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Maximal and explosive force production capacity and balance performance in men of different ages

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Abstract A group of 32 healthy men (M) divided into three different age groups, i.e. M20 years [mean 21 (SD 1); $n = 12$], M40 [mean 40 (SD 2); $n = 10$] and M70 [mean 71 (SD 5); $n = 10$] volunteered as subjects for examination of maximal and explosive force production of leg extensor muscles in both isometric and dynamic actions (squat jump, SJ and counter movement jump, CMJ, and standing long-jump, SLJ). The balance test was performed on a force platform in both isometric and dynamic actions. Maximal bilateral isometric force value in M70 was lower ($P < 0.001$) than in M40 and as much as 46% lower ($P < 0.001$) than that recorded in M20 ($P < 0.001$). The maximal rate of force development (RFD) on the force-time curve was in M70 lower ($P < 0.001$) than in M40 and as much as 64% lower than in M20. The heights in SJ and CMJ and the distance in SLJ in M70 were lower ($P < 0.001$) than in M40 and M20 ($P < 0.001$). In response to modifications of the visual surroundings the older subjects were 24%–47% ($P < 0.05$ and $P < 0.001$) slower in their response time in reaching the lit centre (TT) and remained 20%–34% ($P < 0.001$) less time inside the centre (TC) from the overall time of lighting than M40 and M20, respectively. In both older groups the individual values of isometric RFD correlated significantly ($P < 0.05$) with the individual balance values of TT and TC. The present results would suggest that the capacity for explosive force production declines drastically with increasing age, even more than maximal muscle strength. Aging may also lead to impaired balance with a decrease in event detection and speed of postural adjustments. The decreased ability to develop force rapidly in older people seems to be associated with a lower capacity for neuromuscular response in controlling postural sway.

Key words Aging · Dynamic posturography · Balance · Muscle strength · Explosive force development

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Introduction

A great deal of information has been reported on the age related decline in human muscle strength that takes place especially after the age of 60 years (Larsson 1978; Young et al. 1984; Narici et al. 1991; Frontera et al. 1991; Häkkinen et al. 1995, 1996). The age related decrease in maximal strength has been attributed to a great extent to the reduction in muscle mass which is perhaps related to alterations in hormone balance (e.g. Häkkinen and Pakarinen 1993), and the decline in the quantity and intensity of physical activity (Mälkiä et al. 1994). It has been suggested that the decline in muscle mass is mostly likely mediated by a reduction in number and size of individual muscle fibres, especially of fast-twitch fibres (e.g. Lexell et al. 1998; Porter et al 1995).

However, it has been shown that explosive strength characteristics of neuromuscular performance may decline with increasing age even more than maximal strength whether determined using concentric or stretch-shortening cycle (SSC) actions (Larsson et al. 1979; Bosco and Komi 1980; Häkkinen et al. in press) or rapid isometric muscle actions (Clarkson et al. 1981; Vandervoort and McComas 1986; Häkkinen and Häkkinen 1991; Häkkinen et al. 1995, 1996, in press). Muscle strength and especially the ability of the leg extensor muscles to develop force rapidly are important performance characteristics which have been shown to contribute to several of the tasks of daily life such as climbing stairs, walking or even the prevention of falls and/or trips (Bassey et al. 1992).

The neuromuscular basis of balance has also been found to deteriorate with the process of aging (Whipple et al. 1993; Woollacott 1993) and may compromise the maintenance of a position, the stablization of voluntary movements or the reaction to external disturbances. All of these factors are related to poor balance, the increased risk of falling and moving from one position to another safely. Elderly people have been shown to have slightly higher measurements of sway in double and single static leg stance (Bohannon et al. 1984; Era et al. 1985; Maki 1990), a longer response time to induced postural perturbations and changes in the visual surrounding in dynamic actions when compared with younger adults (Shepard 1984; Stelmach et al. 1990, Berg et al. 1992). Although previous studies have shown relationships between muscle weakness and balance in fallers and non fallers (Danneskiold-Samsoe et al. 1984; Whipple et al. 1987; Gehlsen and Whaley 1990; Stephen et al. 1991), relatively little work has been done on assessing to what extent age related declines in the capacity for force production of the neuromuscular system may also be associated with the overall decline in the postural adjustments for maintaining stability and balance.

