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Effects of plyometric and pneumatic explosive strength training on neuromuscular function and dynamic balance control in 60–70 year old males

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ABSTRACT

The present study compared neuromuscular adaptations to 12 weeks of plyometric (PLY) or pneumatic (PNE) power training and their effects on dynamic balance control. Twenty-two older adults aged 60–70 (PLY $n = 9$, PNE $n = 11$) participated in the study. Measurements were conducted at Pre, 4, 8 and 12 weeks. Dynamic balance was assessed as anterior–posterior center of pressure (COP) displacement in response to sudden perturbations. Explosive isometric knee extension and plantar flexion maximal voluntary contractions (MVCs) were performed. Maximal drop jump performance from optimal dropping height was measured in a sledge ergometer. Increases in knee extensor and ankle plantar flexor torque and muscle activity were higher and occurred sooner in PNE, whereas in drop jumping, PLY showed a clearer increase in optimal drop height (24%, $p < 0.01$) after 8 weeks of training and soleus muscle activity after 12 weeks of training. In spite of these training mode specific adaptations, both groups showed similar improvements in dynamic balance control after 4 weeks of training (PLY 38%, $p < 0.001$; PNE 31%, $p < 0.001$) and no change thereafter. These results show that although power and plyometric training may involve different neural adaptation mechanisms, both training modes can produce similar improvements in dynamic balance control in older individuals. As COP displacement was negatively correlated with rapid knee extension torque in both groups (PLY $r = -0.775$, $p < 0.05$; PNE $r = -0.734$, $p < 0.05$) after training, the results also highlight the importance of targeting rapid force production when training older adults to improve dynamic balance.

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1. Introduction

It is well known that aging causes degeneration of the human neuromuscular system including loss of muscle mass, decreased conduction and contraction velocities and weaker neural activation from central pathways (Harridge et al., 1999; Thom et al., 2007; Vandervoort, 2002; Werner et al., 2012). In aging, rapid force production decreases more than maximal force production (Izquierdo et al., 1999) and its effect on functional muscle capacity may be more crucial, especially in response to sudden balance perturbations (Piirainen et al., 2010). This may be a major contributor to falling accidents and injuries in older adults. The importance of rapid force production suggests that power/explosive strength training may have beneficial effects on functional performance capacity and balance control.

Power/explosive strength training is often performed using pneumatic devices that primarily involve concentric contractions, often leading to improved strength and power (de Vos et al., 2005; Orr et al., 2006). Although minor muscle hypertrophy may occur (Hakkinen et al., 1998), the primary adaptations seem to be related to more effective voluntary activation, especially in the early phase of force production. Typical neural adaptations include increased agonist activation (Hakkinen et al., 1998; Van Cutsem et al., 1998), a possible decrease in antagonist co-activation (Hakkinen et al., 1998), and decreased reciprocal inhibition, especially in the early phase of rapid force production (Geertsen et al., 2008). These neural adaptations seem to be related to improved balance control in older individuals (Izquierdo et al., 1999; Orr et al., 2006).

However, adaptations may be training-mode specific. For example, plyometric training utilizes the stretch shortening cycle (SSC), which is typically associated with more effective use of tendon

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elasticity and stretch reflex activation than concentric only training (Aura and Komi, 1986a; Komi, 2000). Few studies have investigated the effects of plyometric training on neuromuscular function. Chimera et al. (2004), Kyrolainen et al. (2005) both found no changes in lower limb muscle activation after plyometric training, whereas Kubo et al. (2007) showed a significant increment in plantar flexor muscle activity, but only in the concentric phase of drop jumps. In terms of reflex responses, Voigt et al. (1998) showed increased soleus H-reflexes during hopping after plyometric training, which they attributed to more automatic control strategies during jumping with less voluntary activation. Therefore, contrary to pneumatic power training, plyometric training may primarily enhance spinal reflex activity rather than voluntary activation.

In spite of the known benefits of both plyometric and pneumatic power training, it is currently unknown which training mode is more beneficial for balance control, especially in older individuals. The purpose of this study was to examine the effects of plyometric and pneumatic power training on neuromuscular adaptations and dynamic balance control during and after a 12-week training period in males aged 60–70. We hypothesized that pneumatic training would increase neural drive to the muscles, thus improving force production properties. Conversely, plyometric training was expected to enhance spinal reflex activity, leading to more efficient feedback from proprioceptors. Thus, both training regimens were expected to improve dynamic balance control, but via different mechanisms.

