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Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power

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Summary

Ageing compromises locomotor capacity and is associated with an increased risk of falls. Several lines of evidence indicate that both changes in muscle mass and performance are causative. Most studies, however, do not discern between effects of ageing, sedentarism and comorbidity. The present study compares the age effects in muscle cross section, force and power in physically competent self-selected subjects of different age groups. A total of 169 women and 89 men between 18 and 88 years, without any disease, impairment or medication affecting the musculoskeletal system were enrolled in this study. Calf muscle cross-sectional area was assessed by computed tomography. Muscle force and power were assessed by jumping mechanography. No significant correlation between muscle cross section and age was found in the men. A weak correlation in the women disappeared after correction for height. Close correlations with age, however, were found for peak force and peak power. Correction for muscle cross section or body weight further increased these correlation coefficients, particularly for peak power specific to body weight ($r = 0.81$ in women and $r = 0.86$ in men). The non-sedentarian population investigated here depicted a reduction of >50% between the age of 20 and 80 without a reduction in muscle cross section. This suggests a crucial role for muscular power in the ageing process. Possibly, the jumping mechanography as a measurement of anti-gravitational power output is a promising extension of the chair-rising test, known to be predictive for immobilization and the risk of falls.

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Introduction

Current demographic trends show that the number of older people is rapidly increasing. Accordingly, the prevalence of disability in basic, self-care activities of daily living is also rising, posing a great challenge to the health care and social systems that are already experiencing financial constraints. In older persons, disability is caused by multiple causes. Among them, loss of locomotor competence is of paramount importance. In fact, mobility is essential for functional independence, reduced risk of fall, and quality of life (Guralnik *et al.*, 1994, 1995, 2000).

Age-associated decline in mobility results from the combination of three different factors ageing *per se* as a biological irreversible process (Finch, 1990; Hekimi *et al.*, 2001), deconditioning caused by a sedentary life-style, and primary diseases or injuries. The distinction between these three traits is a fundamental issue for those who study ageing.

It is widely accepted that one of the constant features of human ageing is the decline of muscle mass and muscle force. To describe this phenomenon, the term 'sarcopenia' has been coined (Roubenoff, 2000, 2001). Several lines of research, however, point out that the magnitude of age-associated decline in muscle force is in excess compared with what can be predicted by the decline in muscle mass, suggesting that the mechanical output produced per volumetric unit of muscle tissue also declines with ageing. This hypothesis was recently confirmed by Delbono *et al.* (1995) who showed that the tension developed by a single muscle fibre depends on the section of the fibre and the age of the experimental animal (Gonzalez *et al.*, 2000).

Furthermore, the study of muscle performance should consider not only force but also shortening velocity, and thus muscle power. In this study, we describe the effect of ageing on muscle mass and muscle power in non-sedentary persons dispersed over a wide age range. The information provided is relevant to design new strategies of disability prevention in older persons.

Methods

Study population

Study participants were recruited at the AERPAH geriatric hospital in Esslingen (south-western Germany). Potential participants were attracted by advertising the project in the local press and in posters attached in the most frequented places in the hospital. 'Healthy' people of all ages were invited to participate in the study. Patients, staff members and their relatives were enrolled provided that they met the following inclusion criteria: (i) age above 18 years; (ii) ability to walk un-aidedly at least 800 m; (iii) ability to climb a standard staircase without difficulty; (iv) ability to perform two-legged and one-legged jumps.

Subjects preliminarily enrolled in the study came to the clinic where they received a clinical examination and their lower extremity performance was evaluated by the 5-chair stands test (five consecutive stand-ups from a standard chair with arms crossed), a tandem stand for 10 s and a tandem walking (Mathias *et al.*, 1986; Nevitt *et al.*, 1989).

We aimed at enrolling participants free of apparent limitations in motor performance. Therefore, subjects with any disease, impairment or medication known to affect directly the musculoskeletal system, using regularly crutches or other walking aids, with clinically evident disorders of balance or gait, requiring more than 10 s to complete the chair-rising test, and performing more than two errors in the walking tandem test were classified as locomotorily incompetent and were excluded from further analysis.