The purpose of this study were to examine age-related changes in:

1. Postural sway during static and dynamic tests on a force platform
2. Maximal and explosive force production characteristics of the leg extensor muscles recorded during isometric and dynamic actions
3. Possible relationships between measurements of balance and indices of force production characteristics in young, middle-aged and elderly men.

Methods

Subjects

A total of 32 male subjects volunteered for the study. They were divided into three groups according to age: 12 young men in a 20-year-old group [M20, mean age 21 (SD 1)] 10 middle-aged men in the 40-year-old group [M40, 40 (SD 5)] and 10 elderly men in the 70 year-old group [M70, 71 (SD 5)]. The physical characteristics of the groups are given in Table 1. The study was approved by the Ethics Committee of the University of Leon. Verbal informed consent was obtained from all the subjects prior to participation in the study. All the subjects were healthy and habitually physically active. However, none of the subjects had any background in regular strength training or competitive sports of any kind. No medication was being taken by the subjects which would have been expected to affect physical performance.

Test procedures

The subjects were carefully familiarised with the test procedures of voluntary force production of the leg muscles and balance performances during several submaximal and maximal actions a few days before the measurements and also several warm-up contractions prior to the actual maximal test action.

All the subjects were tested for their maximal bilateral isometric leg extension force (MIF), and maximal rate of force development (RFD). The subject squatted in an isometric condition on a force platform (Dinascan 600M), and was prevented from extending upwards by their shoulders being in contact with a fixed bar positioned so that the knee angle was 90°. At a command a subject exerted his maximal force against the force platform by pressing his shoulders against the fixed bar. The subjects were instructed to exert their maximal force as fast as possible during a period from 2.5 to 4 s. The period of rest between each maximal contraction was always 1.5 min. Three trials were completed for each test condition and the best performance was used for the subsequent statistical analysis. In all tests of neuromuscular performance, strong verbal encouragement was given for each subject.

Dynamic explosive force was measured by asking the subject to exert force on a force platform in a maximal vertical squat jump (SJ; from a starting position of a knee flexion of 90°), and a counter movement jump (CMJ; with a preparatory movement from the extended leg position down to the 90° knee flexion followed by a subsequent concentric action) and a standing long jump (SLJ). These have been used successfully in the examination of explosive force production in elderly men and women by Bosco and Komi (1980) and Häkkinen et al. (1997). In SJ and CMJ the height was calculated from the flight time and power from the vertical force-time curve, while in SLJ the distance was measured using a tape. Three maximal jumps were recorded in both cases and the best reading was used for further analysis.

All the performances were executed on a force platform (Piezorresisteive Platform Dinascan IBV, model 600M) and the vertical and horizontal force component was digitally converted (data acquisition model CIO AD-16-12 bit resolution) at 200 samples · s^{-1} and stored on a computer disk. Before the actual measurements, the force platform was calibrated (standardised calibration method PDINCO1-00) with a result of equal to or less than 2% variation from the measured load for both the vertical and horizontal

Table 1 Physical characteristics of young (20 yrs, *M20*), middle-aged (40 yrs, *M40*) and elderly (70 yrs, *M70*) men

Variable		M20 20 years (n = 12)	M40 40 years (n = 10)	M70 70 years (n = 10)	Significance of differences
Age (years)	Mean	21	40	71	
	SD	1	2	5	
Body height (cm)	Mean	174	170	167	M20/M70**
	SD	4	6	4	
Body mass (kg)	Mean	71	72	72	
	SD	5	6	8	
Body fat (%)	Mean	13	19	20	M20/M40** M20/M70**
	SD	2	2	3	

** $P < 0.01$

component. The reproducibility was calculated with repeated measurements of static loads on the force platform ranging from 25 kg to 350 kg. The relative error between the trials was less than 1.75% with a relative difference less than 1.20%. The force platform was fixed on a stable surface in the ground to avoid any external noise of disturbance.

The force signal was recorded on a computer (486 DX-100) and thereafter digitised and analysed by a computerised system (Dinascan IBV Ltd.). Maximal peak force was defined as the highest value of the force recorded during each bilateral isometric contraction. The force-time analysis on the absolute scale included the calculation of the maximal rate of force development (RFD; Viitasalo et al. 1980) and the average force produced from the start of the contraction up to 500 ms (F_{500}; Häkkinen et al. 1996). Maximal and explosive force variables showed reliability coefficients greater than 0.75 and a coefficient of variation (CV) lower than 4%.

