioengineering have led to the manufacture of more sophisticated perturbation devices that closely replicate common postural disturbances such as slipping, tripping, and accelerating or decelerating (Blomqvist, Wester, & Rehn, 2014; Chen et al., 2014; Nonnekes et al., 2013; Piirainen et al., 2013). Some of these perturbation devices were designed as tilting platforms, rotating platforms, and translating platforms (Winter, 1995). Postural response to the translating platform perturbation will depend on the velocity, amplitude, and displacement waveform (Chen et al., 2014).

Across age groups, the ankle strategy appears as the primary response for unexpected perturbations at the anterior-posterior direction. When the ankle torques are insufficient at restoring balance, other strategies such as the knee or hip strategies are performed (Horak, Sharon, & Shumway-Cook, 1997). An examination of perturbation responses by Piirainen et al. (2013) revealed that age-related differences in dynamic balance control were more evident in response to the anterior rather than posterior perturbations, and that the older have larger peak COP displacement and shorter time to peak displacement in response to slow perturbations. Among young adults on the other hand, Chen et al. (2014) found that the ankle and knee joints were significantly affected by perturbation onset latency. Their kinematic investigation also showed that during backward translations, the common reaction among young adults was a hip flexion together with arm movements, while forward translations were responded alternatively with hip extension and knee flexion (figure 5). Decreased central processing and slower sensory and motor conduction of the neuromuscular system have been reported to be responsible for the delays in muscle activation response to perturbations among young adults (Woollacott, Inglin, & Manchester, 1988). Nevertheless, perturbation response in young adults remain generally superior to the older as demonstrated in several studies like that of Lin & Woollacott (2002) which found that the response time for gastrocnemius during backward perturbations was 89ms for young adults ($\bar{x}$ = 25 years) and 93ms for older adults ($\bar{x}$ = 73.5 years).

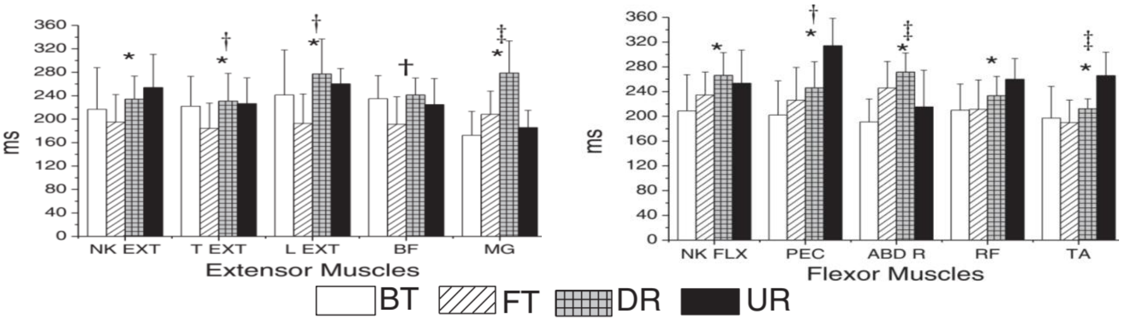

FIGURE 5. Young adult EMG onset latency for the extensor and flexor muscles [cervical paraspinae (NK), thoracic paraspinae (T EXT), lumbar paraspinae (L EXT), biceps femoris (BF), medial gastrocnemius (MG), neck flexor (NK FLX), pectoralis major (PEC), abdominal rectus (ABD R), rectus femoris (RF), tibialis anterior (TA)] during four types of platform displacements [backward translation (BT), forward translation (FT), toe-up rotation (UR), and toe-down rotation (DR)] (Chen et al., 2014).

Since quick and high forces are needed to maintain balance during sudden perturbations, the capacity for high power production especially in lower extremity muscles are critical to prevent falls (Piirainen et al., 2010; Piirainen et al., 2013). Unfortunately, neuromuscular factors such as an increased antagonist coactivation, decreased agonist activation (Laughton et al., 2003), along with diminished structural and functional motor systems increases the risk for falls among the older (Horak et al., 1989).

3 RESISTANCE TRAINING DURING AGING

3.1 Declines in physical activity

Although no universally-accepted criteria yet exists for the diagnosis of age-related weakness in sarcopenia and dynapenia, common measurement variables include 1) physical function, 2) muscle strength, and 3) muscle mass (Cruz-Jentoft et al., 2010; Law, Clark, & Clark, 2016). Several factors, including altered enzyme activity, poor nutrition, changes in the endocrine system, or reduced physical activity, have been investigated for their influence on the age-related weakness (Nashner et al., 1989; Vandervoort, 2002; Clark & Manini, 2010). Among these factors, the effects of reduced physical activity with aging is often overlooked (Narici et al., 2004).

In order to examine the effects of physical activity reductions, D'Antona et al. (2003) studied the effects of immobilization on age-related weakness. In their investigation, biopsy samples were taken from the VL muscle among older (age 72.7 ± 2.3 years) and young adults (age 30.2 ± 2.2 years) whose right leg had been immobilized for 3.5 months. Their results revealed that both immobilization and ageing affected myosin concentration on single fibres in both groups, and that older group underwent further reductions in the shortening velocity of their muscle fibres. The research concluded that immobilization in both groups decreased muscle power not only due to the loss of mass but also to the loss of the intrinsic force development capacity of their muscle fibers. Moreover, in a study by Morse et al. (2004), their healthy, non-sedentary older adult subjects had 30% less physical activity than young adults on an average week, which the authors hypothesized to be an apparent reason for a reduced plantar flexor activation capacity among the older.

Various physical activity interventions have been investigated but with inconsistent results (Kim et al., 2012). Some studies have shown that leisure time physical activity only had minor effects in slowing muscle loss seemingly due to a lack of the needed intensity required to induce positive neuromuscular adaptations (Mitchell et al., 2003; Waters et al., 2010), whereas other studies have shown that among regularly exercising older groups, losses in muscle strength (Marcell, Hawkins, & Wiswell, 2014), and power (Dreyer et al., 2006) were found to be similar among their non-exercising counterparts. Gregg, Pereira, & Caspersen (2000) in a review discussed that higher levels of physical activity could reduce falls in older adults. Nevertheless, they stressed the need to conduct further research on the most optimal type and quantity of physical activity to effectively manage various age-related weaknesses.

Currently, no other intervention has been proven to be as successful as resistance training (RT) at preventing the onset of age-related declines in muscle function, or at increasing strength and power among older adults (Macaluso & de Vito, 2004; Peterson et al., 2010; Häkkinen et al., 2002). RT refers to the structured, voluntary movement exerted against an external load (Fleck & Kraemer, 2014, p.1) that is progressively increased as strength improves (Kraemer & Ratamess, 2004; Liu & Latham, 2009). The American College of Sports Medicine (ACSM) Physical Activity Guideline recommends twice-a-week of RT among adults (Ratamess, 2012). Adherence to this guideline was reported to bring positive neuromuscular adaptations independent of age (Häkkinen, 2003).

3.2 Neuromuscular changes in resistance training

The adaptations that are responsible for increased force generation after RT in both young and older adults were found to be primarily due to two distinct mechanisms. Neural or ‘neurogenic’ adaptations dominate in the acute response, whereas muscular or ‘phenotypic’ adaptations arise at a later onset (Häkkinen et al., 1998a, 1998b, 2001; Moir, 2016). A great variety of neural adaptations have been reported from RT participation (Duchateau, Semmler, & Enoka, 2006) and they have been categorized into those that affect cortical maps, motor command, descending drive, muscle activation, motor units, and sensory feedback (Duchateau & Enoka, 2002).

One of the vital neural adaptation with RT especially in relation to falls is an increased descending neural drive (Aagaard et al., 2002; Unhjem et al., 2015). RT participation have led to increases in surface electromyography (EMG) amplitude, which may indirectly indicate increased central and neural drive to the trained muscles (Aagaard et al., 2002; Häkkinen et al., 2000), increased rate of torque development, and increased discharge rate of motor units (Duchateau, Semmler, & Enoka., 2006). Although humans have been shown incapable of voluntarily producing maximal muscle force (Dowling et al., 1994), the exposure to ample RT intensities has been found to increase this ability (Unhjem et al., 2015).

In regard to muscular adaptations, a meta-analysis of 81 cohorts among older adults revealed a great inconsistency of findings regarding the dose-response relationship of RT for muscular adaptations. Nevertheless, the study found a strong association between RT and increased lean body mass (LBM) (Peterson, Sen, & Gordon, 2011). LBM has been regarded as a convenient indicator of changes in the skeletal muscle tissue and has been shown to improve among older adults after RT with high volumes (Peterson, Sen, & Gordon, 2011; Narici et al., 2004). However, LBM is incapable of quantifying changes in the skeletal muscle and in providing specific details regarding biomolecular morphological adaptations (e.g. in a single muscle fiber cross-sectional area) (Peterson, Sen, & Gordon, 2011). Nevertheless, a number of muscular adaptations have been reported from older adult RT participation such as muscle fiber hypertrophy in type II fibers, fiber type transformation (i.e. shift from type IIB to IIA myosin heavy-chain isoforms), and architectural adaptations (i.e. increased pennation angle after heavy RT, or increased fiber length after explosive training) (Narici et al., 2004; Scanlon et al., 2014; Moir, 2016).

While some longitudinal studies found no age-related differences in hypertrophic response between the older and young adults in either short (10 weeks) (Häkkinen et al., 1998b) or long (6 months) RT durations (Roth et al., 2001), most studies have reported reduced hypertrophic response in the older (Kosek et al., 2006; Mero et al., 2013; Welle, Totterman, & Thornton, 1996). The decreased hypertrophic response in aging has been associated to an age-induced anabolic resistance of intracellular signaling and muscle protein synthesis (Kumar et al., 2009; Welle, Thornton, & Statt, 1995). Moreover, the strength gains after RT among the older have been reported to be primarily induced by neurological adaptations rather than muscle fiber hypertrophy (Frontera et al., 1988; Häkkinen et al., 1998a).

3.3 Acute resistance training variables

RT induces specific adaptive responses depending on the programming of various RT variables such as intensity, volume, order, and frequency of exercises (Ratamess, 2012). The seminal works of DeLorme (1945) and DeLorme & Watkins (1948) on progressive overload whereby increments are ensured as neuromuscular gains are achieved (Peterson, Rhea, & Alvar, 2005; Peterson et al., 2010; Zatsiorsky & Kraemer, 2006) became the foundation of modern day RT designs (Bird, Tarpenning, & Marino, 2005).

Intensity. RT intensity pertains to the load being lifted as a percentage of an individual's one repetition maximum (1-RM) (Magyari, 2010). The ACSM position stand (Ratamess et al., 2009) suggests that higher intensity RT lead to greater strength gains among adults. In young adults, Seynnes et al. (2007) reported that 35 days of high intensity RT resulted to changes in muscle size that were already observable even just within 3 weeks on the program. The study also found that remodeling of muscle architecture among the young participants preceded the gains in muscle cross-sectional area (CSA). Among older adults on the other hand, Fiatarone et al. (1994) showed that loads nearing 80% of 1-RM were helpful in optimizing training adaptations even among frail older adults. The authors however cautioned that training supervisors have to consider the higher injury risks (Porter, 2006).

The most commonly examined percentage range in older adult RT interventions is at 50%-85% of 1-RM or at 6-to 12-RM zones (Fleck & Kraemer, 2014). Motor unit activation were found to depend on the magnitude of load, such that highest threshold motor units are instantly recruited when lifting heavy loads, but delay their recruitment when lifting only light loads (Schoenfeld et al., 2016, 2017; Helms et al., 2015). Tesch et al. (1998), upon examining glycogen depletion in VL biopsy samples from young participants, also showed that recruitment of fast-twitch (Type II) fibers depended on exercise intensity. Their team found that although lighter load (30% of 1-RM) was shown to evoke losses in glycogen energy sources at Type IIA muscle fibers, Type IIAB and IIB fibers were activated only at 50%-60% of 1-RM.

Moreover, in a meta-analysis of 47 studies, Peterson et al. (2010) reported that high intensity RT resulted in greater strength among older adults. The authors noted a 5.3%

average strength enhancement for every increase in loading intensity [i.e., increases from low (<60% of 1-RM), to low/moderate (60–69% of 1-RM), to moderate/high (70–79% of 1-RM), and to high (≥80% of 1-RM)].

Volume. In a review of several RT intervention studies, volume was found to be the most controversial variable in relation to its effectiveness and risk-reward trade-offs (Peterson et al., 2010). Studies have generally shown that although aging could reduce the amount of RT induced LBM adaptations, higher RT volume is vital for maximizing anabolism (Peterson, Sen, & Gordon, 2011). Volume simply refers to the amount of exercise performed over a period of time and is often expressed as the number of repetitions completed in a resistance training bout (sets × repetitions) (Schoenfeld, 2016, p.51). Other variables that would significantly affect RT volume include duration and frequency (Stone et al., 2000).

Regarding the number of sets, Galvão & Taaffe (2005) assessed the effect of single-set versus multi-set twice weekly RT among older adults aged 65 to 78 years. Their group found that even low-volume, single set trainings resulted in substantial strength improvements, although not to the same extent as multi-set. Both regimens were also accompanied by modest increases in lean mass. On the other hand, Radaelli et al. (2015) examined the dose-response of 1, 3, or 5 sets in progressive RT among young adults during a 3-days/week program which lasted for 6 months. They found that multiple sets were superior for strength gains, muscle endurance, and upper arm muscle hypertrophy. The same trend was seen (i.e., 3 sets are better than 1 set) even when the program duration was shortened to just 12 weeks (Rhea et al., 2002). Among young adults, multi-set regimens seemed to induce greater intracellular signaling and muscle protein synthesis compared with single-set (Burd et al., 2010).

As for the number of repetitions, ranges are commonly classified as heavy (1- to 5-RM), medium (6- to 12- RM), and light (15+RM) (Schoenfeld, 2010). A study by Nicholson, Mckean, & Burkett (2015) showed that among the older participants during a 26-week choreographed group class which utilized light weights and very high-repetitions (70–100 reps per body part), adaptations included increased maximal strength, gait speed and static balance control. Among young adults on the other hand, Campos and colleagues (2002) examined 3 types of RT intensities (low: 3–5 RM with 3 min rest in between sets & exercise; mid: 9–11 RM with 2 min rest; high: 20–28 RM with 1 min rest) after 4 weeks of only leg press, squat, and knee extension exercises. Results from their VL muscle biopsy results revealed that types I, IIA, and IIB hypertrophied in the low and mid groups, without any change in the high group. Remarkably, type IIB transformed to type IIA in all groups. While there were relatively similar muscular adaptations in all groups, authors noted that the high-group was superior in aerobic power, time to exhaustion, sub-maximal and prolonged contractions. The authors hypothesized the intensity and number of repetitions in their RT program to have caused the varied adaptation response.