In total, 342 subjects were investigated. Of these, 19 patients were excluded because the physical testing was impossible, 46 because they had severe balance problems (more than two errors in tandem walking), and 19 because of a poor performance in the chair-rising test (>10 s for five stand-ups). Thus, 169 women and 89 men aged 18–88 years were included in the study population. This sample size was considered adequate for this study. In fact, based on the inter-individual variation of calf muscle cross-sectional area [about 12% in both men and women aged 20–30 (Rittweger *et al.*, 2000)] and assuming $\alpha < 0{\cdot}05$ and $<0{\cdot}10$, a minimum of 31 subjects was required to detect differences of at least 10%.

pQCT measurements

Calf muscle cross-sectional area, measured with peripheral Quantitative Computed Tomography (pQCT) was assessed as an indicator of muscle mass. Cross-sectional images were obtained at 66% of the shank length, the position with the greatest calf diameter, with the XCT2000 (Stratec Medizintechnik, Pforzheim, Germany) as described earlier (Rittweger *et al.*, 2000). Measurements were performed with the XCT2000 software (version 5.5) using the mask 'muscle measurement'. The integrated algorithm automatically discriminates the subcutaneous fat tissue from the muscle tissue and the total bone area, thus assessing the entire calf musculature's anatomical cross-sectional area. This procedure has been validated against measurements with whole body spiral CT ($r^2 = 0{\cdot}96$) and with whole body MRI (Gordon *et al.*, 2003).

Jumping mechanography

As a simple test of (loco-) motor performance we used the jumping mechanography, which we recently found to be a reliable and sensitive measure of mobility performance in elite athletes as well as in frail patients (Rittweger *et al.*, 2004). Subjects were allowed to make themselves acquainted with several submaximum jumps. Jumping was performed as counter movement jump with the hands moving freely. The subjects were asked to raise their head and trunk as high as possible, thus producing the maximum elevation of the center of mass. As a variable of interest, the peak power out of three two-legged counter-movement jumps was identified. In former studies, we noticed that the peak force is ~10% greater if the jumping is on one leg only. Hence, peak force was assessed as the best in three one-legged jumps on the dominant leg.

During the jumping tests, the ground reaction force was measured by a Leonardo force platform system (Novotec Medical, Pforzheim, Germany). This system computes the subject's vertical velocity by integrating the ground reaction force, as described in principle by Cavagna (1975). Body mass (BM) and starting point are assessed during quiet stance, immediately before the jump. Instantaneous power is calculated as the product of force and velocity.

Data processing and statistical analysis

The peak power values were normalized separately to muscle cross-section area (CSA) and to BM, yielding the 'CSA-specific power' and the 'BM-specific power'. The same computation was performed with the peak force values. The time required to perform five stand-ups in the chair-rising test was inverted to yield the chair-rising power ($\mathrm{PCSU} = 5/T_{\mathrm{CSU}}$), which as a measure of power is comparable with jumping power.

Statistical analyses were conducted using the SPSS software in its PC version 11.5 (SPSS Inc., Chicago, IL, USA). Correlation analyses were performed to test for the association between anthropometric measures, muscle measures and age. Hidden effects of anthropometrical measures on the correlations between age and muscle measures were tested by partial correlation analysis. Model parameters were estimated by simple and multiple regression analysis. Generally, linear models were assumed as long as higher order polynomial models did not increase the r^2 by more than 0·03. A P-value <0·05 was considered for statistical significance.

Table 1 Anthropometric measures of the study population.

	N	Age (years)	Weight (kg)	Height (cm)	BMI (kg m^{-2})
Women	169	20–88 (median 59)	65·5 (SD 11·3)	163·2 (SD 6·35)	24·6 (SD 4·08)
Men	89	18–79 (median 60)	76·4 (SD 10·3)	174·7 (SD 6·93)	25·1 (SD 3·19)

Table 2 Correlation of the variables of interest with age.