Balance was measured using computerized dynamic posturography of a subject standing on the force platform with hands on hips. Balance was assessed by modifying the visual surroundings and asking the subject to score a bull's-eye as fast and precisely as possible in response to the change in the external signal by moving his body. Four red centres were randomly lit for periods of 5 s. The total duration of the test was 30 s. The analysis of the transitional period from one lit centre to another included the calculation of the time to reach the liit center (time of transition; TT), the percentage of the time during which the subject remained inside the centre as a percentage of the overall time of the lighting of the centre (time inside centre; TC) and quality of the performance (straightness of the trajectory, ST). The Eq. 1 was used to calculate the straightness of the trajectory as a index of quality. First an ellipse was calculated including all the positions covered by the centre of pressure of each individual subject. This was followed by a calculation of the square of the standard deviation of the trajectory of movement in the main axis of the ellips (λ1 and λ2).

$$Q = 100 \cdot (1 - \lambda 1/\lambda 2) \qquad (1)$$

where Q is quantity (%) and λ1 and λ2 are the squares of the standard deviations of the trajectories in the main axis of the ellipse. In addition, the analysis of the performance of the subject inside the centre included the calculation of the successful trials and the balance area (BA).

Balance also was measured in dynamic actions, the subject being in a standing position with the hands on the hips. The subject was asked to raise the knee (in a flexed position) to 90°, alternately. The one leg stance time was controlled using a metronome with a frequency of 50 Hz. The analysis of the kinetics parameters of the centre of pressure (CP) included the total distance in the x and y axes and BA. The Eq. 2 was used to calculate BA. This estimates the area in which the movement of the subject has taken place. First an ellipse was calculated including all the positions of BA where the movements have taken place. Thereafter, a calculation was done for the area of the polygon insert in that ellipse. Balance variables showed moderate reliability coefficients ranging from 0.6 to 0.35 and CV from 9% to 15%.

$$BA = 4 \cdot \sqrt{\lambda 1 \cdot \lambda 2} \qquad (2)$$

where BA is the balance area, λ1 and λ2 are the squares of the standard deviations in the main axis of a elipse. The percentage of fat in the body was estimated form measurements of skinfold thickness (Durnin and Womersley 1967).

Statistical methods

Standard statistical methods were used for the calculation of the means and standard deviations (SD), standard errors (SEM) and Pearson product moment correlation coefficients. The data were then analysed using analysis of variance (ANOVA). Probability adjusted student's t-tests were used for pairwise comparisons where appropriate. The P equal to or less than 0.05 criterion was used to establish statistical significance.

Results

The maximal bilateral voluntary isometric leg extension force of 747 (SEM 63) N in M70 was lower ($P < 0.001$) than that of 1039 (SEM 92) N recorded for M40 and lower ($P < 0.001$) than the force of 1381 (SEM 81) N recorded for M20 (Fig. 1).

The shape of the average bilateral isometric force-time curve in the absolute values differed also among the groups. Both maximal RFD and the force produced during the first 500 ms were lower in M70 ($P < 0.001$–0.01) than in M40 and M20 (Fig. 2A, B). The mean

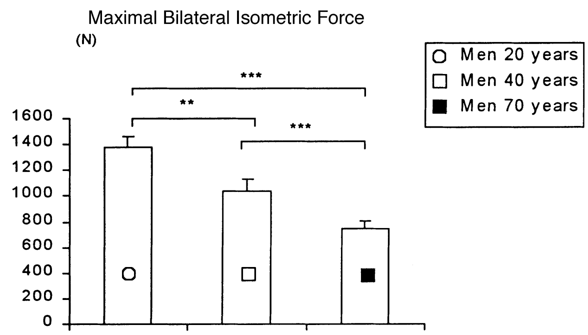

Fig. 1 Mean and SEM maximal voluntary isometric force of the leg extensor muscles in young (20 years), middle-aged (40 years) and elderly (70 years) men **$P < 0.01$, ***$P < 0.001$