Duration. Silva et al. (2014) in a meta-analysis which examined 8-52 week RT programs found that RT participation produced significant strength gains among the older only with extended training durations, and that longer durations also had greater strength yield compared to shorter duration studies. For instance, 8 weeks of progressive RT showed a non-significant 1.5% increase in elbow flexor CSA among the older, whereas young adults already incurred hypertrophy at 4 weeks and increased further to 9.1% after 8 weeks. Caution should however be exercised since CSA was measured using an imprecise anthropometric method (Moritani & DeVries, 1980). In another study, 12 weeks of heavy RT among the older eliminated only the deficits in leg press strength but not in muscle size, when compared to that of young adults (Candow et al., 2011). Nonetheless, Kosek et al. (2006) showed that after only 16 weeks of 3 days/week RT, older adults were able to restore their type II fibers similar to that of the pre-training sizes found in young participants.

Frequency. The ACSM position recommends at least two RT sessions per week among healthy adults (Ratamess et al., 2009). In a study comparing the effects of 1- versus 3-days per week *(days/wk)* of equal-volume RT among resistance-trained young adults, McLester & Guilliams (2000) found maximal strength increases among the 1-day/wk group, although the 3-days/week group produced superior gains in 1RM and lean body mass. Among the older, a review which examined the dose-response relationship of RT, suggested that 2-3 days/wk yielded large effects on muscle strength (Borde, Hortobágyi, & Granacher, 2015). Nevertheless, Taaffe et al. (1999) showed that 24 weeks of 1 day/wk of heavy RT improved muscle strength and neuromuscular performance among the older.

3.4 Types of resistance training

The manifestation of desired training goals and the transfer of training effects rely primarily on the specificity of the training program (Stone et al., 2002). This implies that the acquisition of performance improvements will largely depend on the similarity of the kinetic and kinematic training conditions (i.e., movement pattern, joint position, velocity) with the testing conditions (Beurskens et al., 2015; Ema et al., 2017; Stone et al., 2000). Several types of RT have been studied for their effects for age-related weakness.

3.4.1 Hypertrophy Training

Hypertrophy RT is characterized by training at a medium-repetition range of 6–12 reps per set with 60–90 seconds rest intervals between sets (Schoenfeld, 2010) using loads approximately 65% of 1-RM or greater (McDonagh & Davies, 1984; Wernbom, Augustsson, & Thomeé, 2007). This type of resistance training has been shown to induce significant metabolic stress and mechanical muscle tension that is capable of producing maximal gains in LBM (Schoenfeld, 2010).

In a study which investigated the effects of both age and hypertrophic RT during 21 weeks of 40–80% 1-RM training loads, Mero et al. (2013) revealed that both type I and type II VL muscle fibers increased more in young adults than the older, and that leg extension 1RM after 10.5 weeks was also higher in young adults. The authors found that the statistical difference of the results from the young adults compared to the older disappeared after the entire 21-week intervention. The authors suggested that an increased myostatin gene expression along with a lower protein intake may explain the lower magnitude of adaptations among the older.

As for balance control, the author of the current study found no research that directly investigated the effects of hypertrophy RT on balance, which seem to be supported by a finding that muscle strength, not muscle mass, was associated with standing balance (Bijlsma et al., 2013).

3.4.2 Heavy Resistance Training

Traditional heavy resistance training (HRT) which uses high loads at 80% of 1-RM using slow movement velocities (Miszko et al., 2003) has been shown to significantly increase maximal strength of the trained adult muscle, albeit with minor changes in explosiveness (Häkkinen et al., 1998b). Nevertheless, 14 weeks of HRT among young adults increased explosive muscle strength (i.e., contractile RFD and impulse) which seemed to be due to an enhanced neural drive as shown by the increased EMG signal amplitude and rate of EMG rise during the early phase of muscle contraction (Aagaard et al., 2002).

Among the older, Lexell et al. (1995) reported that after 11 weeks of HRT, increases in 1RM values already occurred in elbow flexion and knee extension (i.e., 49% ±16 and 163% ±75 respectively). Results from the muscle biopsies showed adaptations in muscle fiber type population such as an increased fiber area of both type I & II in the biceps brachii, and type II in the VL. Increases on non-mass dependent muscular factors such as muscle fiber fascicle length (10%) and tendon stiffness (64%) have also been reported (Reeves, Maganaris, & Narici, 2003). Moreover, 8 weeks of HRT among nonagenarians (age 90 ± 1 years) have also been shown to increase muscular CSA, functionality, and lower-extremity, with the latter widely ranging from 61 - 374% (Fiatarone et al., 1990).

Increasing HRT duration further, Frontera et al. (1988) reported that 12 weeks of HRT augmented lower extremity strength by 227% among the sedentary older participants. On the other hand, Beurskens et al. (2015) found that 13 weeks of HRT increased the older MVIC at levels similar to the magnitude of improvements among young adult counterparts. Ferri et al. (2003) also showed that 16 weeks of 3-days/wk of HRT using only 2 exercises (i.e., calf raise and leg press) induced greater muscle power increases than isometric strength among the older. The authors explained that the improved strength and not force generation velocity was responsible for the increased power generation.

Pertaining to balance, results from HRT interventions have been inconsistent. Studies among the older showed that 13 weeks of HRT did not improve their ability to compensate for perturbations in platform tests (Granacher et al., 2009) and gait tests (Granacher et al., 2006) even if subjects demonstrated improvements in maximal and explosive strength. In contrast, a study by Hess et al. (2006) showed that among balance-impaired older adults, 10-weeks of HRT which targeted the lower extremity muscles, particularly the tibialis anterior (dorsiflexor), gastrocnemius (plantar flexor), quadriceps (knee extensor), and hamstrings (knee flexor), successfully enhanced maximal strength, explosive strength, and dynamic balance control during perturbations. The authors suggested that the increased force production in the ankle contributed primarily for greater balance control.

3.4.3 Power training

Power training refers to a resistance training program that focuses on moving loads with fast velocities (de Vos et al., 2005; Miszko et al., 2003; Orr et al., 2006) such that concentric action usually lasts for only a second compared with a longer duration (approximately 2 seconds) of eccentric action (Miszko et al., 2003). A review by Porter (2006) discussed that power training was better than heavy-resistance strength training at enhancing explosiveness among the older. In an 8–12 week power training study by de Vos et al. (2005), explosive training at high loads (80% of 1RM) resulted to greater magnitudes of improvements in muscle power, strength and endurance compared with medium (50% of 1RM) and low loads (20% of 1RM). Nevertheless, all the loads gave similar relative improvements in peak power in the older.

In a similar study, Kaneko et al. (1983) reported that training at 30% of MVIC produced greater improvements in peak power compared to training at 60% or 0% MVIC, although training at 100% MVIC was similarly effective. Their study also demonstrated the ‘specificity’ in adaptations to power training effect such that training at 0% MVIC through maximum isotonic contractions was most effective for increasing maximal velocity during the test without an external load. The greatest increase in maximal strength was only seen after training at 100% MVIC.

Since rapid force production declines at a faster rate than maximal strength with aging (Skelton et al., 1994), an emphasis on explosive force production during RT is necessary during workouts in the older. Power is a product of force generation and speed/velocity of muscle contraction (Evans, 2000). Both components must be trained to optimize power measures. The primary adaptations from power training include efficient early voluntary activation, increased neural activity, increased agonist activation, decreased antagonist co-activation, and a minor change in hypertrophy (de Vos et al., 2005; Häkkinen et al., 1998b; Piirainen et al., 2014). These adaptations were reported to help increase dynamic balance control especially among the older (Izquierdo et al., 1999; Orr et al., 2006). A dose-response study by Orr et al. (2006) showed that low intensity (20% of 1RM) power training induced the greatest magnitudes in balance performance, when compared with medium (50%) or high (80%) intensity. Their findings support the ACSM recommendation for power training among older adults, which is to train at 1-3 sets of with light to moderate loads (40–60% of 1RM) at high-movement velocity (Ratamess et al., 2009).

Moreover, a review by Granacher et al. (2011) demonstrated the superiority of power training over traditional HRT at improving measures of balance and strength although only one study (Orr et al., 2006) used a perturbation device for measuring balance control while the rest tested with functional dynamic tests. Furthermore, a cross-sectional research design between young adult athletes who were either power- or endurance-trained showed that the power-trained group stabilized their COP faster (figure 6) and at activating postural muscles during a fast horizontal platform perturbation (10cm at 80 cm/sec) (Johnson & Woollacott, 2011). Authors hypothesized this was due to the greater association of their training background with what the test demanded.

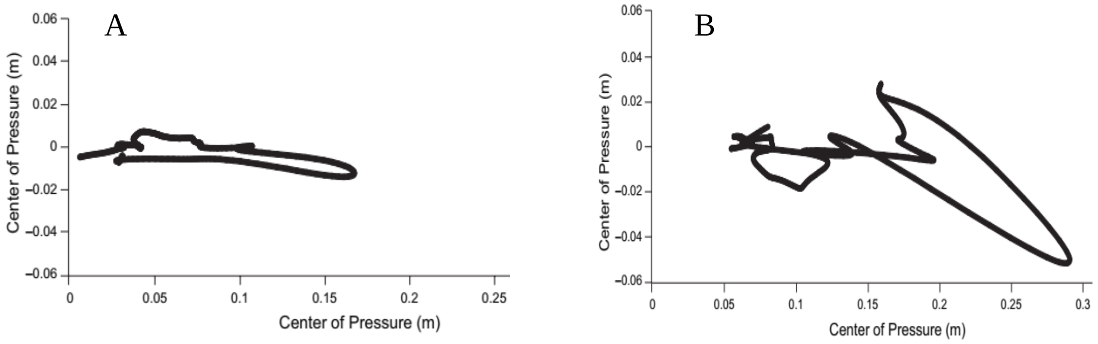

FIGURE 6. Center-of-pressure trajectory for power- (A) and endurance-trained (B) athletes in response to fast perturbation (Johnson & Woollacott, 2011).

3.4.4 Plyometric Training

Several power training studies included jump training, otherwise called plyometrics, to generate improvements in power production (Piirainen et al., 2014; Chimera et al., 2004; Kyrolainen et al., 2005). Plyometric training focuses the stretch shortening cycle (SSC), a muscle mechanical behavior where the pre-stretch of an active muscle potentiates the subsequent concentric contraction (Bosco & Komi, 1980). The usually reported positive neuromuscular adaptations derived from plyometric exercises include an improved intermuscular coordination, increased muscle voluntary activation, increased fiber shortening velocity, increased muscle fiber power output, increased joint stiffness, and muscle fiber hypertrophy (Markovic & Mikulic, 2010).

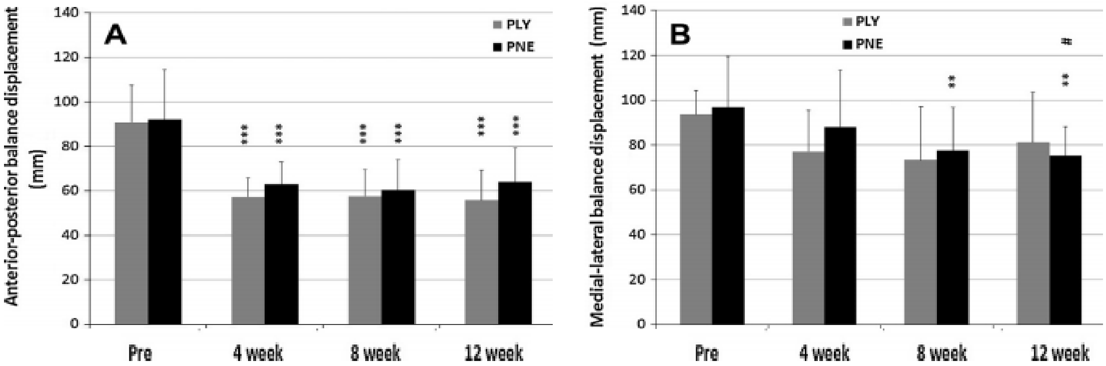

FIGURE 7. Anterior–posterior (A) and medial–lateral (B) COP displacement before, during and after 12 weeks of pneumatic (PNE) or plyometric (PLY) training (**p < 0.01, ***p < 0.001 compared to pre-level) (Piirainen et al. 2014).

Pertaining to balance, a study by Piirainen et al. (2014) among the older showed similar benefits in perturbation response from 12-weeks of either plyometric training or pneumatic power training (figure 7). The authors found that dynamic balance correlated with increased rapid knee extension torque, albeit with some mechanical between-group differences in the adaptive response (i.e., pneumatic group increased vastus lateralis muscle activity and knee extension torque, but the plyometric group did not show increments in the triceps surae muscle activity during maximal knee extension isometric contractions). The authors associated the enhanced pneumatic group performance with an increased neural drive, while adaptations in the plyometric group seemed to be explained by other mechanisms such as increased utilization of elastic energy or increased reflex activity. Although authors cautioned on the interpretation of the results due to unmatched training loads and task specificity, their results highlight the efficacy of focusing on rapid force production to improve dynamic balance in older adults.

The different benefits that come from each training type have also encouraged studies which examine the effects of combining different training types while being progressed in a linear fashion. Combined heavy RT and power training that lasted for 6 months was shown to improve both MVC and isometric RFD during concentric actions in older adults (Häkkinen et al., 1998b; 2001) while a 12-week combination of heavy RT with loaded plyometric exercises among young adults was found to promote greater adaptations in muscular strength indices than what would have been achieved if performed with either type of exercise in isolation (Prue Cormie, McCaulley, & McBride, 2007).

Moreover, while improvements in strength and power as a result of RT participation are well substantiated in research (Macaluso & de Vito, 2004), adaptations that optimize balance-control seem to warrant further investigations (Behm et al., 2015; Muehlbauer et al., 2015). In a review among older adult interventions which compared current approaches in enhancing balance (i.e., traditional, multitask, & perturbation-based balance training) and strength (i.e., traditional, high-velocity, or power training), Granacher, et al. (2011) suggested that power training was better at improving explosive force production and physical functions than traditional RT. Nevertheless, adaptations from RT participation among the older have generally shown to have large inter-individual variations (Häkkinen et al., 1998b).

