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Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people

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Abstract Effects of a 24-week strength training performed twice weekly (24 ST) (combined with explosive exercises) followed by either a 3-week detraining (3 DT) and a 21-week re-strength-training (21 RST) (experiment A) or by a 24-week detraining (24 DT) (experiment B) on neural activation of the agonist and antagonist leg extensors, muscle cross-sectional area (CSA) of the quadriceps femoris, maximal isometric and one repetition maximum (1-RM) strength and jumping (J) and walking (W) performances were examined. A group of middle-aged (M, 37–44 years, n = 12) and elderly (E, 62–77, n = 10) and another group of M (35–45, n = 7) and E (63–78, n = 7) served as subjects. In experiment A, the 1-RM increased substantially during 24 ST in M (27%, P < 0.001) and E (29%, P < 0.001) and in experiment B in M (29%, P < 0.001) and E (23%, P < 0.01). During 21 RST the 1-RM was increased by 5% at week 48 (P < 0.01) in M and 3% at week 41 in E (n.s., but P < 0.05 at week 34). In experiment A the integrated electromyogram (IEMG) of the vastus muscles in the 1-RM increased during 24 ST in both M (P < 0.05) and E (P < 0.001) and during 21 RST in M for the right (P < 0.05) and in E for both legs (P < 0.05). The biceps femoris co-activation during the 1-RM leg extension decreased during the first 8-week training in M (from 29 ± 5% to 25 ± 3%, n.s.) and especially in E (from 41 ± 11% to 32 ± 9%, P < 0.05). The CSA increased by 7% in M (P < 0.05) and by 7% in E (P < 0.001), and by 7% (n.s.) in M and by 3% in E (n.s.) during 24 ST periods. Increases of 18% (P < 0.001) and 12% (P < 0.05) in M and 22% (P < 0.001) and 26% (P < 0.05) in E occurred in J. W speed increased (P < 0.05) in both age groups. The only decrease during 3 DT was in maximal isometric force in M by 6% (P < 0.05) and by 4% (n.s.) in E. During 24 DT the CSA decreased in both age groups (P < 0.01), the 1-RM decreased by 6% (P < 0.05) in M and by 4% (P < 0.05) in E and isometric force by 12% (P < 0.001) in M and by 9% (P < 0.05) in E, respectively, while J and W remained unaltered. The strength gains were accompanied by increased maximal voluntary neural activation of the agonists in both age groups with reduced antagonist co-activation in the elderly during the initial training phases. Neural adaptation seemed to play a greater role than muscle hypertrophy. Short-term detraining led to only minor changes, while prolonged detraining resulted in muscle atrophy and decreased voluntary strength, but explosive jumping and walking actions in both age groups appeared to remain elevated for quite a long time by compensatory types of physical activities when performed on a regular basis.

Key words Ageing · Strength training · Detraining · Muscle hypertrophy and atrophy · Agonist-antagonist

Introduction

Human muscle strength and the ability to develop explosive force are well known to decrease in both genders with increasing age, especially at the onset of the sixth decade (Larsson 1978; Bosco and Komi 1980; Clarkson et al. 1981; Häkkinen 1994; Porter et al. 1995; Vander-voort 1998). The decrease in strength performance capacity can be explained in part by the decreased maximal voluntary activation of the agonist muscles and/or
changes in the degree of agonist-antagonist co-activation (Kamen et al. 1995; Häkkinen et al. 1998b) and, to a greater extent, by the reduction in muscle mass associated with age-related changes in hormone balance (Häkkinen and Pakarinen 1993) and the decline in the intensity of daily physical activities (Måkkia et al. 1994). The decline in muscle mass is thought to be mediated by a reduction in the size and/or number of individual muscle fibres, especially of fast-twitch fibres (Essen-Gustavsson and Borges 1986; Lexell et al. 1988).

However, it has been shown that systematic strength training not only in middle-aged but also in older people can lead to substantial increases in strength performance. This results primarily from the considerable neural adaptation observed especially during the earlier weeks of training (Moritani and DeVries 1980; Häkkinen and Häkkinen 1995; Keen et al. 1994; Häkkinen et al. 1996, 1998a, b). This initial training-induced increase in strength in elderly people may be accounted for primarily by increases in the voluntary activation of the agonist muscles (Moritani and DeVries 1980; Häkkinen et al. 1998a) although changes in co-activation of the antagonists may occur also (Häkkinen et al. 1998a). Muscle hypertrophy of both fibre types may also contribute to further strength development during subsequent months when using typical heavy-resistance training programs with older people (Frontera et al. 1988; Charette et al. 1991; Pyka et al. 1994; Häkkinen et al. 1998b).