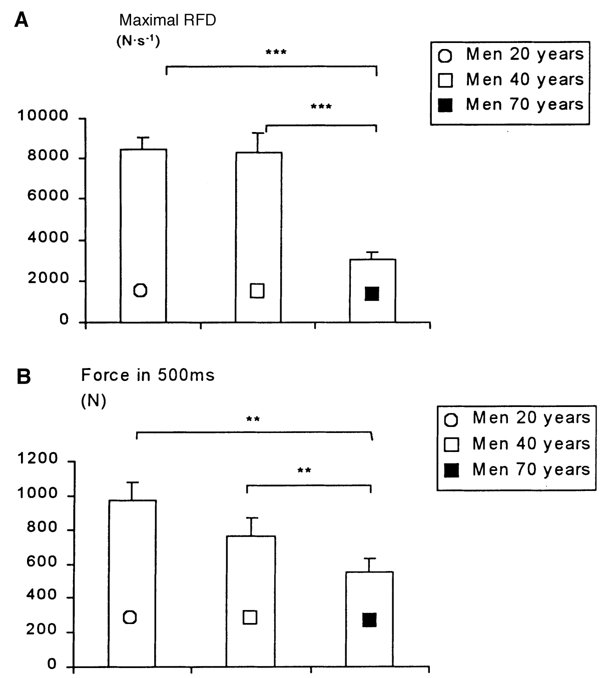

Fig. 2 Mean and SEM of maximal voluntary rate of force development (*RFD*, **A**) and mean and SEM of voluntary explosive force produced during the first 500 ms of the bilateral isometric leg extension action (**B**) in young (20 years), middle-aged (40 years) and elderly (70 years) men. **$P < 0.01$, ***$P < 0.001$

values between M40 and M20 did not differ significantly from one another.

The jumping heights in SJ and CMJ and the distance in SLJ differed among the groups, such that all values were greater ($P < 0.001$) in M20 than in M40, while M70 demonstrated the lowest values ($P < 0.001$; Fig. 3).

Table 2 provides the bivariate correlation coefficients between various dynamic and isometric variables in M20, M40 and M70, separately. This relationship was also observed in a combined *old* group (M40 + M70) to examine whether strength performance variables were related similarly in a combined group with greater interindividual variation compared to the separate groups. The values for explosive SJ concentric action were not correlated with either isometric explosive (RFD and

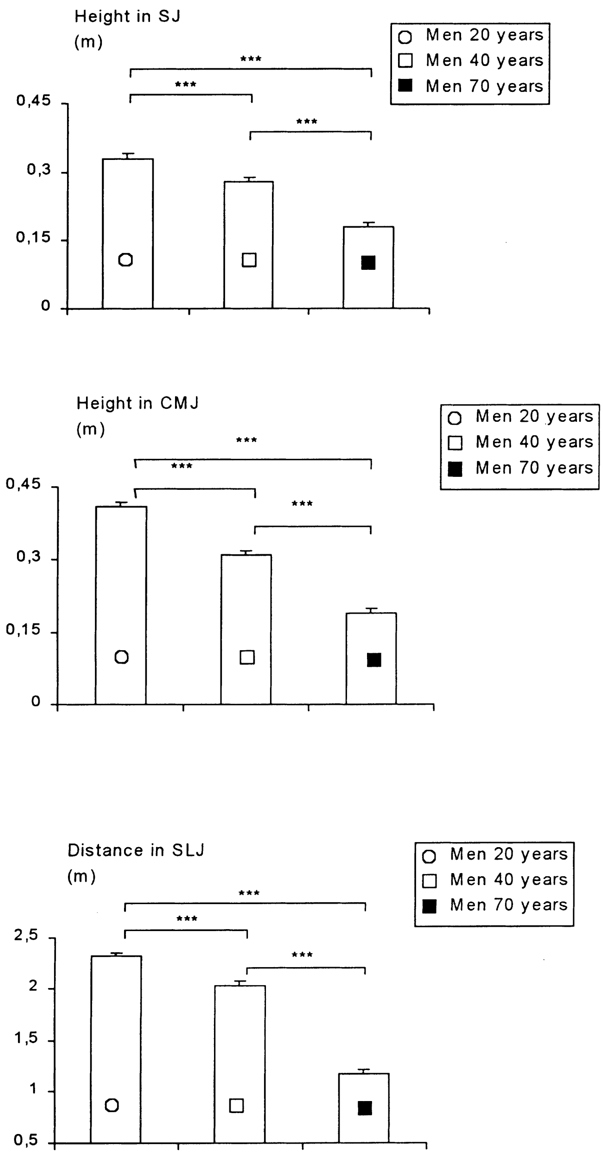

Fig. 3 Mean and SEM of heights in maximal vertical jumping height in the squat jump (*SJ*) and in the countermovement jump (*CMJ*) and distance in the standing long jump (*SLJ*) in young (20 years), middle-aged (40 years) and elderly (70 years) men. $***P < 0.001$