3.5 Periodized Resistance Training

Conventional RT interventions for both older and young adults have been commonly programmed using the progressive overload principle (Hass, Feigenbaum, & Franklin, 2001). In this approach, the exercise intensity (i.e. load) is gradually increased while the number of sets and repetitions are held constant (Ferri et al., 2003; Häkkinen et al., 2002; Krist, Dimeo, & Keil, 2013). However, monotonous training seem to be disadvantageous since it could induce psychological symptoms such as mental fatigue and mood disturbances (Fry et al., 1994; Wan et al., 2017). Guided by the principles from the general adaptation syndrome earlier proposed by Hans Selye in 1976 (Kraemer et al., 2002), the insufficient recovery and monotony from a linear loading could lead to stagnation or overtraining (Williams et al., 2017). An approach used to maximize the benefits of RT among adults which appears to also be the most examined resistance training theory pertaining to RT variation is periodization (Kraemer et al., 2002). This refers to the careful programming or manipulation of acute training variables into manageable fitness phases and time periods (Kraemer et al., 2002). Periodization is done by dividing the overall training period *(lasting 1 to 4 years)* (Fleck & Kraemer, 2014; Strohacker et al., 2015) into manageable mesocycles *(lasting weeks to months)* or further into shorter cycles or "periods" called microcycles *(lasting usually for 1 week)* (Williams et al., 2017). The programming variations and planned recovery in periodized RT have been reported to optimize fatigue management, physical preparedness and performance optimization (Williams et al., 2017)

In a periodized RT, the mesocycles are usually treated as a block where workout sessions are targeted at achieving specific training outcomes (i.e., strength, power, hypertrophy, etc.) (Conlon et al., 2016). Traditional or parallel periodization is usually implemented using a planned timing which combines periods of overload and recovery, shifting from general- to specific-training, or from high volume/low intensity to low volume/high intensity (Kraemer & Ratamess, 2004). During the final mesocycle, or theoretically the period when the maximal strength is acquired (DeBeliso et al., 2005), the main objective is usually to peak the subject for competition or testing (Schoenfeld, 2016).

Most periodization studies have focused on trained young adults (Grgic et al., 2017; Rhea & Alderman, 2004; Williams et al., 2017). Majority of the investigations compared periodized and non-periodized RT - the latter referring to an RT program with more frequent variations in volume and intensity within shorter cycles/schedules (i.e., weekly or even daily basis) (Majeedkutty et al., 2018). Compared to non-periodized RT, superior adaptations in lean body mass, percent body fat (Kraemer, 1997), strength (Willoughby, 1993), and power (Baker, Wilson, & Carlyon, 1994) have been reported for periodized RT especially during initial training periods, (Fleck, 1999; Prestes et al., 2009; Rhea & Alderman, 2004; Rhea et al., 2003) among young adults. On the other hand Majeedkutty et al. (2018) reported contrasting findings pertaining to balance, such that a non-periodized RT enhance dynamic postural control, but not periodized RT. The short 4-week intervention used in their study, in addition to the limitation of using a field test (i.e., Y-Balance Test) could help explain the result. Furthermore, a meta-analysis by Williams et al. (2017) examined several types of periodization (i.e., traditional, undulating, block, etc) and showed that periodized RT is vital for optimizing maximal strength but suggested higher gains from longer participation at higher frequencies.

Periodized RT interventions among the older, however, are still limited despite its widespread application in fitness and sports (Conlon et al., 2016; Debeliso et al., 2005; Jimenez & Paz, 2011). In fact, some studies have raised that in general, inactive older adult would likely acquire certain health gains upon participation in any type of RT which makes it unnecessary to design rigid manipulations in training intensities aimed at increasing strength levels during the acute phase of RT (Strohacker et al., 2015). This finding is supported by a finding by DeBeliso et al. (2005) which revealed that 18-weeks of conventional fixed repetition versus periodized RT among the older resulted in similar magnitudes of strength gains. However, certain modifications may be added to ensure an increased RT adherence, and to prevent physical or physiological signs of overtraining syndrome among the older RT participants, (Ekkekakis, Parfitt, & Petruzzello, 2011).

The progressive overload and variation used in a periodized RT have been reported as a feasible regimen (Haff, 2004; Strohacker et al., 2015). Relatively recent investigations have shown that short-term periodized RT seem to also induce positive adaptations in 1-RM (Williams et al., 2017), functional capacity, lower limb strength, and power (Jimenez & Paz, 2011; Prestes et al., 2015). However, studies found that short-term periodized RT failed to decrease body fat or increase body mass among the older (Maddalozzo & Snow, 2000; Prestes et al., 2015), while extending the duration to 6 months increased the older lean body mass (Maddalozzo & Snow, 2000). In addition, Conlon et al. (2016) reported that balance confidence assessed by a questionnaire increased after 22 weeks of periodized RT.

Sarcopenia and dynapenia increases the risk of falling in older adults (Benjumea et al., 2018; Mitchell et al., 2012; Neves et al., 2018). These age-related conditions necessitate the design of a training program that can effectively mitigate their symptoms or prevent their early onset. In a meta-analysis, Rhea et al. (2003) suggested that regardless of physical activity background, periodization has been shown to induce significant gains in maximal strength and that untrained participants could experience larger positive adaptations. Nevertheless, results from a systematic review (Strohacker et al., 2015) suggested that periodized RT could be a feasible intervention for improving health outcomes among inactive older and young adults. The authors of the review also identified traditional periodization as the most common method used in the interventions they examined. Moreover, Fleck (1999) in an earlier critical review showed that periodized RT optimized increases in strength, power, body composition and motor performance among young adults. These reviews, however, failed to elucidate the mechanisms that mediated the gains from periodized RT participation among older and young adult participants which would have been important to design programming variables that would be most optimal for both groups. Further researches which would compare the implications of periodized RT on the neuromuscular performance, body composition and balance control among both older and young adults are nevertheless warranted (Conlon et al., 2016; DeBeliso et al., 2005)

4 RESEARCH QUESTIONS AND HYPOTHESIS

The purpose of the present study was to examine the effects of a 14-week traditional periodized resistance training program on the neuromuscular performance, body composition, and balance control among older and young adults. The main research questions and hypothesis were the following:

1. Is periodized RT capable of improving neuromuscular performance in the older and young adults?

   Hypothesis: Neuromuscular performance in isometric (PF & KE) and dynamic (1RM leg press & CMJ) will increase in both groups (Baker et al., 1994; Prestes et al., 2015, 2009; Williams et al., 2017).

2. Is periodized RT capable of improving body composition in the older and young adults?

   Hypothesis: Total lean mass and total fat-free mass will increase in the young, but not in the old, considering the short duration of the current periodized RT (Kraemer, 1997; Maddalozzo & Snow, 2000)

3. Is periodized RT capable of improving static and dynamic balance control in the older and young adults?

   Hypothesis: Static balance control will not change in both groups, consistent with earlier studies which reported of the inherent limitation of static balance tests (Piirainen et al., 2010). Dynamic balance control will increase in both groups, similar with earlier findings which reported positive adaptations after conducting tests using perturbation devices (Piirainen et al., 2010, 2014). Magnitudes of adaptation in both groups will vary depending on the direction and intensity of the perturbations (Piirainen et al., 2013).

4. Is there an age-related difference in the magnitude of neuromuscular performance adaptations?

   Hypothesis: The magnitude of adaptations will only be different on the vertical jump performance considering the coordination limitations in the older (de Vito et al., 1998; Haguenauer et al., 2005)

5. Is there an age-related difference in the magnitude of balance control adaptations?

   Hypothesis: The magnitude of adaptations will be different on dynamic balance control (Barry & Carson, 2004; Piirainen et al., 2010).

5 METHODS

5.1 Subjects

Thirty-five healthy, physically active but non-strength-trained male and female subjects from the Jyväskylä region (Finland) participated in the study (table 1). Older subjects were part of a control group from an earlier study (Fernández-Lezaun, 2016) while the young adult subjects were recruited through advertisements in email, newspapers, and social media. This study was part of a broader study (*Porukalla Kuntoon 2*).

TABLE 1. Group anthropometric data at pre-test

Group	Age (years)	Body mass (kg)	Height (cm)	BMI (kg/m^2)
Older (n=14; 8M & 6F)	69 ± 2	71.6 ± 11.3	167.1 ± 8.9	25.7 ± 2.1
Young (n=17, 4M & 13F)	25 ± 3	68.6 ± 12.9	171.7 ± 10.2	23.7 ± 4.8

The inclusion criteria to be eligible included: 1) no previous resistance training experience, 2) no usage of beta blockers, 3) no cardiovascular diseases and lower limb disabilities (cartilage damage, replaced joints, etc.) 4) having less than 3 hours per week of moderate physical activity as recommended by ACSM, and 5) non-smoking. Subjects underwent medical examination which included resting ECG and self-reported medical questionnaires in order to have clearance for participation. Subjects were properly informed about the design and risks of the study, including their option to abort participation at any point. Thereafter, subjects signed and submitted written consent forms before beginning the measurements . The study was approved by the Ethics Committee of the University of Jyväskylä and was conducted according to the guidelines of the declaration of Helsinki.

From 35 participants, one young adult subject dropped out during the pre-measurements due to personal reasons. In addition, two older subjects dropped out during the training intervention due to health reasons unrelated to the study. One older subject also dropped out after incurring a back injury during training. This led to a total of 31 subjects completing the entire study (figure 8). Participant anthropometric data are presented in detail at Table 2. Total body estimates of muscle, fat tissues, and body mass were measured with the subjects fasted (12h) and wearing only their under garments, using a dual-energy x-ray absorptiometry scanner (DEXA) (*LUNAR Prodigy Advance with enCORE software version 9.3; GE Medical Systems, Madison, WI, USA*) with an accuracy of 0.1kg. Height was measured using a wall-mounted tape measure with 0.1 cm accuracy.

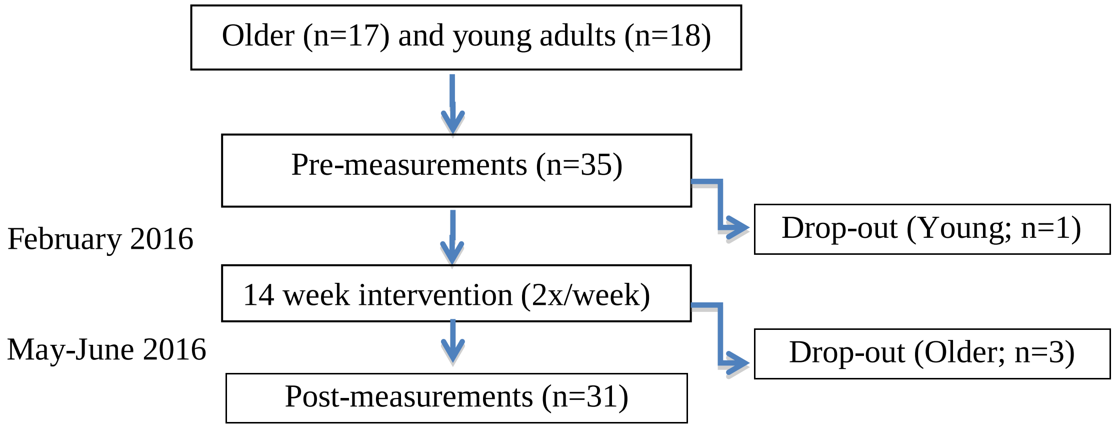

FIGURE 8. Overview of the study flowchart

5.2 Study design

The study was conducted from February to June 2016 (figure 8). Subjects were assigned in two groups (i.e., older and young adults) without controlling for sex. Both groups participated in a 14-week periodized RT program with pre- and post-training neuromuscular measurements and balance tests. A week prior to pre-measurements, subjects were instructed to visit the lab at specific intervals for familiarization with the tests and equipment. During the familiarization session, 1) the equipment configuration were set according to individual subject anthropometry, 2) surface EMG placements were measured and marked with indelible ink tattoos, 3) subjects practiced maximum isometric plantar flexion and knee extension trials, and 4) subjects underwent trials with the perturbation device. During pre- and post- measurements, the static balance test was conducted in between neuromuscular measurements while the dynamic balance test was performed on an adjacent day by research partners from *Vuokatti*. All measurements were performed during the same time of the day (±1 hour) for each subject. Neuromuscular measurements and static balance tests lasted for two hours while the dynamic balance test lasted one hour.

5.3 Training protocol

During the 14 week intervention, subjects underwent supervised resistance training twice per week at one hour per session. Two qualified instructors ensured that subjects safely performed proper exercise techniques. The instructors also motivated the subjects to perform with maximal effort at every exercise. Subjects were expected to record their training load and repetition for every exercise. Each training session began with 5 minute warm-up on a treadmill, cycling machine, or rowing machine. Exercise for the lower body, upper body, and core were included in the hour-long trainings (table 2).

TABLE 2. Mesocycles in the traditional periodized resistance training program

Weeks	Training Type	Intensity (% 1RM)	Sets	Reps	Rest (min)
1-2	END	40-60	2-3	14-16; c=16-20	1
3-5	HYP	70-80; c=50-70	2-3	10-12; c=14-16	1-2
6-7	HYP	80-85; c=70-80	2-4	8-10; c=10-12	1-2
8-9	HVY	85-90; fw=60-70	2-3	5-8; fw & c= 12-14	2-3
10-12	HVY +POW & PLYO	85-90; fw=70-80	2-3	6-8; j=5-8; fw=10-12; c=14-16	2-4
13-14	HVY +POW & PLYO)	90-95; fw=85-90; c&a=80-85	2-3	4-6; fw=7-8; j=5-8; c&a= 8-10; c=16-20	2-5

END=muscular endurance training; HYP=hypertrophy training; HVY=heavy resistance training; POW=power training; PLYO=plyometric training; c & a = chest & arms;
c= core training; fw=free weights; j=jumps

Initially, all exercises were performed on a machine and eventually progressed to free weights and body weights. Core training was also incorporated early on (3rd week) while plyometric training was added only on the 10th week. The first two weeks were considered preparatory and targeted muscular endurance development. During the remaining weeks, the traditional periodized RT program included the following training goals: muscle hypertrophy, maximal strength and power. In addition, plyometric exercises such as calf jump, lunge to jump, and countermovement jump were introduced from weeks 10 to14 (table 3).

TABLE 3. Exercise programming applied on both older and young adults in the current traditional periodized resistance training intervention.