Much less information is available on training-induced neuromuscular adaptation in older people during prolonged strength training lasting for several months, a year, or even longer (Lexell et al. 1995; Morganti et al. 1995; McCartney et al. 1996). Furthermore, in addition to maximal strength of various muscle groups, the role of explosive strength characteristics of the leg extensors is also important for various functional physical activities in the elderly (Bassey et al. 1991). As in the case of younger adults, to achieve increases in the explosive strength capacity of older people heavy resistance training should probably be combined with explosive exercises by paying special attention to the higher action/movement velocities of the exercises performed (Häkkinen and Häkkinen 1995; Häkkinen et al. 1998a). The extent to which these resistance training-induced increases in maximal and explosive strength characteristics are related to changes in dynamic functional capacities, such as jumping and walking performances, is of both scientific and practical interest. Finally, although it is known that detraining leads within a few weeks to a decrease in maximal voluntary muscle activation, muscle atrophy and decreased strength in young adults (Häkkinen et al. 1985; Narcisi et al. 1989), only very limited information is available on effects of short-term and prolonged detraining on neuromuscular performance in older people (Lexell et al. 1995).

This study was conducted to examine both functional and structural adaptation in the neuromuscular system and changes in vertical jumping and normal walking performance in middle-aged and elderly people during prolonged strength training lasting for 24 weeks followed (after 3 weeks) by an additional re-strengthening period of 21 weeks utilizing a program planned not only for maximal strength development but also including exercises of an explosive nature. The second aim of this study was to examine neuromuscular adaptation and changes in the functional capacities of these middle-aged and older people during both short-term and prolonged detraining periods of 3 and 24 weeks after the termination of systematic strength training.

Methods

Subjects

A group of middle-aged (M, age range 37–44 years, n = 12, six women and six men) and of elderly (E, 62–77, n = 10, five women and five men) subjects volunteered as subjects for a strength-training-detraining-re-strengthening-training study (experiment A). Another group of M (35–45, n = 7, four women and three men) and elderly E (63–78, n = 7, four women and three men) subjects volunteered as subjects for a strength-training-detraining study (experiment B). The actual recruitment took place so that subjects volunteered to enter either group A or B.

The percentage of fat in the body was estimated from the measurements of skinfold thickness (Durnin and Womersley 1967). The subjects were informed carefully about possible risks and discomfort that might result and each gave written consent prior to participation in the project. The study was conducted according to the declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä, Finland. The subjects were recruited from the town of Jyväskylä via various fliers delivered all over the town. Only healthy subjects, based on medical screening, were accepted. All were living independently and, according to data collected via questionnaire, were habitually physically active. To keep fit and as recreation they took part in various physical activities such as walking, jogging, swimming, biking and aerobics 1–3 times weekly but none had any background of regular strength training. The subjects were taking no medication that would have been expected to affect physical performance or endocrine profile.

Experimental design

The total duration of the present study was 48 weeks. The first 4-week period (between measurements made at weeks 4 and 0) in both experiments A and B was used as a control period, during which no strength training was carried out, although subjects maintained their normal recreational physical activities (e.g. walking, jogging, biking, swimming and aerobics). The subjects were tested before and after this control period. Thereafter, all subjects in both experiments started a supervised experimental strength-training period for 24 weeks utilizing the same program. The measurements were repeated during the 24-week training period in both experiments A and B at 8-week intervals (i.e. at weeks 0, 8, 16 and 24). Thereafter, the subjects in experiment A underwent a 3-week detraining period without any strength training at all (until week 27). This 3-week detraining period was then followed by a re-strengthening period for 21 weeks (weeks 27–48). The measurements were repeated during the re-strengthening period at 7-week intervals (i.e. at weeks 27, 34, 41 and 48). The subjects in experiment B terminated their strength training for the entire detraining period of 24 weeks (weeks 24–48). The present study is the continuation of a previous project (Häkkinen et al. 1998a).

Testing

The subjects were familiarized carefully with the testing procedures of voluntary force production of the bilateral leg extension and