Table 2 Correlation coefficients between various dynamic and isometric variables in *M20*, *M40* and *M70* and for a combined group of *M40 + M70*. *SLJ* Standing long-jump, *SJ* squat jump, *CMJ* countermovement jump, *MIF* maximal isometric force, *RFD* maximal rate of force development, *F500* force in 500 ms. For other definitions see Table 1

	M20				M40				M70				M40 + M70			
	SLJ	SJ	CMJ	MIF	SLJ	SJ	CMJ	MIF	SLJ	SJ	CMJ	MIF	SLJ	SJ	CMJ	MIF
RFD	0.05	0.07	0.29	0.36	0.07	0.02	0.07	0.15	0.14	0.41	0.68*	0.18	0.76**	0.63**	0.66**	0.42*
F500	0.63*	0.24	0.61*	0.45	0.37	0.13	0.14	0.70*	0.41	0.26	0.13	0.70*	0.31	0.34	0.46*	0.74**
SLJ	–	0.59*	0.83**	0.40	–	0.27	0.01	0.14	–	0.04	0.25	0.35	–	0.73**	0.70**	0.51*
SJ	–	–	0.69*	0.03	–	–	0.78**	0.35	–	–	0.53	0.53	–	–	0.88**	0.60**
CMJ	–	–	–	0.65*	–	–	–	0.63*	–	–	–	0.03	–	–	–	0.65**

$* P < 0.05$, $** P < 0.01$

F_{500}) or maximal isometric force values in any of the separate age groups. When the relationships were calculated for a combined group of M40 and M70, the SJ concentric performance correlated significantly with isometric RFD and maximal force values ($r = 0.63$ and 0.60; $P < 0.01$). No significant correlations were found between maximal strength and RFD values in any of the groups, while in a combined group of M40 and M70 the respective correlation coefficient was significant ($r = 0.42$; $P < 0.05$).

Figure 4 shows the kinetic parameters of the centre of pressure during the balance performance. In M20 the TT between the centres (when they were lit) was shorter (n.s.) than that recorded in M40 and shorter ($P < 0.001$) than in M70. Also the time inside the centre as a percentage of the overall time of lighting was greater in M20 than that recorded for M20 and greater ($P < 0.001$) than in M70. The quality of the performance estimated as the straightness of the trajectory remained statistically unaltered in all groups [75 (SEM 2), 74 (SEM 3) and 76 (SEM 5)% for M20, M40, M70, respectively]. The average number of the centres of 3.1 (SEM 1) searched successfully in M70 was lower ($P < 0.05$) than that recorded for M40 [3.8 (SEM 1)] and lower ($P < 0.05$) than that for M20 [4 (SEM 0)].

The sway area and the displacement of the centre of pressure in the alternative dynamic leg-stance balance test of 4926 (SEM 215) mm^2 and 5814 (SEM 387) mm in M20 were lower ($P < 0.05$) than those of 5546 (SEM 857) mm^2 and 10707 (SEM 2372) mm recorded for M40 and lower (n.s) than those of 6305 (SEM 627) mm^2 and 9463 (SEM 2079) mm^2 recorded for M70.