	Exercises	1-2		3-5		6-7		8-9		10-12		13-14	
		a	b	a	b	a	b	a	b	a	b	a	b
LOWER BODY	Leg Press (m)	/	/	/	/	/	/	/		*		**	
	Knee extension (m)	/	/	/	/	/	/	/	/	/	/	/	/
	Knee flexion (m)	/	/	/	/	/	/						
	Seated calf raise (m)		/		/		/	/					
	Incline calf raise (hm)			/		/							
	Leg Curl (m)							/	/	/	/	/	/
	Standing calf raise (sm)							/		/		/	
	Calf jump (bw)									/	/	/	/
	Lunge (b)							/					
	Lunge to jump (bw)									/		/	
	Extended leg seated calf raise (m)								/		/		/
	Squat (sm)								/		/		**
	CMJ (bw)										/		/
	Deadlift (db)								/				
UPPER BODY	Chest press (m)	/		/		/							
	Lat pulldown (m)	/		/		/							
	Triceps extension (p)	/		/		/							
	Shoulder press (m)		/		/		/						
	Seated lat row (m)		/		/		/						/
	Biceps curl (p)		/		/		/						
	Bench press (b)							/		/			
	Shoulder press (d)							/		/			
	Bent over row (b)								/		/		
	Assisted pull-ups (m)								/		/		
	Pec Deck (m)											/	
	Assisted dips (m)											/	
	Upright row (b)												/
CORE	Abdomen curl (m)	/	/	/	/	/							
	Back extension (m)	/	/	/	/	/	/						
	Ab rotation (m)						/						
	Sit-ups (bw)							/	/	/	/	/	/
	Back extension (bw)							/	/	/	/	/	/

hm hack machine	m machine	b barbell
sm smith machine	p pulley	*1st 2 sets: 90-95%; last set 50-60-%
bw body weight	d dumbbell	** 1st set: 90-95%; last 2 sets 50-60-%

Some unique features of the periodized RT program in this research included the presence of a machine-based knee extension exercise all throughout the training program, and power training in leg press and squat exercises during the final 5 weeks. The two latter exercises were included as they have been reported by Wirth et al. (2016) to improve CMJ performance, although their team reported better improvements from squats. Training them at 90-95% was also reported to produce the greatest amount of muscle activation during the 1RM (Gonzalez et al., 2017).

Considering the number of subjects who trained at the same time at the gym facility, subjects were allowed to alter the order of exercises for each session according to availability of training equipment. In line with this, Farinatti, da Silva, & Monteiro, 2013) suggested that energy expenditure was unaltered by exercise order in RT for both young and older adults. After every training session, subjects were advised to do a 5-minute cool-down through stretching or light aerobic exercise. A minimum of 48 hours was advised as rest interval between training sessions. Apart from gym sessions, subjects were also given counseling on nutrition and were informed to maintain their daily physical activities like walking or running.

5.4 Data collection

5.4.1 Neuromuscular Performance: Isometric tests

Subjects underwent both unilateral plantar flexion and knee extension isometric tests. Plantar flexion (PF) maximal isometric voluntary contraction (MVC) was measured using a custom-built force dynamometer (figure 9A, University of Jyväskylä). Subjects were seated in the dynamometer with the hip, right knee, and right ankle joint angles at 110°, 180°, and 90° respectively. To stabilize the right leg during MVC performance, the knee was cushioned with foam and strapped while the left knee was kept at a bent position. Torque values were calculated by multiplying the force by the lever arm (i.e., ankle joint center to head of 1st metatarsal distance). On the other hand,

Unilateral knee extension (KE) maximal isometric voluntary contraction (MVC) was measured using a custom-built force dynamometer (figure 9B, University of Jyväskylä) wherein the subjects were seated with their right knee and hip angles firmly secured at 107° and 110°, respectively. The 107° knee angle was measured with the trochanter major and the lateral malleolus serving as reference points. To stabilize the right leg during knee extension, the right ankle and cushioned right upper leg were strapped.

Torque values were calculated by multiplying the force by the lever arm (i.e., ankle joint center to strain gauge center distance).

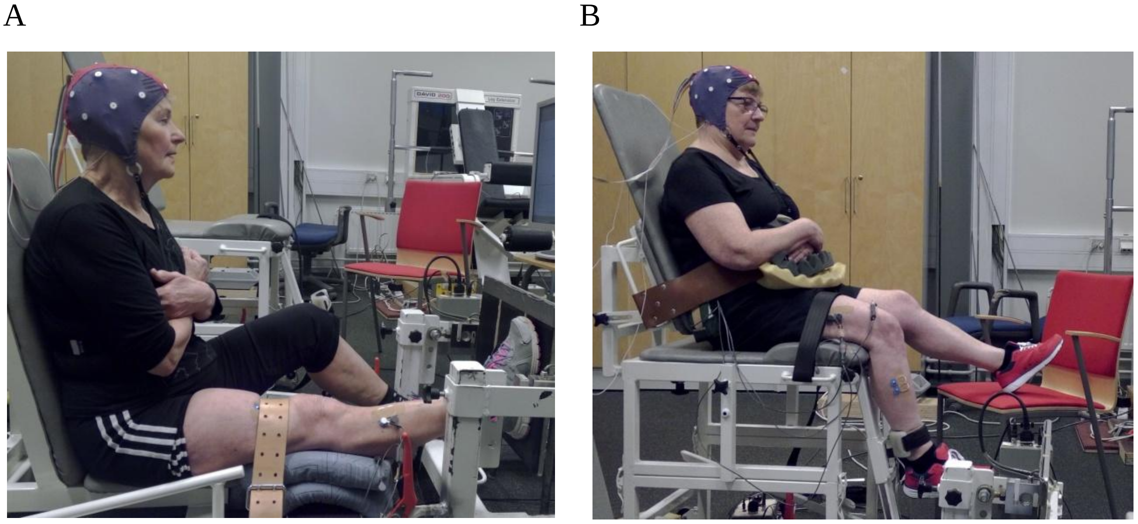

FIGURE 9. Isometric plantar flexion (A) and knee extension (B) testing device, designed and manufactured by the Unit of Biology of Physical Activity, University of Jyväskylä, Finland

For both isometric tests, subjects were instructed to push "as fast and as hard as possible" and to maintain their maximum force for approximately 2-3 seconds. A minimum of three trials were performed with one minute intervals. If a 5% improvement was observed between trials, the subject was asked to do another trial until maximal performance was determined. Further analysis was made for the isometric trials with the highest force in order to determine the maximal torque, average torques over 0-100 ms and 500-1500 ms, and maximum RTD at 10ms. Data were collected using an A/D converter (*CED Power1401; CED*) and analyzed using Signal software *(version 4.04; Cambridge Electronic Design, Cambridge, United Kingdom.*

5.4.2 Neuromuscular Performance: Dynamic Tests

5.4.2.1 1RM Leg press

Maximum bilateral concentric force production of the leg extensors was measured using David 210 horizontal leg press dynamometer (*David Sports Ltd., Helsinki, Finland*). The subjects were seated making certain their knee angle was approximately at 60°. Subjects were instructed to fully extend their legs (knee = 180° and hip = 110°). After each trial, the load was increased without informing the subjects of the amount of load increment. Testers estimated the load increase to ensure that each subject only performed 3–5 trials before failing to fully extend both legs. A rest period of 2 minutes was observed between trials. The last trial with the heaviest load was recorded as the 1RM. Further analysis for segmental power and angular velocity was performed by dividing the knee extension angles in 20 intervals (60°-80° to 160°-180°) similar to the analysis conducted by Walker, Ahtiainen, & Häkkinen (2010)

5.4.2.2 Countermovement Jump

Lower extremity power characteristics were measured using the countermovement jump test over a force plate. Without standardization of the squat depth during the eccentric phase of the jump, subjects were instructed to do explosive CMJs with hands akimbo. Subjects were also instructed to keep an extended leg while on the flight phase, and were allowed to have their knees bent upon landing considering the potential safety concerns in landing with high impact forces. Each subject jumped a minimum of 3 trials with one minute rest intervals. If the last jump was higher by 5%, subjects were instructed to perform another trial. Jump height was calculated through a built-in script in Signal software *(version 4.04; Cambridge Electronic Design, Cambridge, United Kingdom)* which provided immediate jump height feedback. Since CMJ height is unable to provide details on the mechanisms behind resultant jump height, recent studies have suggested the use of a more detailed temporal phase analysis such as the one proposed by McMahon et al. (2017) which is able to delineate phases such as unweighing, eccentric and concentric phases. This approach could be helpful with its ability to reveal specific changes in the shapes of the power-, force-, velocity-, and displacement-time curves throughout the entire jump movement (Cormie et al., 2011; Cormie, Mcbride, & McCaulley, 2009). In this study, further analysis was conducted by transforming the individual force-time data into 100 time points using a custom-made matlab script. CMJ data were normalized to body weight.

5.4.3 Electromyography

Electromyography measurements of the TA, S and MG for plantar flexion and the VL, VM and BF for knee extension, CMJ and 1-RM leg press were recorded from the right leg with commercial bipolar Ag/AgCl surface electrodes (*AMBU*; 5 mm pickup area and 2 cm inter-electrode distance, >100 dB common mode rejection ratio, >100 M**Ω** input impedance, <1**µ**rms baseline noise) (Walker et al., 2014). SENIAM guidelines were observed in the shaving, skin abrasion, and placement of electrodes. Small ink dots were tattooed on the skin during familiarization to ensure the consistency of electrode placement during pre- and post-measurements. During the neuromuscular performance tests, surface EMG was sampled at a frequency of 2000 Hz and amplified at a gain of 500 (sampling bandwidth, 10–500 Hz). Raw signals were transmitted from a transportable pack *(Telemyo 2400R; Noraxon, Scottsdale, AZ, USA)* which was wrapped around subject's waist to a receiving box, and passed through an analog-to-digital (A/D) board converter *(Micro1401; Cambridge Electronic Design)* for recording and analysis using Signal software *(version 4.04; Cambridge Electronic Design, Cambridge, United Kingdom)*. Electromyography signal data were bandpass filtered (20–350 Hz) before analysis using customized scripts. EMG data were also transformed to root mean square (rms) prior to normalization. Isometric MVC EMGrms were normalized to knee flexion MVC; CMJ values were normalized to body weight; and leg press EMG values were normalized to knee angles. During isometric actions, EMG amplitudes were analyzed over the force plateau's most stable 1-second time window using fast fourier transformation (Hamming, 2,048 data points). During the 1-RM leg press, concentric EMG amplitudes were assessed between 60° and 180° knee extension angle.

5.4.4 Balance tests

Static balance was measured using an AMTI balance analysis force platform (*OR6-6 model; Watertown, USA*). Subjects assumed their preferred stance in eyes open and eyes closed condition for 120 seconds each. On the other hand, dynamic balance control was measured using a custom-made perturbation device as described in an earlier study by Piirainen et al. (2013) and colleagues (2013) (figure 10; University of Jyväskylä). Perturbation parameters (acceleration and velocity) were initially determined and standardized perturbations were delivered automatically using LabVIEW (National Instruments, USA) and IndraWorks software (Bosch Rexroth, Germany). Balance was measured in three different conditions [Low: maximum (max) acceleration 1.7 m/s^2, max velocity 8 cm/s; moderate (Mid): max acceleration 2.1 m/s^2, max velocity 17 cm/s;

high (Hi): max acceleration 2.9 m/s^2, max velocity 24 cm/s]. A total of 32 perturbations were delivered: 16 in anterior (Ant) (plate moved forward) and 16 in posterior (Post) (plate moved backward) direction. The order of inducing the perturbations was according to the perturbation velocity: low (first 5), mid (middle 5), and high (last 6) with 8- to 12-second intervals. The maximal peak displacement of the center of pressures (COP) served as the parameter for perturbation response, wherein larger displacements mean poorer dynamic balance control. A black mark was fixed on the wall 2.8 m from the subject at eye level to stabilize the subject's visual focus during the measurements. Subjects were instructed to stand upright with extended arm and hands held together in front of the body. COP displacements were analyzed from three perturbation velocity categories, similar to the methods conducted by (Piirainen et al., 2013).

FIGURE 10. Dynamic perturbation device, designed and manufactured by the Unit of Biology of Physical Activity, University of Jyväskylä, Vuokatti, Finland

5.5 Statistical Analyses

Conventional statistical methods were used to calculate means, standard deviations (SD) and Pearson product moment correlation coefficients. Normal distribution of the data was examined through the Shapiro-Wilk test. Significant changes in the pre- and post-training values between groups were assessed using two-way ANOVA for repeated measures (2 times* 2 groups), with Bonferroni adjustments as post hoc test when a significant main effect for group was identified. For the coutermovement jump test, a paired samples *t* tests was used for comparison within groups (time-effects) in areas under curve of the jump performance variables. All statistical analyses were conducted using IBM SPSS statistics 24 software. Statistical significance was established at $p \leq 0.05$.

6 RESULTS

6.1 Neuromuscular Performance: Isometric tests

6.1.1 Plantar Flexion torques and EMG amplitudes

After normalizing the maximal isometric unilateral PF torque with the moment arm, significant main effects for time (F=9.380, $p<0.01$, $\eta^2=0.258$) and interaction (F= 10.943, $p<0.01$, $\eta^2=0.288$) were observed. Post hoc tests revealed significant increase in the maximal isometric PF performance only among young adults (Δ 25.33 ± 20.65 N*norm*, $p<0.001$) (figure 11A).

Analyzing the PF torques across 2 timepoints from the start of contraction, no significant main effects were observed on the 0-100ms in both groups (figure 11B). But at 500-1500 ms, significant main effects for time (F=14.809, $p<0.01$, $\eta^2=0.354$) and interaction (F= 8.705, $p<0.01$, $\eta^2=0.244$) were observed. Post hoc tests showed that over time, there was a significant increase in PF torque at 500-1500ms only among young adults (Δ 170.76 ± 121.51 N, $p<0.001$) (figure 11B).

Further examination of the EMG amplitudes at 2 timepoints, a significant main effect for time was observed on the 0-100ms PF EMG of the medial gastrocnemius (MG) (F=23.941, $p<0.001$, $\eta^2=0.47$) and soleus (S) (F=26.094, $p<0.001$, $\eta^2=0.491$) but not of the tibialis anterior (TA). Over time, both groups made statistically significant EMG amplitude increases in the MG (older: Δ 0.01 ± 0.003 mV, $p<0.01$; young adults: Δ 0.012 ± 0.003 mV, $p<0.01$) and S (older: Δ 0.012 ± 0.004 mV, $p<0.01$; young adults: Δ 0.01 ± 0.002 mV, $p<0.001$) (figure 11C).

At 500-1500 ms, a significant main effect for time was also observed in the EMG amplitudes of the MG (F=19.518, $p<0.001$, $\eta^2=0.42$), S (F=19.261, $p<0.001$, $\eta^2=0.42$) and TA (F=6.318, $p<0.05$, $\eta^2=0.19$). Post hoc tests revealed significant EMG amplitude differences in both groups for MG (older: Δ 0.064 ± 0.078 mV, $p<0.05$; young adults: Δ

0.059 ± 0.072 mV, $p<0.01$), but only in the young adults for both S (Δ 0.083 ± 0.077 mV, $p<0.01$) and TA (Δ 0.014 ± 0.006 mV, $p<0.05$) (figure 11D).