	Muscle CSA	PCSU	Peak force	Peak power	CSA specific peak force	BW specific force	CSA specific power	BW specific power
Women	−0·15*	−0·56**	−0·65**	−0·72**	−0·59**	−0·75**	−0·70**	−0·81**
Men	−0·04	−0·48**	−0·61**	−0·80**	−0·53**	−0·66**	−0·81**	−0·86**

Pearsons correlation coefficients. *P<0·05, **P<0·001. Muscle CSA = calf cross section as assessed by computed tomography; PCSU = chair-rising power (=5 s/chair-rising time); peak force and peak power as assessed during the pushing phase in jumping mechanography. For peak force and power, values specific to the muscle cross sectional area (CSA) and to body weight (BW) have been calculated.

Results

The study population is described in Table 1. Body weight was unrelated to age but height and BMI decreased and increased, respectively, with age. The correlation coefficients were −0·40 for height and age in the women and −0·47 in men, and 0·25 for the BMI in women and 0·36 in men (P<0·01). Both in males and in females, muscle CSA was weakly correlated with peak jumping power (r = 0·34 and 0·43, respectively; P<0·01), but only in females a significant correlation was found between jumping force and mCSA (r = 0·44, P<0·01).

Table 2 reports the correlation analysis between age and measures of muscular parameters. The relationship between age and muscle CSA is reported in the scatter plot of Fig. 1. We found no correlation between age and muscle CSA in men and a borderline significant, negative correlation in women. However, after adjusting for height, the correlation between age and muscle CSA was completely removed also in women (r = 0·05, P = 0·49).

All parameters of muscle performance were negatively correlated with age (Table 2). The correlations observed were linear, except for peak force in males, where a second-order polynomial model yielded a better fit than a linear model (r^2 = 0·410 versus r^2 = 0·377). In general, the correlation coefficients were greater for the parameters concerning power than for those concerning force measures. Furthermore, when forces and power specific to muscle CSA and body weight were considered, the correlations with age increased further. Both in men and women, the greatest r was observed for the correlation between age- and weight-specific power (men: −0·86; women: −0·81) (Fig. 2). Body weight specific jumping power was also positively correlated with body height (r = 0·31 in the women and r = 0·31 in the male men). However, after controlling for age, the relationship between body height and jumping power was no longer significant, suggesting that such a relationship is actually independent of body height.

Finally, BM-specific jumping power was significantly correlated with chair stand-up power (P<0·01). The correlation coefficient was 0·58 in women and 0·61 in men. Chair stand-up power (PCSU) was significantly correlated with age, yielding a correlation coefficient of −0·56 in men and −0·48 in women (see Table 2 & Fig. 3). Multiple correlation analysis with a hierarchical model yielded highly significant correlations between PCSU and peak jumping power, both in females and in males (P<0·001 for both genders), but no significant correlation with muscle CSA in males and a weakly significant correlation in females (P = 0·018). Here, the standardized coefficient was negative (−0·19), and after correcting for age, no significant correlation was found between muscle cross and PCSU, indicating that jumping power rather than muscle CSA had an effect upon PCSU in both genders.

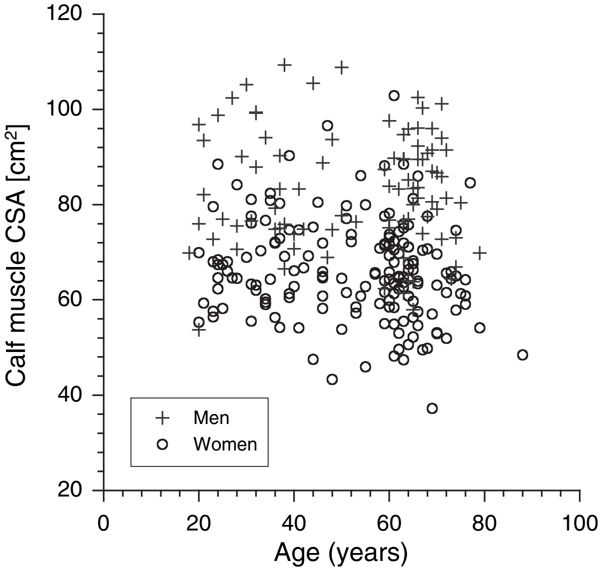

Figure 1 Calf muscle cross section and age. The calf muscle anatomical cross sectional area was assessed by computed tomography. No significant correlation was found with age in the 89 men (inverted triangles), and a borderline significant correlation in the 169 women disappeared when controlling muscle cross section for height.