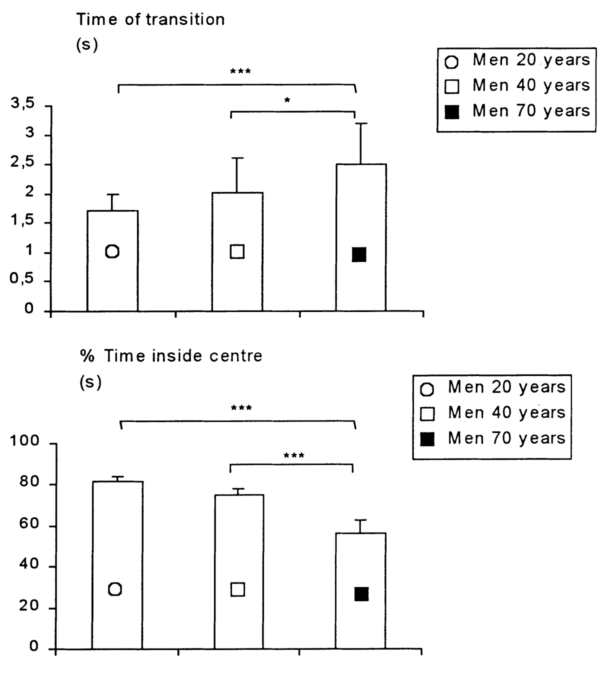

Fig. 4 Mean and SEM of time of transition and mean and SEM of time inside centre in the balance test in young (20 years), middle-aged (40 years) and elderly (70 years) men. *$P < 0.05$, ***$P < 0.001$

Table 3 Correlation coefficients between various indices of explosive and maximal force production and measurements of balance in *M20*, *M40* and *M70* and for a combined group of *M40 + M70*. *SLJ* Standing long-jump, *SJ* squat jump, *CMJ* countermovement jump, *MIF* maximal isometric force, *RFD* maximal rate of force development, *F500* force in 500 ms, *TT* time of transition, *ST* straightness of the trajectory, *TC* time inside center, *BA* balance area, *DCP* distance center of pressure. For other definitions see Table 1

Variables	SJ	CMJ	SLJ	F500 ms	MIF	RFD
M20						
TT (s)	0.04	0.22	0.43	0.43	−0.12	−0.27
ST (%)	0.18	−0.26	−0.15	−0.50*	0.45	0.06
TC (%)	0.27	0.42	−0.56*	0.52*	0.13	−0.21
BA (mm^2)	−0.42	−0.29	−0.29	−0.53*	0.08	0.4
DCP (mm)	−0.18	−0.26	−0.37	−0.13	−0.11	−0.25
M40						
TT (s)	−0.13	0.14	0.23	0.22	0.06	−0.56*
ST (%)	0.21	0.37	−0.24	0.56*	0.56*	0.20
TC (%)	0.31	−0.02	−0.29	−0.01	−0.43	0.90**
BA (mm^2)	−0.04	−0.1	−0.66*	0.10	−0.15	0.38
DCP (mm)	0.57*	0.25	0.42	−0.26	0.03	0.2
M70						
TT (s)	−0.55	−0.69*	0.5	0.01	0.03	−0.53*
ST (%)	−0.19	−0.62*	0.18	0.08	−0.04	−0.10
TC (%)	−0.08	0.03	0.56*	0.51	0.47	0.40
BA (mm^2)	−0.05	−0.46	0.21	0.12	0.11	−0.32
DCP (mm)	0.53	0.78**	0.13	−0.08	0.03	0.11
M40 + M70						
TT (s)	−0.33	−0.31	−0.25	−0.02	−0.16	−0.56**
ST (%)	0.07	0.05	−0.08	0.29	0.21	0.01
TC (%)	0.39	0.33	0.54**	0.38	0.31	0.58**
BA (mm^2)	−0.17	−0.28	−0.24	0.05	−0.13	−0.18
DCP (mm)	0.49*	0.38	0.14	−0.09	0.05	0.1

*$P < 0.05$, **$P < 0.01$

In both older groups the individual values of isometric RFD correlated significantly ($P < 0.05$) with the individual balance values of TT and TC (Table 3). The distance in SLJ correlated significantly with TC in M70 ($P < 0.05$) and in a combined group of M40 and M70 ($P < 0.01$). The individual values of TT and RFD, TC and RFD as well as TC and SLJ are plotted together for the combined sample of subjects in Fig. 5.

In both older groups the height in SJ correlated significantly ($P < 0.05$–0.01) with the distance of the centre of pressure covered in the balance performance ($r = 0.57$ and 0.53 for M40 and M70, respectively).