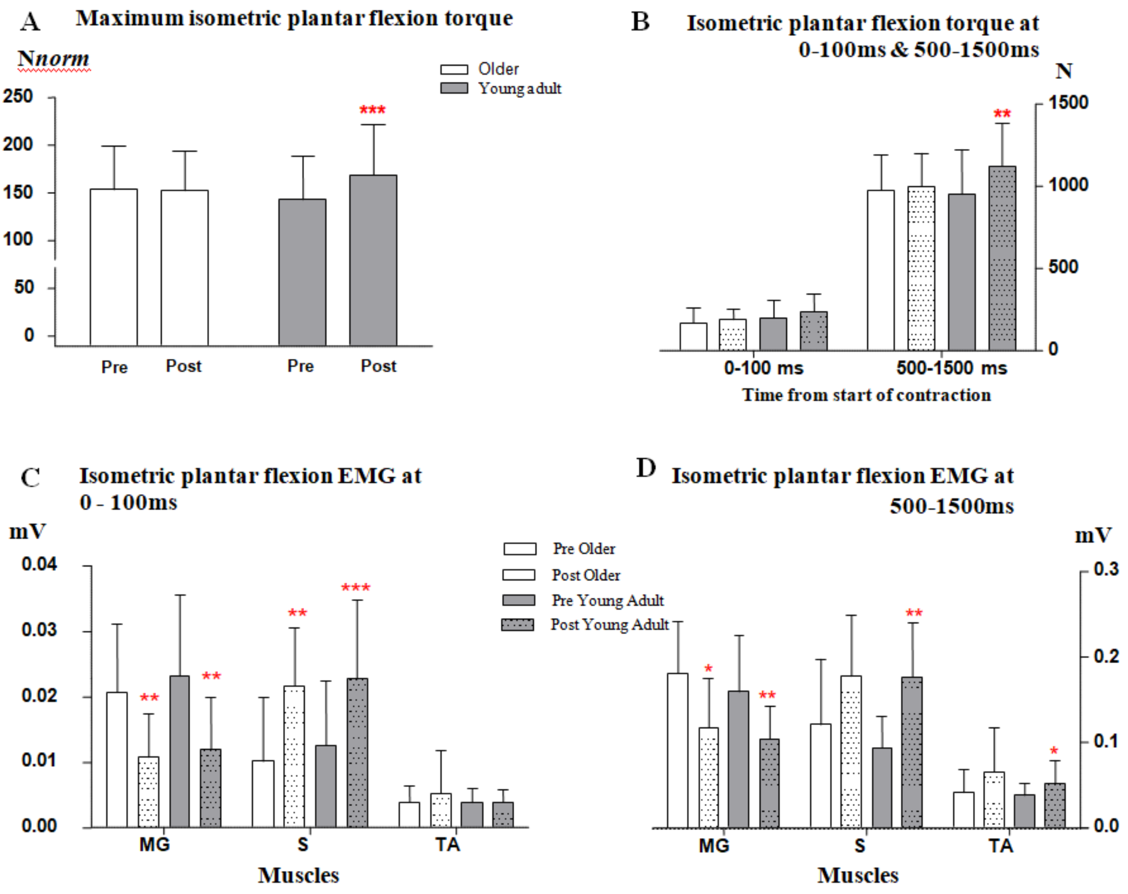

FIGURE 11. Mean (± SD) plantar flexion (PF) normalized MVIC (*A*), PF torques during the early contraction phase (0-100 ms) and peak torque phase (500-1500 ms) (*B*) and the corresponding electromyographic activity of the medial gastrocnemius (MG), soleus (S), and tibialis anterior (TA) muscles (*C & D*) among the older (n=13) and young adults (n=16). (*$p<0.05$, **$p<0.01$, ***$p<0.001$).

6.1.2 Isometric knee extension torques and EMG amplitudes

After normalizing the maximal isometric KE torque with the moment arm, significant main effects for time (F=98.764, $p<0.001$, $\eta^2=0.785$) and interaction (F= 15.582, $p<0.001$, $\eta^2=0.366$) were found. Post hoc tests revealed significant KE torque increases in both older (Δ 22.33 ± 19.15 N*norm*, $p<0.01$) and young adults (Δ 51.77 ± 20.6 N*norm*, $p<0.001$) (figure 12A).

Analyzing the KE torques across 2 timepoints from the start of contraction, a significant main effect for time (F=12.707, p<0.001, η^2=0.312) was observed at 0-100ms. Over time, a significant torque increase was revealed only in young adults (Δ 51.05 ± 39.77 N, p<0.001) (figure 12B). At 500-1500ms, significant main effects for time (F=90.458, p<0.001, η^2=0.764) and interaction (F= 17.051, p<0.001, η^2=0.378) were also found. Post hoc tests showed that over time, KE torque at 500-1500ms significantly increased in both older (Δ 59.82 ± 63.89 N, p<0.01) and young adults (Δ 151.62 ± 57.53 N, p<0.001) (figure 12B).

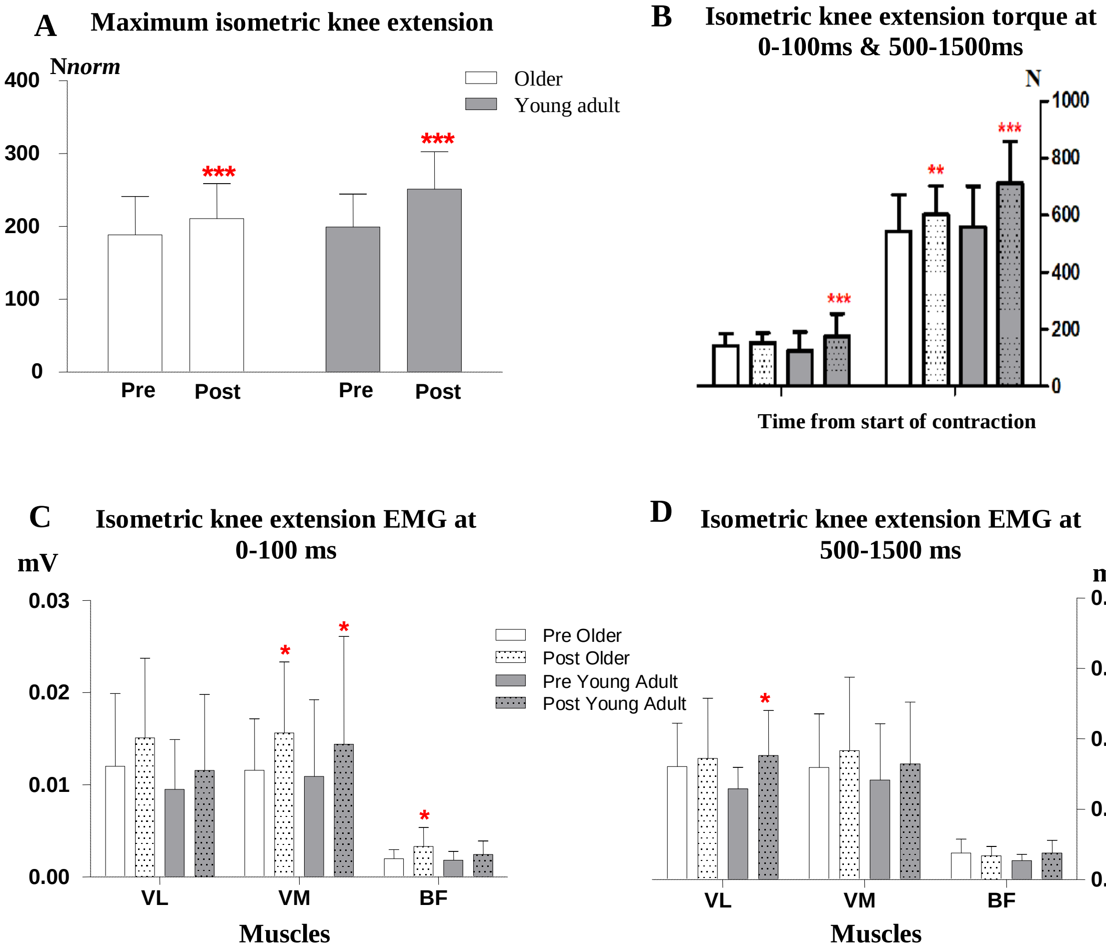

FIGURE 12. Mean (± SD) knee extension (KE) normalized MVIC (*A*), KE torques during early contraction phase (0-100ms) and peak torque phase (500-1500ms), (*B*) and the corresponding muscular electromyographic activity of the vastus lateralis (VL), vastus medialis (VM) and biceps femoris (BF) muscles (*C & D*) among the older (n=13) and young adults (n=16) (*p<0.05, **p<0.01, ***p<0.001).

An examination of the lower extremity muscle EMG amplitudes during KE at 2 timepoints revealed that at 0-100ms, there was a significant main effect for time in the vastus lateralis (VL) ($F=6.392$, $p<.05$, $\eta^2=.186$), vastus medialis (VM) ($F=10.685$, $p<.01$, $\eta^2=.276$), and biceps femoris (BF) muscles ($F=8.7$, $p<.01$, $\eta^2=.237$). Post hoc tests revealed significant EMG amplitudes increases in the VM of both groups (older: Δ 0.004 ± 0.002 mV, $p<0.05$; young adults: Δ 0.003 ± 0.001 mV, $p<0.05$), and in the BF only among older adults (Δ 0.001 ± 0.001 mV, $p<0.05$) (figure 12C).

At 500-1500 ms, a significant main effect for time was only observed in the KE VL EMG amplitude ($F=9.664$, $p<0.01$, $\eta^2=0.257$). Post hoc tests revealed significant increase only in young adults (Δ 0.047 ± 0.051 mV, $p<0.05$) (figure 12D). In addition, a significant main effect for interaction was observed on the biceps EMG ($F= 5.515$, $p<0.05$, $\eta^2 =0.165$).

6.1.3 Rate of torque development

A significant main effect for time was observed on the isometric plantar flexion RTD at 10ms ($F=7.413$, $p<0.05$, $\eta^2=0.215$). Post hoc tests revealed significant RTD increase only among young adults (Δ 1,118.84 ± 1,399.31 $N.s^{-1}$, $p<0.01$ (figure 13). No significant RTD main effects were observed during knee extension.

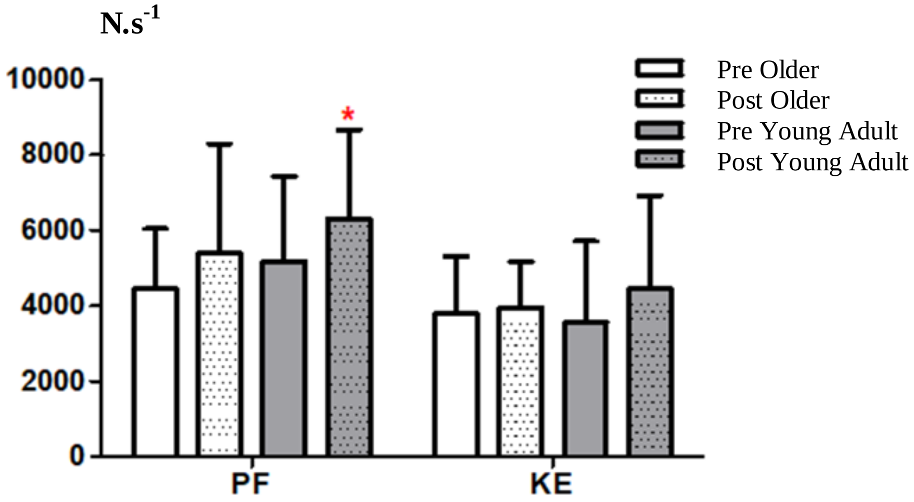

FIGURE 13. Plantar flexion (PF) and knee extension (KE) rate of torque development at 10 milliseconds. (*$p<0.05$).

6.2 Neuromuscular Performance: Dynamic tests

6.2.1 1-RM leg press

During the 1-RM leg press performance, a significant main effect for time (F=97.42, $p<0.001$, η2=.777) was found (figure 14A). Post hoc tests revealed that over time, both older (Δ 19.62 ± 11.36 kg, $p<0.001$) and young adults (Δ 20.88 ± 10.97 kg, $p<0.001$) increased their leg press one repetition maximum loads.

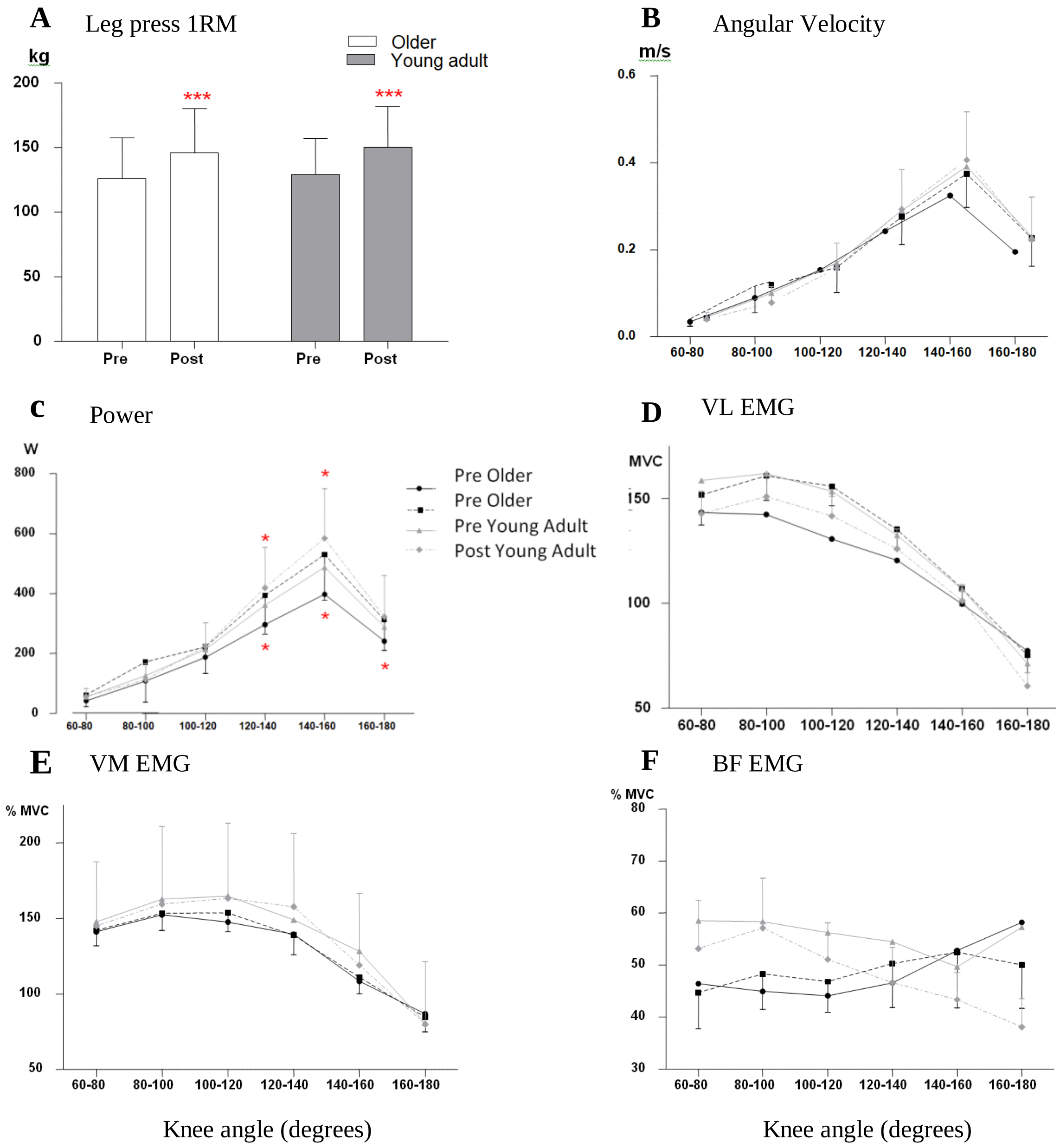

FIGURE 14. Leg press one-repetition maximum (1-RM), angular velocity, power, and EMG amplitudes among the older (n=13) and young adults (n=17). (*$p<0.05$, ***$p<0.001$).