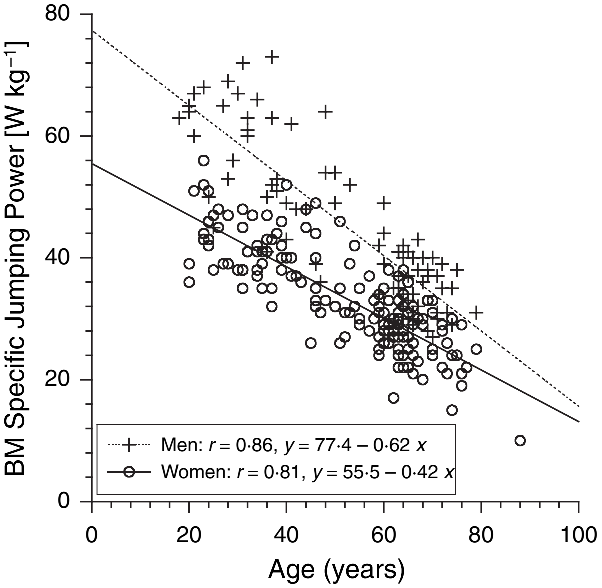

Figure 2 Jumping power and age. The peak power was measured on a ground reaction force platform during a counter-movement jump. Here, we have plotted the peak power specific to body weight versus age for the same subjects as in Fig. 1. Both for the women as well as for the men, highly significant correlations were found.

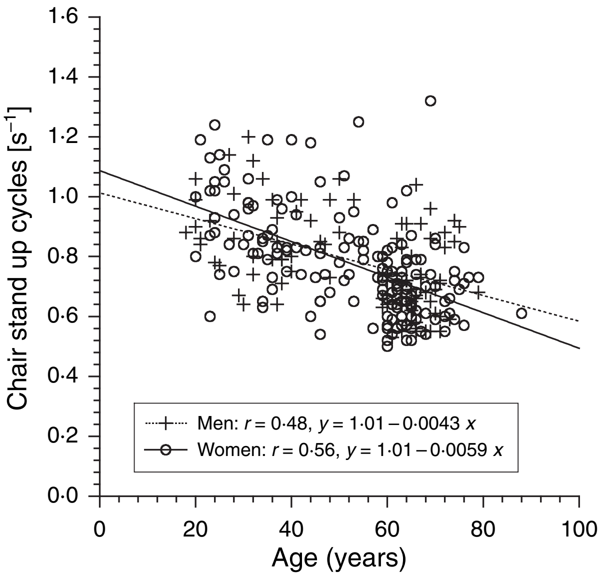

Figure 3 Chair stand up cycles per second (P_{CSU}) and age. This measure of antigravitational power was measured in the standardized way (Nevitt *et al.*, 1989).

Discussion

It should be noted that this study is not population based. Hence it is not representative of a general population, but rather of a self-selected group of highly selected, physically competent subjects. We believe that this selection may give an idea of the physical decline with age in fit elderly without any major deficits caused by disease or disability. In this group, we found no significant correlation between age and muscle cross-sectional area for male and only a weak correlation for female subjects. The latter was completely obliterated after adjusting the analysis for height.

A remarkable decline, however, was observed in the performance variables (power and force) assessed by the chair-rising test and by jumping mechanography. Both tests, the jumping mechanography and the chair-rising test, measure power during an activity which involves raising the centre of gravity. In fact, to do the test more vigorously, many young subjects literally 'jump-up' from the chair. On the other hand, and contrasting with our former expectations, the jumping mechanography could be performed by frail, older persons who are unable to complete the chair-rising test. In other words, the jumping mechanography appeared to assess meaningful information over a broader range of physical performance.