Discussion

It is not an surprising that the present strength data provided some further information for the concept of an age-related decrease in maximal human strength that has been found by others (Larsson 1978; Häikkinen et al. 1984; Young et al. 1984; Rice et al. 1989; Frontera et al. 1991; Häkkinen and Häkkinen 1991; Narici et al. 1991; Häkkinen and Pakarinen 1993; Häkkinen et al. 1995, 1996). Maximal bilateral isometric force of the leg extensor muscles in M40 was 25% lower than in M20 and

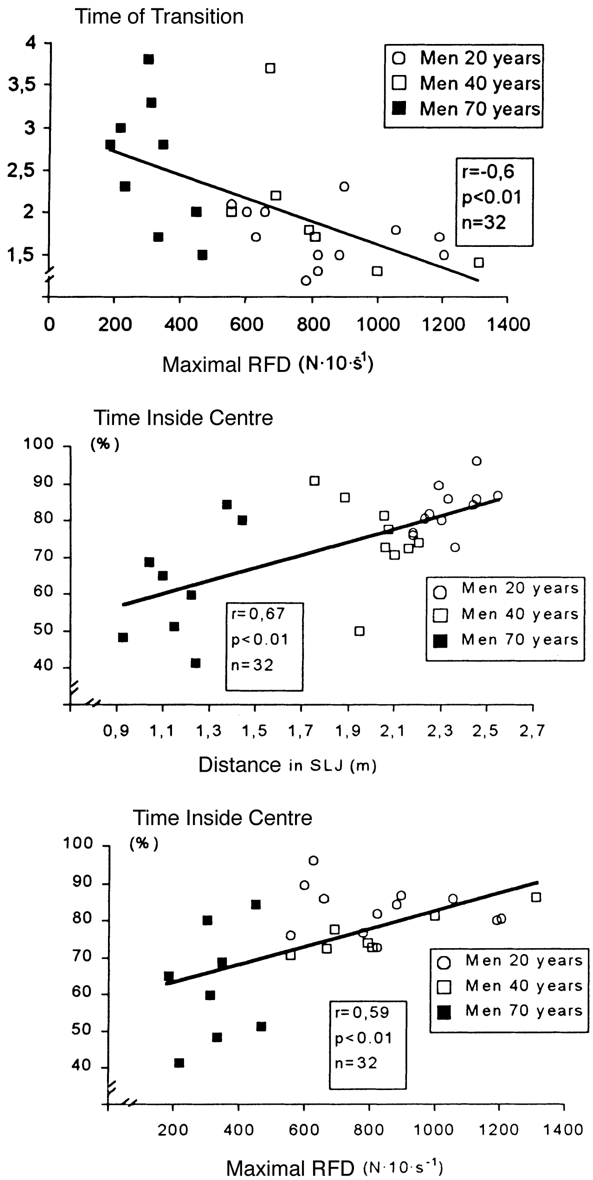

Fig. 5 The relationship between the time of transition (*s*) and the time inside centre in the balance test and the maximal voluntary rate of force development (*RFD*) in the bilateral isometric action of the leg extensors and the distance in the standing long-jump (*SLJ*) in all of the middle-aged (40 years) and elderly (70 years) men

in M70 29% lower than in M40 with a difference of as 46% being recorded between M70 and M20. The age-related decrease in maximal strength performance has been attributed to a loss of muscle mass mediated by both a loss and a decrease in the size of individual muscle fibres (Larsson 1978; Aniansson et al. 1981; Lexell et al. 1983, 1988; Essen-Gustavsson and Borges 1986; Porter et al. 1995).

However, the magnitude of the age related decrease in explosive strength of the leg extensor muscles seems to be even greater than that observed in maximal strength of the same muscle group (Larsson et al. 1979; Bosco and Komi 1980; Clarkson et al. 1981; Vandervoort and McComas 1986; Häkkinen and Häkkinen 1991; Bassey et al. 1992; Häkkinen et al. 1995, 1996). The differences in dynamic concentric and SSC explosive strength variables were in M40 13%–25% lower than in M20, while the differences between M70 and M40 were as much as 33%–43%. The difference in the maximal RFD between M70 and M20 was as large as 64%. The present results are therefore in accordance with previous suggestions that in addition to a loss and a decrease in the size of especially fast twitch muscle fibres, an age-related reduction in the ability for rapid recruitment of motor units may also take place to explain further the great decrease observed in explosive force production (Häkkinen et al. 1995, in press).