Further examination of the leg press performance revealed significant main effects for time on the power values at different knee angles, such as at 120°-140° (F=11.88, $p<0.01$, $\eta^2=0.298$), 140°-160° (F=13.782, $p<0.001$, $\eta^2=0.33$), and 160°-180° (F=5.725, $p<0.05$, $\eta^2=0.170$) (figure 14C). Post hoc tests revealed significant power increases for both groups at 120°-140° (older: Δ 96.84 ± 135.37 W, $p<0.05$; young adults: Δ 57.67 ± 110.26 W, $p<0.05$) and 140°-160° (older: Δ 132.62 ± 177.94 W, $p<0.05$; young adults: Δ 96.4 ± 159.1 W, $p<0.05$), but only for the older at 160°-180° (Δ 71.22 ± 115.78 W, $p<0.05$). No significant main effects were observed on the angular velocities (figure 14B) and EMG amplitudes (figures 14D, E & F) during the leg press performance.

6.2.2 Countermovement jump

After expressing the force data relative to body mass, analysis of the CMJ heights showed significant main effects for time (F=37.49, $p<.001$,$\eta^2=0.57$) and age (F=10.47, $p<0.01$, $\eta^2=0.27$) (figure 15A). Bonferroni post hoc tests revealed significant age-related CMJ height difference (mean difference = 5.5 cm, 95% CI = 2.01-8.99, $p<0.01$). Over time, both older (Δ 1.29 ± 1.48 cm, $p<0.01$) and young adults (Δ 2.16 ± 1.57 cm, $p<0.001$) increased their CMJ heights.

EMG amplitude analysis during the different CMJ phases revealed that during the unweighing phase, significant main effects for time (F=11.41, $p<0.01$, $\eta^2=0.352$), age (F=7.14, $p<0.05$, $\eta^2=0.254$) and interaction (F=4.6, $p<0.05$, $\eta^2=0.18$) were found in the VL EMG (figure 15B). Bonferroni post hoc tests revealed significant age-related VL EMG amplitude difference (mean difference = -13.85 mv, 95% CI = -24.62 to -3.07, $p<0.05$). Post hoc analysis also revealed that over time, the older (Δ -11.04 ± 12.62 mV, $p<0.05$) decreased VL EMG amplitude during the CMJ unweighing phase (figure 15B).

Further analysis of the CMJ unweighing phase also showed significant main effect for interaction in the VM EMG (F=5.05, $p<0.05$, $\eta^2=0.194$) and significant main effect for time in the BF EMG (F=4.77, $p<0.05$, $\eta^2=0.192$) (figure 15D). Post hoc analysis revealed that over time, the young adults (Δ -8.12 ± 10.05 mV, $p<0.05$) showed a significant decrease in BF EMG amplitude during the CMJ unweighing phase.

In addition, analysis of EMG amplitudes during the eccentric phase revealed significant main effects for time in the VL (F=4.99, $p<0.05$, $\eta^2=0.192$) and BF (F=5.73, $p<0.05$, $\eta^2=0.223$) but post hoc tests did not reveal significant changes. Furthermore, during the concentric phase, significant main effect for time was only found in the BF (F=12.33, $p<0.01$, $\eta^2=0.381$) which was shown to significantly decrease over time only among young adults (Δ -37.63 ± 33.83 mV, $p<0.01$) (figure 15D).

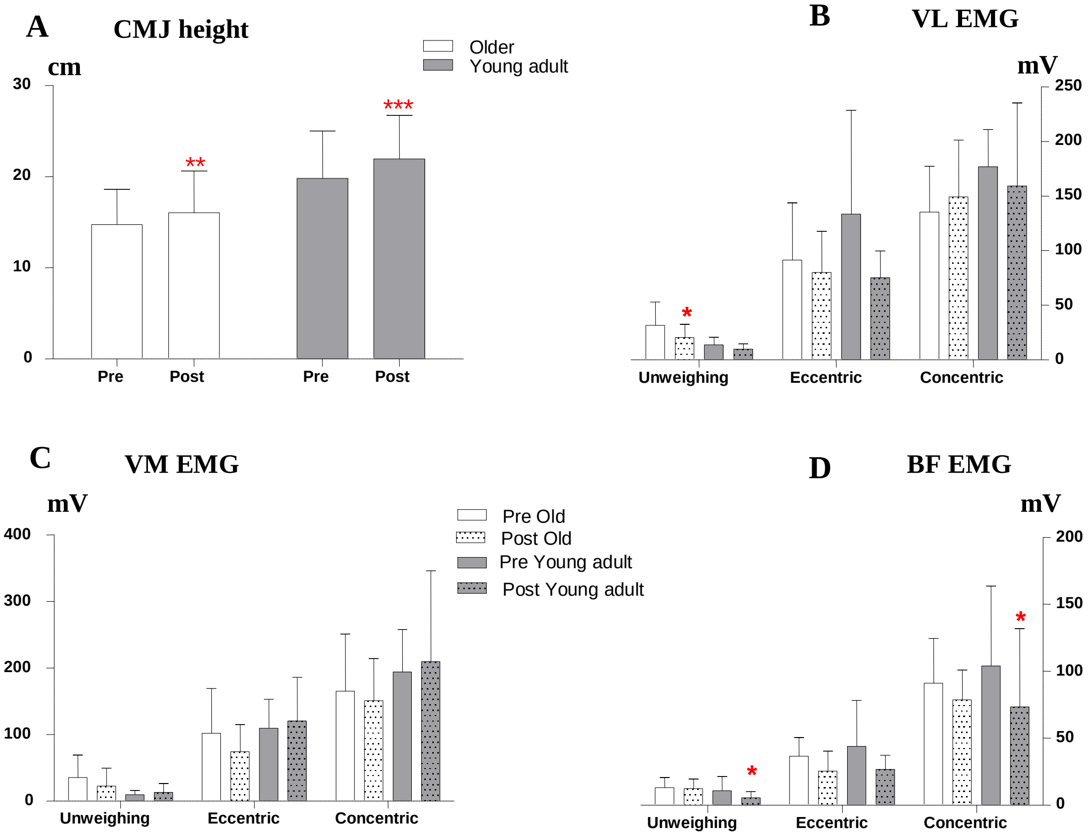

FIGURE 15. Countermovement jump height and EMG data during the 3 phases of CMJ (unweighing, eccentric & concentric) among the older (n=13) and young adults (n=17). (*$p<0.05$, **$p<0.01$, ***$p<0.001$).

The added analysis of other CMJ performance variables (table 4) revealed significant main effect for time only in peak power (F=6.72, $p<0.05$, $\eta^2=0.194$), and not in any other variable such as force at peak power, acceleration and peak velocity. Post hoc tests revealed that over time, only the young adults increased in CMJ peak power (Δ 3.59 ± 6.02 W/kg, $p<0.01$).

TABLE 4. The impact of 14-week periodized resistance training on countermovement jump variables (**p<0.01)

	Older (n=13, 7M & 6F)		Young adults (n=17, 4M & 13F)	
	Pre-training	Post training	Pre-training	Post training
Peak power (W/kg)	36.59 ± 8.95	39.06 ± 12.69	45 ± 10.17	48.59 ± 10.63**
Force at Peak Power (N/kg)	15.69 ± 1.49	16.13 ± 2.24	17.52 ± 1.46	17.72 ± 1.16
Acceleration (m/s^2)	9.10 ± 1.89	9.57 ± 3.58	10.97 ± 3.13	10.55 ± 2.91
Peak velocity (m/s)	3.54 ± 0.47	3.62 ± 0.67	4.11 ± 0.49	4.3 ± 0.5

Extended CMJ analysis comparing the force-, power-, velocity-, and displacement-time curves showed age-related differences at different CMJ phases (figure 16). In older adults, significant changes were found in the relative force-time curves at 6.3-12.5% and 97.8-99.3% (figure 16A), in the relative power-time curves at 97.1-99.2% (figure 16B), and in the relative acceleration-time curves at 87.6-88.6% (figure 16D).

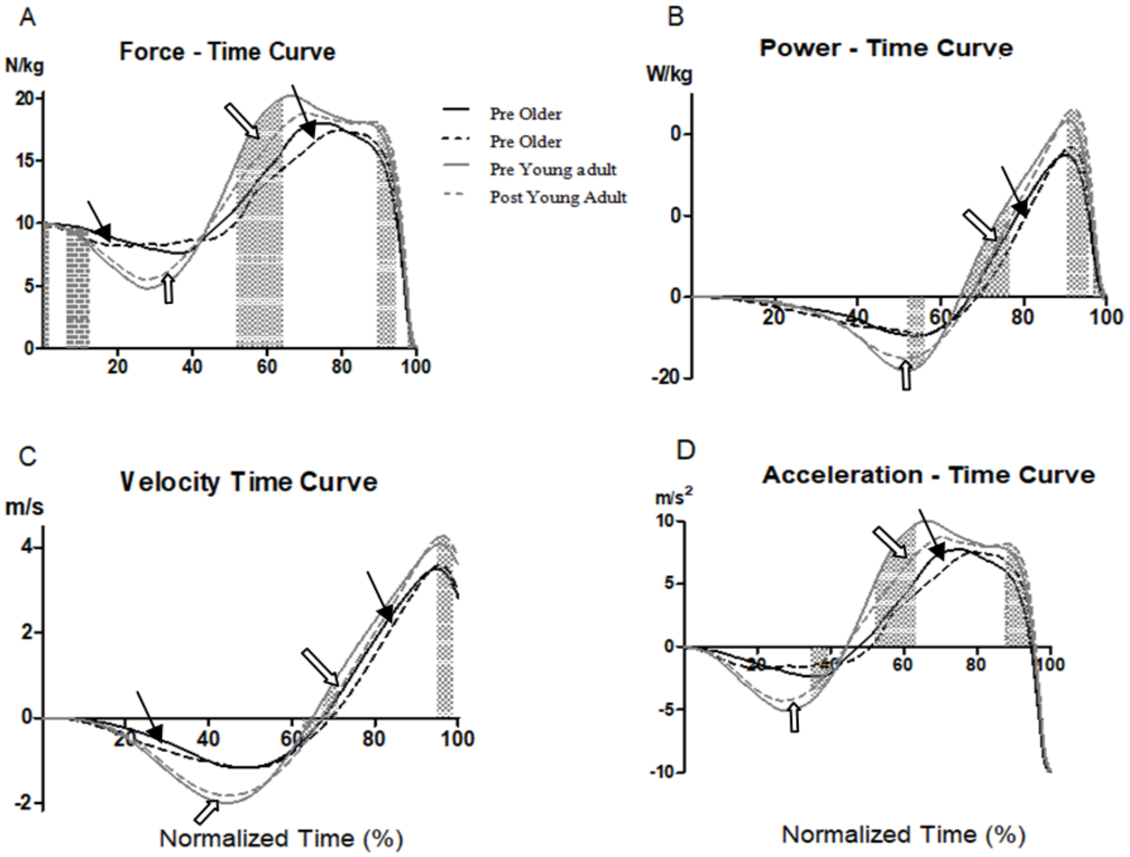

FIGURE 16. Performance curves with force-time data scaled to 100 time-points during the countermovement jump performance. Vertically highlighted segments represent changes in jump performance after periodized RT. ↑ = older; ⇧ = young adults. (O: n=13; YA: n=17).

In young adults on the other hand, significant changes were revealed in all curves, such as the relative force-time curves at 51.8-64.6% (figure 16A), in the relative power-time curves at 52-56.2 %, 64.3-76.8 % and 90.6-95.8% (figure 16B), in the relative velocity-time curves at 62.8-71% and 94. -99% (figure 16C), and in the relative acceleration-time curves at 34.9-39.6 %, 52.4-63.5% and 88.4-95% (figure 16D).

6.3 Body composition

Analysis of body composition variables showed significant main effects for time in total lean mass (F=10.86, p<0.01, η^2=0.272), total fat-free mass (F=11.96, p=0.002, η^2=0.292), and body mass, (F=5.87, p<0.01, η^2=0.173). Post hoc tests revealed that over time, the older significantly increased in body mass (Δ 1.63 ± 2.54 kg, p< 0.05) and the young adults in total lean mass (Δ 1.43 ± 2.08 kg, p<0.05) (table 5).

TABLE 5. Age-related difference (mean ± SD) in body composition measurements using a DEXA scanner.

	Older (n=14, 8M & 6F)		Young adults (n=17, 4M & 13F)	
	Pre-training	Post training	Pre-training	Post training
Total Fat Mass (kg)	20.5 ± 5.7	21.4 ± 5.9	21.7 ± 9.4	21.5 ± 9.3
Total Lean Mass (kg)	48.1 ± 10.4	48.9 ± 10	44.2 ± 8.2	45.6 ± 8.7*
Total Fat-Free Mass	50.3 ± 11.1	51 ± 10.6	46.9 ± 8.6	48.4 ± 9**
Body Mass (kg)	71.6 ± 11.3	73.1 ± 11.4*	68.6 ± 12.9	69.9 ± 12.6
Total Tissue %Fat	31.2 ± 8.1	31.6 ± 7.5	32.2 ± 9.6	31.4 ± 9.7

*p<.05, **p<.01, refers to the significant differences between pre and post measurements.