Several studies have found that performance in the chair-rising test alone or combined with balance and gait is a strong predictor of incident disability, mortality, falls, hospitalization and health care resources consumption. Hence, chair-rising power can be regarded as an indicator of physical performance at old age. Interestingly, no substantial correlation was observed between muscle cross section and chair-rising power. However, significant correlations were indeed found between jumping power and chair-rising power.

As outlined in Table 2, the decline with age was consistently stronger for jumping performance than for chair-rising power. Of all variables, the most pronounced decline with age was found for peak power specific to BM, with an estimated loss of more than 50% between 20 and 80 years of age. Interestingly, the decline in power was continuous and linear across the entire age range, from the very young to the very old. All of these observations suggest that the jumping mechanography might assess the effects of ageing on muscle power even with more sensitivity than the chair-rising test.

It is noteworthy that the correlation of jumping power with age was substantially improved by correcting for body weight. This has practical and theoretical implications. On a practical level, it is the BM that the musculoskeletal system has to act with to enact locomotion and to prevent falls. On a theoretical level, the jumping test can be considered an ecological measure of performance as the resistance against the measured movement depends on a value that is inherent to the subject being tested, which is also the same intrinsic resistance encountered in everyday activities. This is certainly a potential advantage of the jumping mechanography with respect to other methods such as isokinetic dynamometry (Frontera *et al.*, 1991; Shephard *et al.*, 1991) or power rig testing (Bassey *et al.*, 1992) in which muscle power is exerted against an external resistance.

As to the reasons for the age-related decline in power output, several factors have to be considered. First, fat mass (Baumgartner *et al.*, 1993) and the extra cellular space increase with age (Kyle *et al.*, 2001) and make up a passive mass which does not contribute. However, in our study group BM was not correlated with age. Hence, it would be a change in relative body composition rather than the absolute fat content which might serve as an explanation.

Secondly, and in combination with the former, muscle mass may be lost during ageing to a different in different muscles. Kubo *et al.* (2003) have found that in sedentary and mildly active subjects muscle thickness appears to decline ~40% more with age in the vastus lateralis muscle than in the medial gastrocnemius muscle. Although these data are difficult to compare with our study, there is an undoubted need to consider locally specific patterns of muscle atrophy in future studies. It should not be forgotten, however, that the calf muscle-tendon complex in healthy young subjects contributes >50% to jumping power (Bobbert *et al.*, 1986). Thus, most likely other factors should play a role.

A third group of explanatory mechanisms focuses on skeletal muscle. It has been recognized recently that – ceteris paribus – changes in muscle CSA should affect output power more than proportionally (Minetti, 2002). This effect could potentially explain why in past studies comparatively small reductions in muscle CSA with age were paralleled by a decline in power output that lies in the same range as reported here (Grassi *et al.*, 1991; Ferretti *et al.*, 1994). Moreover, ageing appears to affect the fibre pennation angle (Narici *et al.*, 2003). Another critical factor may be a greater percentage of slow twitch muscle fibres in older people (Lexell *et al.*, 1988; Melichna *et al.*, 1990; Lexell, 1995), which reduces the maximum contraction speed. Moreover, the electromechanical coupling has been shown to deteriorate with age (Delbono *et al.*, 1995), or even a reduced central nervous 'excitability' might be relevant (Scaglioni *et al.*, 2002).

Finally, changes in tendon properties might play a crucial role. During a vertical jump, the Achilles tendon serves as a store for elastic energy in the initial phase, and it quickly releases the stored energy briefly before the toe-off phase (van Ingen Schenau *et al.*, 1985; Bobbert *et al.*, 1986; Finni *et al.*, 2000). Although there are not many studies available, there is some indication that at old age, the Elastic modulus of the Achilles tendon declines, and that whole-tendon stiffness is decreased at old age (Narici *et al.*, 2002).

In conclusion, we have found that peak power rather than calf muscle cross section seems to affect chair-rising performance, and that peak power output substantially declines with age. This suggests that in physically competent elderly, the reasons for the age-related decline in physical performance are unlikely because of a generalized sarcopenia. Rather, a combination of changes in muscle function and architecture, tendon properties, body composition and loss of muscle mass in specific regions should be considered as causes.

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