2. Methods

2.1. Subjects

A total of 20 male subjects aged 60–70 (9 plyometric; PLY age 63 ± 2, weight 84 ± 9 kg, height 176 ± 7 cm and 11 pneumatic; PNE age 65 ± 3, weight 77 ± 8 kg, height 176 ± 6 cm) volunteered and completed this 12-week study. After volunteering, subjects were randomly assigned to the two groups. All subjects were physically active but did not participate in any systematic training programs. Exclusion criteria were high blood pressure (systolic over 160 mmHG), heart and circulatory system diseases and musculoskeletal diseases. Subjects provided written informed consent and were aware of the protocol and possible risks of the study. The study was conducted according to the declaration of Helsinki, and was approved by The University of Jyväskylä Ethics Committee.

2.2. Test protocol

To minimise the effects of learning during training, subjects performed a familiarisation session three days prior to the beginning of the study. Subjects then completed 12 weeks of training, with follow-up measurements performed at pre, 4, 8 and 12 weeks. On each measurement day, after preparations and a 10 min cycling warm-up (80 W), measurements were performed in the following order: (1) dynamic balance control, (2) H-reflex during standing rest, (3) maximal voluntary isometric plantar flexion contractions (MVC), (4) maximal drop jumps, (5) H-reflex during drop jumps and (6) isometric knee extension MVC. H-reflexes were only measured pre- and post-training. The total time of one test session was approximately 2.5 h.

2.3. Training program

Subjects trained 2 times per week during weeks 1–3 and 9–12 of the 12-week training period. In weeks 5–7 they trained 3 times per week, while in weeks 4 and 8 they had only one session which was a control measurement session. PLY trained the legs using a sledge apparatus (University of Jyväskylä, Finland) that enables drop jumps to be performed more safely than standard vertical jumping. This was deemed necessary considering the age of the subjects. The sledge jumping angle was 23.6° from horizontal and the load consisted of sledge weight (33 kg) and each subject's own body mass. The average load in PLY was 459 ± 38 N during the entire 12-week training period. Jumps were performed as continuous countermovement jumps. The lowest knee angle during the jumps was 70–90°, which was determined based on a position signal from the sledge apparatus. The PNE group trained using pneumatic leg extension and calf raise devices (HUR, Kokkola, Finland) with a load of 40% of MVC, which was measured and updated every four weeks. For leg extension, absolute loads were 94 ± 13 N, 118 ± 20 N and 148 ± 20 N in weeks 1–4, 5–8 and 9–12, respectively. Corresponding values for calf raises were 147 ± 22 N, 200 ± 27 N and 308 ± 48 N, respectively. Concentric MVCs were measured by increasing the load by 10 N m after each trial until full extension was no longer achieved. Because of the nature of the different training tasks, it was not possible to match the training loads between groups. However, both groups performed the same number of repetitions (6) and sets (5) in each session during the entire period. In addition, trials were always performed with maximal effort as explosively as possible. Despite the differences between training modes, the same main muscle groups (thigh and calf) were trained in both groups. Both groups also performed an identical hypertrophy protocol for the upper body throughout the study period, leading to whole body development of strength properties and thus improved training motivation.

3. Measurements

3.1. Dynamic balance

Dynamic balance was measured using a custom-made dynamic balance measurement system (University of Jyväskylä, Finland; HurLabs Oy, Tampere, Finland), which consists of four pneumatic cylinders placed vertically under a BT4 balance platform (HurLabs Oy, Tampere, Finland). Maximal cylinder displacement amplitude is 12.5 cm, giving 12° freedom of movement in each direction. By releasing air out of the cylinders, it is possible to drop (free fall) each side of the plate independently to produce a perturbation. The device is described in more detail elsewhere (Piirainen et al., 2010). Hur Balance software (HurLabs Oy, Tampere, Finland) was used for data collection. During the measurements, subjects stood on the balance plate for two 30 s sets, during each of which four sudden balance perturbations were induced, one in each direction (medial–lateral, anterior–posterior). Subjects were unaware of the direction and timing of the perturbations. During each perturbation, one side of the plate dropped by 12.5 cm in free fall. A black mark was fixed on the wall ~2.8 m from the subject at eye level to stabilize their visual focus during the measurements. For each perturbation direction, the attempt with the least average centre-of-pressure (COP) sway was chosen for further analysis. Average maximal swaying distance in the medial–lateral and anterior–posterior stabilograms were analysed during a one second period after the disturbance while the platform remained in the tilted position.

3.2. Plantar flexion and knee extension MVC

Plantar flexion MVC was measured using a custom-built force dynamometer (University of Jyväskylä, Finland). Subjects sat in the dynamometer with hip, knee, and ankle joint angles at 110°, 180°, and 90°, respectively, and performed five MVCs at 1 min inter-

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