6.4 Balance tests

Static balance control. No significant main effects for time, age or interaction were observed in the anteroposterior (x) and mediolateral (y) direction during the eyes open and eyes closed conditions in testing static balance (figure 17A).

Dynamic balance control. During the dynamic balance control test using a perturbation device in the anteroposterior direction, COP disturbance responses were categorized into 3 groups according to the intensities of induced perturbations (low, mid, and high). For low-intensity perturbation, significant main effects for time were observed in the

Low Ant COP (F=23.221, p<0.001, η^2=0.472) and Low Post COP (F=6.385, p<0.05, η^2=0.197) (figure 17C). Over time, both groups had significant lower disturbance in Low Ant COP (older: Δ -7.91 ± 6.3 mm, p<0.01; young adults: Δ -9.24 ± 10.6 mm, p<0.01) while only young adults experienced lower disturbance in Low Post COP (Δ -12.82 ± 18.26 mm, p<0.05). For mid-intensity perturbation, a significant main effect for time (F=8.286, p<0.01, η^2=0.242) was observed in Mid Ant COP (figure 17C). Over time, only the young adults experienced lower disturbance in Mid Ant COP (Δ -10.59 ± 10.19 mm, p<0.001) (figure 17B). For high-intensity perturbation, a significant main effect for time (F=4.694, p<0.05, η^2=0.153) was observed in Hi Post COP and post hoc test revealed significant lower disturbance only among the older (Δ -15.45 ± 18.77 mm, p<0.05) (figure 17C).

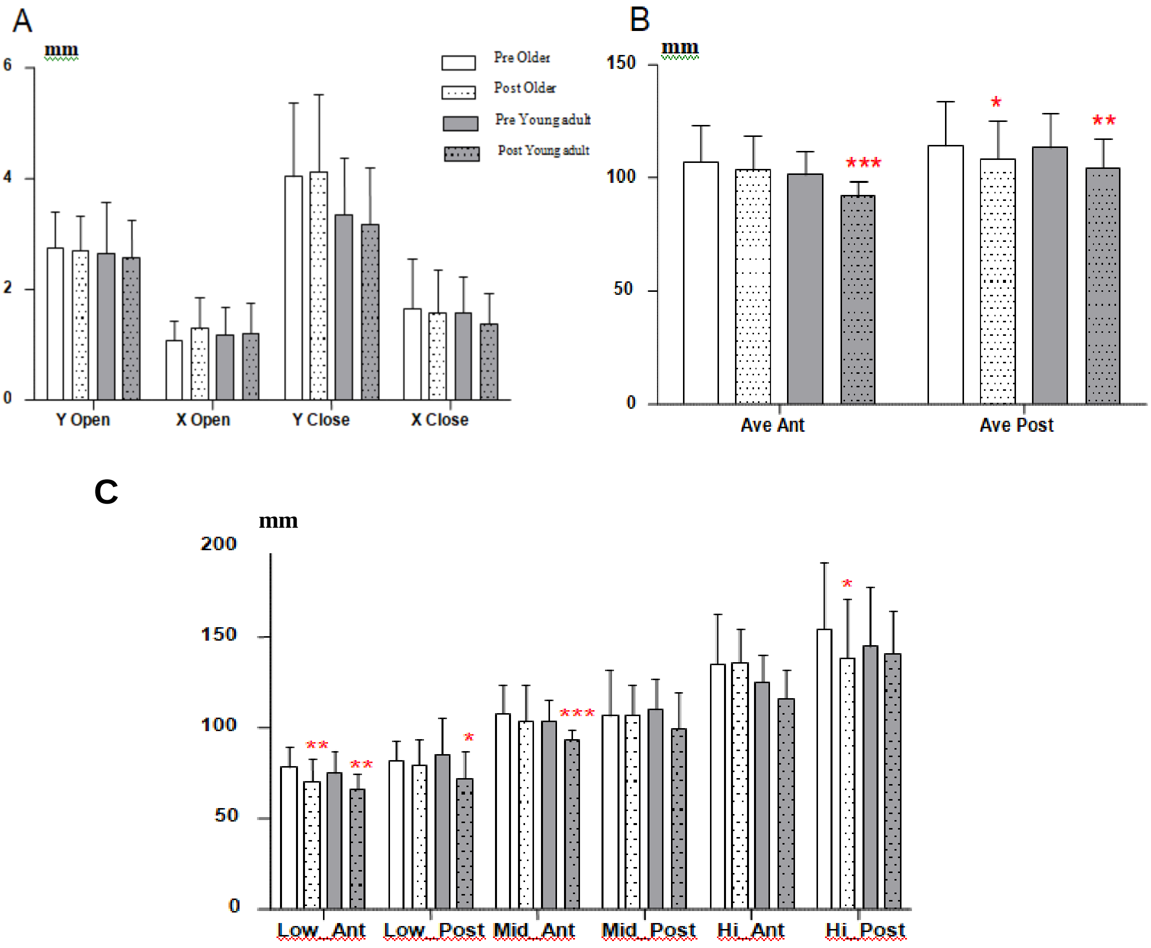

FIGURE 17. Static (A), averaged COP displacements (B), and COP displacements at 3 perturbation intensities [low, mid and high (*Hi*)] (C) in the anterior (*Ant*) and posterior (*Post*) directions among older (n=11) and young adult (n=17) participants (*p<0.05, **p<0.01, ***p<0.001).

Averaging the COP disturbance from the three types of perturbation intensities, significant main effects for time (F=10.909, $p<0.05$, $\eta^2=0.296$) and age (F=4.359, $p<0.05$, $\eta^2=0.144$) were observed in Ave Ant COP. Bonferroni post hoc tests revealed significant age-related difference in Ave Ant COP (mean difference = 8.6, 95% CI = -17.07 to -.133, $p<0.05$) and that over time, there was a significant lower Ave Ant COP disturbance among the young adults (Δ -9.57 ± 8.06 mm, $p<0.001$) (figure 17B). In the Ave Post COP, a significant main effect for time (F=11.875, $p<0.01$, $\eta^2=0.314$) was also observed and over time, significant lower COP disturbance were seen in both groups (older: Δ -5.64 ± 7.29 mm, $p<0.05$; and young adults: Δ -9.16 ± 12.92 mm, $p<0.01$) (figure 17B).

6.5 Correlations

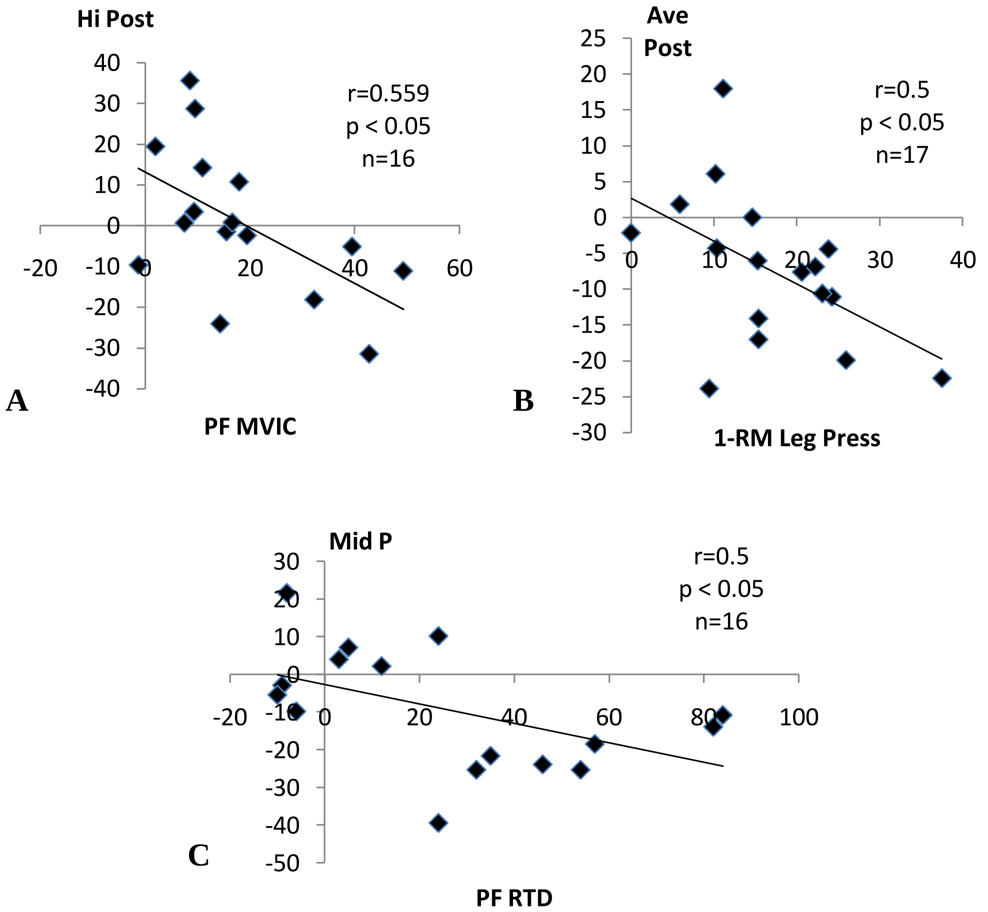

FIGURE 18. Correlations between variables in neuromuscular performance and balance control in young adults.

Percentage changes of improvements from baseline among different neuromuscular performance and balance control variables were further analyzed to reveal correlations. Results showed no significant correlation in any variable among the older. Data from young adults revealed significant correlations in Hi Post and PF MVIC ($p<0.05$), Ave Post and 1-RM leg press ($p<0.05$), and Mid Post and PF RTD ($p<0.05$) (figure 18).

7 DISCUSSION

The aim of this study was to examine the effects of periodized resistance training on the neuromuscular performance, body composition and balance control among older and young adults. This study found that:

1. For neuromuscular performance tests, both groups increased knee extension (KE) maximal voluntary isometric contraction (MVIC), one-repetition maximum (1-RM) leg press and countermovement jump (CMJ) height, but only young adults increased plantar flexion (PF) MVIC, PF rate of torque development (RTD) and CMJ peak power.
2. For body composition measurements, only the older increased body mass while only the young adults increased total lean mass and total fat free mass.
3. For dynamic balance control, both groups decreased center of pressure (COP) disturbance during low-anterior and average-posterior perturbations. In addition, only the older decreased COP disturbance from high-intensity posterior perturbations, while only the young adults decreased COP disturbance from low-posterior, mid-anterior and average-anterior perturbations. Both groups did not show changes in static balance control.
4. Data from CMJ height, and COP disturbance at averaged anterior perturbations both showed age-related differences.

7.1 Neuromuscular Performance

Isometric maximal strength findings from this study showed the expected increase in PF MVIC (17%, $p<0.001$) among young adults. Surprisingly, the older group failed to show any difference on PF MVIC whereas earlier studies presented increases in post-intervention PF torque magnitudes at 17.8 - 28% (Scaglioni et al., 2002; Ferri et al., 2003). The older PF MVIC confidence interval data *(-14.31 to 12.37)* also supports a finding that strength responses to resistance training could vary extensively between subjects (Ahtiainen et al., 2016). In spite of a concentrated training of plantar flexors throughout the course of the intervention, the lack of change in PF finds support in the finding of Scaglioni and peers (2002) such that while the older can maintain capacity for maximal activation during PF, the limited adaptive response from resistance training could be due to an aging-related and muscle group dependent (i.e., lower extremity) degenerative phenomena of the peripheral neuromuscular system (Lemmer et al., 2007). On the other hand, results in KE MVIC showed that both older and young adult groups increased (11.83% vs 25.97% respectively; both at $p<0.001$) primarily due to neural mechanisms as indirectly shown by changes in EMG amplitudes. Results from dynamic tests also showed that both older and young adult groups increased performances in 1RM leg press (15.55% vs 16.16%, both at $p<0.001$) which agrees with the findings of Williams et al. (2017) on the moderate effects of periodized RT on leg press performance. Candow et al. (2011) discussed that the increased older leg press load after their 12 weeks intervention were primarily due to neural adaptations, whereas increases after 22 weeks training were mostly due to muscular mechanisms. In contrast, the increased 1-RM leg press performance in our study was not accompanied by increased EMG amplitudes.

Previous researches which assessed explosiveness after a periodized RT are limited. Isometric tests showed that only the young adults increased PF RTD (20.82%, $p<0.05$) which was accompanied by increased agonist activation as shown by significant changes in the MG, S & TA EMG amplitudes in fig.12C & 12D. Among the older, neural adaptations seem to also be evident albeit shown only by a statistical trend for increased PF RTD (17.11%) and increased agonist activation at least during the early contraction phase (fig.11C). These results seem to suggest the role played by the nervous system for the initial improvements on isometric strength gains and RTD for both groups (Häkkinen et al., 1998a; Henwood et al., 2008). Surprisingly, no differences were found for both groups in KE RTD. Häkkinen et al. (1998a) presented a similar finding on the unaltered rapid force knee extension performance in the older after a 10-week progressive RT and explained that gains from training with dynamic actions could not be transferred to rapid isometric force actions such as knee extension. Meanwhile, de Moura et al. (2018) recently showed that a low-volume, non-periodized RT (i.e., RT with frequent variations in intensity and volume) which lasted for 12 weeks increased maximal dynamic strength and KE RTD among older participants due to neural mechanisms.

Englund and colleagues (2017) earlier investigated that 6-weeks of high velocity knee extension training, in contrast with the outcomes in training with low velocities, resulted in rapid and maximal KE torque improvements. Aware of the results from this short intervention, this study intended to optimize power adaptations by varying the loads in the leg press and squat exercises only during the final 5 weeks of the periodized RT program. The absence of RTD changes seems to also suggest a lack in the duration and intensity of the introduced program modification at the final mesocycle. This assumption is in relation to an earlier finding (de Vos et al., 2005) which showed increased explosive strength even just after 8-12 weeks of explosive training at high loads (80% of 1RM). In general, results from explosive strength corroborate with that of Candow & Chilibeck (2005) such that the greatest torque deficits of the older in relation with young adults were shown in the knee extensors and ankle plantar flexors during fast contractions.