Age-related decreases in maximal eccentric strength are known to be smaller than those of concentric or isometric actions (Poulin et al. 1992; Porter et al. 1995). The preservation of higher efficiency in eccentric actions in ageing populations could be related in part to the changes in mechanochemical, neuromuscular activation, contractile velocity and connective tissue factors that have been shown to occur with advancing age (Lexell et al. 1983; Poulin et al. 1992; Porter et al. 1995). In the high velocity SSC performance in which eccentric muscle action precedes concentric muscle action, it has been shown that the force outcome will be greater than in pure concentric muscle action alone (Assmussen and Bonde-Petersen 1974; Komi and Bosco 1978; Bosco and Komi 1982). The results given in Fig. 3 support this suggestion, since the height in SJ in the two younger groups (M20 and M40) were 10% and 20% lower, respectively, than in CMJ, although the respective difference of 6% in M70 was not statistically significant. It is difficult to determine to what extent the latter observation could be explained by a lack of neuromuscular skill to perform the present CMJ exercise in a proper manner and/or by functional and structural factors which have been shown to be related to the utilisation of elasticity (Bosco and Komi 1980; Bobbert et al. 1996).

The present correlation data for the separate age groups would also suggest that the level of performance in explosive SJ concentric action may not necessarily be related to the level of maximal or explosive isometric force production capacity of the muscles. It has been suggested that different tests designed to estimate the capacity for explosive force production in dynamic compared isometric actions may indicate distinct qualities of muscle functions (Murphy et al. 1994; Abernethy et al. 1995). Under these conditions differences in mechanical, neuromuscular activation, and aspects of movement patterns may explain the findings of the unrelated tests scores (Baker et al. 1994; Wilson et al. 1995). However, when the data from the two older groups were combined, the correlation coefficients between explosive concentric SJ and explosive isometric actions as well as maximal strength performances reached statistically significant levels. Moreover, among a greater number of untrained subjects with greater inter-individual variation in explosive performance capacity, positive relationships between selected characteristics of the isometric force-time curve and explosive force production in dynamic muscle actions have been demonstrated in both younger (Viitasalo et al. 1981) and elderly subjects (Häkkinen et al. in press).

Although the present results should be treated with caution due to the small number of subjects, the data support several previous observations about impaired balance and event detection as well as prolonged response times in postural muscles with increasing age (Era and Heikkinen 1985; Whipple et al. 1987; Manchester et al. 1989; Stelmach et al. 1990; Judge et al. 1995; Wolfson et al. 1996). The elderly subjects in this study were 24% to 47% slower in their response times in reaching the lit centre and remained 20%–34% less time inside the centre from the overall time of lighting than M40 and M20, respectively. In addition, some elderly subjects needed more than 5 s for the transitional period within the lit centres and did not even complete the test successfully. Although great caution must be exercised with the interpretations of the present balance data due to possible limitations with regard to the reproducibility of the measurements, the individual values in TT and TC did correlate significantly with the individual values recorded for explosive force production, especially in the two older groups. However, the individual values in TT and CT did not correlate significantly with the individual levels of maximal isometric strength of the same muscles. Moreover, no statistically significant differences were observed among the groups in the average ST (as an indicator of quality of the performance) followed by each subject from one centre to another. The present findings therefore suggest that an age-related decrease in the older groups may be related to a reduced capacity for a quick time response to a change of the body position rather than to a differences in the control of the postural sway of the trajectory.

Measurements of dynamic sway on a force platform alternating leg stance demonstrated a similar stability in the elderly compared to the middle-aged subjects. There was no statistically significant difference in the average displacements and sway area of CP, when the base of support was voluntarily changed from one leg to another. These results area in agreement with previous findings (Maki et al. 1990; Stelmach et al. 1990; Wolfson et al. 1996) that have shown age-related decreases in time response to an external visual event and speed of movement, while the sway area and displacement of CP during a double static or a single dynamic leg stance have remained unchanged.

In summary, the present results are in line with earlier findings that the capacity for explosive force production of the leg extensor muscles declines drastically with increasing age, even more than maximal muscle strength. Elderly people showed impaired balance with an age-related decrease in the event detection and speed of postural adjustment, while they were able to maintain the sway area and average displacement at the same level recorded for younger subjects. In physically active young men the level of explosive force may not necessarily be related to impaired balance, while in older people the decreased ability to develop force rapidly seems to be associated with a lower capacity for neuromuscular response in controlling postural sway. One could further suggest that in order to minimise age-related decreases in functional capacity and risk of falling, proper strength training among elderly subjects could include not only strengthening exercises but also various exercises of an explosive nature as well as specific exercises to improve balance.

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