As regards dynamic actions, dividing the phases of knee extension during the 1RM leg press showed that power improved at certain angles in both older (120°-180°) and young adults (120°-160°). Only statistical trends were observed for angular velocity, which seem to suggest that power increased due to enhancements in the force production capacity instead of on the shortening contraction velocity. Findings of McNeil, Vandervoort, & Rice (2007) indicated that age-related decreases in movement velocity is usually the primary factor for decreased power in both older and young adults. The current study however showed that shortening velocity was not enhanced for both groups. Moreover, while earlier resistance training studies have reported the increased leg press movement velocities due to enhancements in motor unit discharge rates, and firing frequencies and muscle fiber composition (Häkkinen et al., 1998a; Hakkinen et al., 2001), the current failed to show an apparent change in EMG amplitudes. However, the incorporation of plyometric exercises and power-type training only for 2 movements (i.e. leg press and squat) on the final 5 weeks of the intervention seem to be insufficient in augmenting the contraction speeds during the 1RM testing.

Although the analysis used for the EMG amplitudes in this study will not be able to determine the onset of fatigue (Dimitrova & Dimitrov, 2003), it can be assumed that fatigue may have set-in considering that 1RM was the final test conducted during neuromuscular performance assessments. An earlier finding showed that reduced conduction velocities in the action potentials of recruited muscle fibers is a characteristic of the onset of fatigue (Viitasalo & Komi, 1977). Moreover, increased dynamic maximal strength shown in the increased 1-RM leg press loads show the apparent specificity of adaptive response, such that the training variable that was trained at length (*maximal force*) would undergo more improvements than variables trained less (*explosiveness*).

Results from the second dynamic test also showed that both older and young adult groups increased CMJ height (8.68% vs 10.9%, $p<0.01$ & $p<0.001$ respectively). The shapes of the performance curves show age-related adaptive responses in increasing CMJ height. These adaptations could be hypothesized to be driven by neural mechanisms as reflected in the changes on EMG amplitudes during the different CMJ phases for both groups. This study also found an increased CMJ peak power ($p<0.01$) only for among young adults. Cormie, McBride, & McCaulley (2009) theorized that the ability to quickly accelerate body mass, which allows for greater peak eccentric and ultimately concentric forces, seem to be the primary means to increase CMJ height.

Bobbert & Van Soest (1994) showed in a simulation study that strength gains cannot impact jump height without an enhanced intermuscular coordination, or the efficient control of the magnitude, timing and activation of agonist, synergist, and antagonist muscles. Systematic changes were only evident among young adults and were apparent on the shapes of their force-, power-, and acceleration-time curves (fig.16). These changes seem to indicate an enhanced capacity for intermuscular coordination that optimized the power flow during the a CMJ triple extension (i.e., in the hips, knees and ankle plantar flexion) (Cormie, Mcguigan, & Newton, 2011). The power and plyometric training conducted at the final 5 weeks of the current periodized RT program may have been enough to optimally induce acceleration- and velocity-related adaptations in the young (Cronin, Mcnair, & Marshall, 2002), but not in the older participants. However, the magnitudes of adaptations found in the current study (i.e., acceleration, peak velocity, peak power, force at peak power) seem to be less than the values shown in a study by Cormie, McBride, & McCaulley (2009) among untrained young adults. The lesser magnitudes of adaptation response could be attributed to a rather brief facilitation of plyometric and power training in the present study.

Moreover, changes in CMJ performance was found to be have an age-related difference and could be hypothesized to be driven by the attenuation of the stretch-shortening response among the older. Although not measured in this study, the current periodized RT seem to be insufficient at increasing the ability of the older participants to change their reduced capacity for muscle stiffness regulation and their attenuated ability to use the elastic energy of the motor-unit tendon (Hoffren, Ishikawa, & Komi, 2007; Y. Liu et al., 2006).

7.2 Body composition

Increased strength and power after RT have also been related with morphological mechanisms. Lean body mass has been commonly used as an indicator of skeletal muscle tissue (Peterson & Gordon, 2011). As expected, the current data showed the hypothesized higher total lean mass (3.24%) and total fat free mass (3.09%) in young adults. Muscular adaptations found in previous studies may have also occurred among young adults in this study, as supported by the positive adaptations in relevant body composition variables (i.e., increased total lean mass and total fat free mass). This agrees with an earlier finding that a traditional periodized RT induced hypertrophic adaptations in young adults (Baker et al., 1994). However, DEXA results cannot be assumed specifically for any single muscle (Kosek et al., 2006).

Despite the limitations of our methodologies in claiming specific lower extremity muscle hypertrophy or increased agonist cross sectional area, there is reason to believe that maximal strength improvements in the 1RM leg press could also be due to muscular adaptations, at least among the young adults. A similar finding was reported by (Seynnes et al., 2007) who found that changes in muscle size were already detectable among young adults even after only 3 weeks of heavy resistance training. Their team even reported that muscle architecture remodeling preceded the increases in muscle cross-sectional area.

Similar to young adults, gains in neuromuscular performance among the older have been reported to be related with neural and muscular factors (Narici et al., 1989). However, body composition results among the older only showed positive statistical trends in total lean mass and total fat free mass. Although the older showed an increased body mass (2.1%), the positive statistical trends in total tissue percent fat (1.22%) and total fat mass (4.9%) that came along were unexpected. A similar finding was reported in a longitudinal study among adults aged 20–96 years by Jackson et al. (2012) which showed that body mass increased in sedentary older adults up to age 60 years primarily due to augmented fat mass. However, majority of findings among older RT participants reported fat reductions (Baker, Wilson & Carlyon, 1994; Binder et al., 2005; Hunter et al., 2002; Campbell et al., 1994).

A suggested explanation for the contrasting body composition adaptations among the older in this study could be the absence of dietary control during the intervention. Although the subjects received lectures on proper food intake, the higher energy demand may have led the participants to increase their total calorie intake of usually preferred food instead of protein sources. Older RT participants are usually advised to consume higher amounts of dietary protein (i.e., between 1 and 1.5 g/kg) compared with young adults in order to augment the gains in muscle mass during resistance training (W. J. Evans, Boccardi, & Paolisso, 2013) Notwithstanding, an RT intervention study which controlled protein consumption among the older during a 12-week program reported that dietary protein intake did not prevent fat infiltration (Campbell et al., 1994).

Hypertrophic response have been shown to occur after RT interventions among the older (Hunter, Mccarthy, & Bamman, 2004). A review of 81 cohorts found a strong association between participation in RT and an increased lean body mass among studies with adults over 50 years (Peterson & Gordon, 2011). However, studies found that short-term periodized RT failed to decrease body fat or increase body mass among the older (Maddalozzo & Snow, 2000; Prestes et al., 2015), although extending the duration to 6 months have been shown to augment lean body mass among the older (Maddalozzo & Snow, 2000). Moreover, a meta-analysis identified training volume to predict lean body mass gains (Peterson, Sen, & Gordon, 2011).

Although not measured in this study, some morphological adaptations that could have occurred for both groups in this study may include increased amounts of type II or fast twitch fiber distribution, increased fiber pennation angle, and increased velocity of contraction, although this seems more apparent among the young adults (Runge et al., 2004; Singh et al., 2014). Nevertheless, it has been shown earlier that irrespective of training program design, young novice trainers will always adapt with superior hypertrophy compared with their older counterparts (Kosek et al., 2006). Since less robust adaptations were seen among the older for explosiveness and lean muscle mass in this study, alternative programming may consider increases in frequency, duration and intensity.

7.3 Balance control

Low levels of strength and power especially in the lower extremity appear to contribute to incidence of falls with age (Wang et al., 2016; Thelen et al., 1996). Results from previous studies suggested that recovery from perturbations could be age-related (Piirainen et al., 2010) wherein the older have more delayed muscle activation and larger horizontal COP displacements compared with young adults (de Freitas et al., 2010; Piirainen et al., 2013). Mackey & Robinovitch (2006) for instance revealed that in response to perturbations, the older had smaller peak ankle torque (<7.7%), slower reaction time (<27%), and slower rate of ankle torque generation (<15.6%) in comparison with young adults. As hypothesized, the periodized RT intervention led both older and young adults to incur gains in dynamic balance control expressed as lesser COP disturbance from perturbations in the anterior (*forward plate translation*) and posterior (*backward plate translation*) directions. For the 3 categories of perturbation intensities (low, mid & high), the older optimized performance in the Low Ant, Hi Post and Ave Post conditions, while the young adults improved during the Low Ant, Low Post, Ave Ant and Ave Post conditions.

The manifestation of desired training goals and the transfer of training effects rely primarily on the specificity of the training program (Stone, Plisk, & Collins, 2002). This implies that kinetic and kinematic training conditions (i.e., movement pattern, joint position, velocity) especially for exercises targeted at the lower extremity muscles may, for instance, help prevent falls only when they are trained similar to the testing conditions (Beurskens et al., 2015; Ema et al.,2017; Stone et al., 2000). To the author's best knowledge, this is the first study to compare age-related dynamic balance control adaptations from a balance-protocol-deprived periodized RT. Although an earlier investigation on 3x/week heavy RT failed to improve perturbation response among the older, in spite of their concurrent gains in explosive strength (Granacher, Gruber & Gollhofer, 2009), an augmented dynamic balance control through RT have already been shown. For instance, Hess, Woollacott, & Shivitz (2006) showed that 10-week of heavy RT increased balance among the older through an increased ankle force production, whereas Piirainen et al. (2014) demonstrated that 12 weeks of either plyometric or power training increased dynamic balance control through different neural adaptation mechanisms which targeted the capacity for rapid force generation among the older participants. It seems that the overall design of the current periodized RT program bears potential for a transfer of motor skill and coordination that will enhance dynamic balance control. Despite the absence of increased explosiveness during isometric plantar flexion among the older and isometric knee extension for both groups, the increased coordination as shown in the gains from 1RM leg press and CMJ performance could be hypothesized to facilitate the improved perturbation response.

The current periodized RT program incorporated whole body exercises that emphasized leg workouts, in agreement with a finding by Chen et al. (2014) of the need to not only prioritize distal lower extremities but to also include more proximal axial (i.e. core) muscles. Orr et al. (2006) determined which power training intensity (i.e., 20% -low, 50% -med, or 80% -high) of 1RM would yield greatest balance improvements and found that it was at low load. Researchers of the present study investigated if training for 50% in 1-2 sets for just 2 exercises (i.e., leg press & squats) during the final mesocycle could improve balance. However, due to the methodological limitations of this study, it is impossible to determine if balance improvements already appeared during earlier mesocycles. Nonetheless, there is reason to believe that the parallel or traditional model of periodization especially during the final 5 weeks which included plyometric training and interspersed power training contributed to the results. This could be supported by earlier findings on power training-induced increases in the early onset on force production, neural activity, peak power and maximal isometric and dynamic strength (de Vos et al., 2005; Häkkinen et al., 1998b).

In addition, while the methodological limitations of the study hindered direct neuromuscular or physiological measurement to explain the mechanisms following adaptations in dynamic balance control, gains from neuromuscular performance tests could provide relevant insight. Although the young adults showed increases in maximal and explosive plantar flexion strength, these gains were absent among the older, contrary to earlier findings (Hess et al., 2006; Piirainen et al., 2014). This finding could be noteworthy considering the implications of sarcopenia and dynapenia and seem to suggest the need to modify some variables in current periodized RT programming.

Our study has shown the hypothesized age-related difference in average anterior perturbation peak COP displacements ($p<0.05$), which seem to be connected with the age-related difference in countermovement jump height performance, since both tests require power. An age-related difference during anterior perturbation response, highlighting the role of the soleus muscle, was also reported by Piirainen & colleagues (2013). Nevertheless, the older showed enhanced dynamic control which could be due to the dominant activation of other muscles as supported by an earlier finding that during high perturbation magnitudes, the older respond by changing the natural distal-to-proximal sequence of muscle activation into proximal-to-distal (i.e., hip strategy instead of ankle strategy) (Okada et al., 2001) and by increasing agonist–antagonist co-contraction (Laughton et al., 2003). Finally, although not a primary goal of this research, the significant but small-sized correlations in the neuromuscular and balance variables among the young are surprising. Among the older, a non-correlation agrees with the findings in a review by Granacher et al. (2011), while the results in young adults warrant more investigation. This age-specific correlation seems to suggest a maturation effect in establishing associations between neuromuscular function and balance control.

7.4 Strengths and limitations of the study

Strengths of the study. The methods to investigate the changes in neuromuscular performance, body composition and balance control were comprehensive and systematic. Testing was conducted with laboratory grade measures which ensured precision in determining training effects. The mechanistic analysis of neuromuscular performance tests further identified age-related training adaptations. Moreover, the research findings stir further investigations on the more ideal programming variables that can be modified in designing a periodized resistance training intervention on both groups.

Limitations of the study. Although training volume and relative intensity were equated for both groups, subjective individual motivation determined at which repetition ranges (i.e., 8 vs 10 reps for an 8-10 rep range) would the participants train for each exercise. Total number of participants for each group was low and uneven; hence statistical significance for some measures (i.e., peak power among the older) may have been compromised. Gender distribution between groups was also unequal so that caution should be exercised when interpreting the data based on an age standpoint alone; for instance, the uneven distribution of subjects according to gender may have confounded the results especially for body composition. The use of more general neuromuscular assessments (i.e., EMG & DEXA) failed to specifically identify the mechanisms behind age-related adaptations. Furthermore, the underlying mechanisms behind the gains in dynamic balance control could have been elucidated if additional methods (i.e., EMG and motion capture) from wide-ranging anatomical locations (i.e., hip, knee & core) were used in determining perturbation responses. The inclusion of EMG data alone could have helped determine the power related responses (i.e., EMG onset, EMG time-to-peak displacement, and agonist–antagonist co-activation). Finally, since measurements were only conducted before and after progressive RT, there is no way to determine at which mesocycle have changes started to appear during the current periodized RT.

8 CONCLUSION

This study has shown that a short-term traditionally periodized resistance training led to gains in neuromuscular performance, body composition, and dynamic balance control among physically active but non-resistance trained older and young adult groups. Specifically, both groups increased maximal force production in knee extension, 1RM leg press & countermovement jump, but only the young increased in plantar flexion.

On the other hand, only the older increased total body mass and only the young adults increased total lean mass and total fat free mass. In addition, only the older decreased COP disturbance from high-Post perturbations while only the young adults decreased from low Post, mid Ant and Ave Ant perturbations. Finally, age-related differences were revealed for CMJ height and Ave Ant COP. Positive adaptations were incurred primarily through neural mechanisms among the older, while the young adults exhibited gains from both neural and muscular mechanisms. The current periodized RT program seems to be a viable design for optimizing adaptations that could address age-related weaknesses. Results from this study encourage researchers and trainers to evaluate other programming variables in designing a periodized RT that could especially address explosiveness and hypertrophy among older adults.

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