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ORIGINAL ARTICLE

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Power output, isometric strength and steadiness in the leg muscles of pre- and postmenopausal women; the effects of hormone replacement therapy

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Abstract There are conflicting reports of the effects of hormone replacement therapy (HRT) on strength preservation in postmenopausal women, while any effect on power output has received little attention. Decreased steadiness of force generation has been reported in older muscles and may be related to the hormonal changes associated with the menopause, but the effect of HRT has not been investigated. We have studied the effect of HRT on strength, power output and isometric force steadiness in healthy women. Sixteen young (aged 27.4 ± 1.4 years, mean ± SEM) and 29 postmenopausal women were studied. Fifteen of the latter were taking HRT (68.1 ± 1.4 years, HRT+) and 14 (70.5 ± 1.5 years, HRT−) had never done so. During isometric quadriceps contractions the force steadiness (coefficient of variation of force) was measured at 10, 25, 50 and 100% maximum voluntary contraction (MVC). The average power generated by an explosive leg extension was recorded. The HRT− group generated less power (110.2 ± 7.2 W) than both the HRT+ (136.5 ± 10.9 W, $P=0.027$) and young (136.2 ± 5.8 W, $P=0.027$) subjects. Power output was similar in the HRT+ and younger subjects. The HRT− subjects were weaker than the younger ones (241.3 ± 14.0 N vs. 297.6 ± 13 N, $P=0.006$). The strength of the HRT+ group (255.5 ± 14 N) was not significantly different to the other two groups. There was no difference in steadiness between the three groups at any of the force levels. HRT appears to maintain power output to a greater extent than isometric strength in postmenopausal women. There was no evidence for an effect of either age or HRT on isometric steadiness in the quadriceps.

Keywords Ageing · Skeletal muscle · Steadiness · Strength · Power output · Hormone replacement therapy

Introduction

The progressive muscle atrophy associated with ageing (Lexell et al. 1983, 1988; Janssen et al. 2000) results in decreased strength (Skelton et al. 1994; Jubrias et al. 1997; Lindle et al. 1997; Vandervoort et al. 1990; Frontera et al. 2000), predominantly due to a loss in the size and number of type II fibres (Lexell et al. 1983, 1988; Lexell and Downham 1992). This affects the ability to perform everyday tasks and may be related to the risk of falling. Whilst strength is clearly important, the ability to generate power is arguably more important in functional terms both for the performance of everyday activities and also in the ability to correct posture and avoid falling. There are some reports that power output decreases more than isometric force generation (Skelton et al. 1994; Vandervoort et al. 1990; Bassey et al. 1992), presumably due to the combined effects of atrophy and mechanical slowing, but this has been little researched.

The age-related decline in strength in women occurs dramatically at the menopause (Phillips et al. 1992; Samson et al. 2000), presumably as a consequence of hormonal changes. Hormone replacement therapy (HRT) is widely used and affects many tissues and systems. It has been reported to reduce the postmenopausal loss of strength (Heikkinen et al. 1997; Greeves et al. 1999; Skelton et al. 1999; Onambele et al. 2001), although not all workers have found this (Brown et al. 1997; Armstrong et al. 1996).

There are reports that the ability to perform steady force muscle contractions also decreases with age (Galganski et al. 1993; Erim et al. 1999; Enoka et al. 1999; Laidlaw et al. 1999; Burnett et al. 2000; Graves et al. 2000; Semmler et al. 2000; Tracy and Enoka 2002). Most of these have studied upper limb muscles (Galganski

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et al. 1993; Erim et al. 1999; Laidlaw et al. 1999; Burnett et al. 2000; Semmler et al. 2000; Tracy and Enoka 2002), although a loss of steadiness in weight bearing muscles would have a much greater implication for functional activities such as standing and walking and possibly the risk of falling. There are few reports of steadiness of force generation in the quadriceps; Tracy and Enoka (2002) found decreased steadiness in older people although Hortobágyi et al. (2001) and Schiffman et al. (2002) did not.

The muscle weakness in older people and animals appears not to be fully explained by atrophy and may be related to altered motor control (Jubrias et al. 1997; Enoka et al. 2003). While the mechanisms underlying an effect of HRT on skeletal muscle are unclear, it has been suggested that it might be due to a central nervous system mechanism involving motor control. There are reports that increased levels of oestrogen are associated with enhanced motor skills and co-ordination (Hampson 1990; McEwen and Alves 1999) and the oscillatory output of motor neurones (Smith 1998). Therefore any age-related decrease in steadiness may have an underlying mechanism similar to that of the loss of strength. If this is so, then HRT may affect both.

In view of the reported effects of HRT on muscle strength and possibly on motor control, motor skills and coordination, we hypothesised that it would also preserve power generation and the steadiness of contraction force. The aim of this study was therefore to investigate leg extensor power output, quadriceps isometric strength and steadiness in three groups of healthy women; younger, premenopausal ones and two groups of postmenopausal ones—those who were taking HRT (HRT+) and those who had never done so (HRT−).

Methods

Subjects

A total of 45 women participated in this study which was approved by the local ethics committee. All subjects gave written informed consent prior to participating. There were 16 younger healthy controls [aged 27.4 ± 5.6 years (mean ± SD)], 15 older women on HRT (HRT+, 68.1 ± 5.3 years) and 14 older women who had never received any form of HRT (HRT−, 70.5 ± 5.8 years). The older subjects were all aged > 60 years. Those who were on HRT had been taking it for an average of 13.2 ± 5.5 years. Nine women were taking combined oestrogen and progesterone and six were taking oestrogen-only forms.

Young subjects were recruited from friends and colleagues. They all had normal menstrual cycles. Older subjects were recruited from an existing database of elderly subjects, adverts in the local newspaper and the University of the Third Age. Candidates were excluded if they were receiving any form of medication that affected the central nervous system, suffered from any neurological disorder, osteoarthritis or painful conditions of their legs, or had any prosthetic leg joints. Their health status was discussed and they completed a basic health questionnaire.

Activity levels of the older groups were similar. The HRT+ group performed an average of 2.5 ± 2.4 h (range 0–6.5) of exercise per week and the HRT− group did 2.7 ± 2.9 h (range 0–8) per week. This consisted of light activities such as dancing, walking, swimming and yoga. The young subjects had slightly higher activity levels (4.6 ± 2.6 h, range 1.5–8) but this was still light activity.

Procedures

Isometric quadriceps strength

The subjects sat in a custom-built adjustable strength testing chair (Edwards et al. 1977) with their hips and knees flexed to 90° and arms folded. The pelvis was stabilised by a lap strap. A strap around the ankle was attached to a non-extensible cable to a strain gauge at the back of the chair. The output from the strain gauge was amplified and sampled at 10,000 Hz—higher than needed but used because of other tests being carried out. Knee extensor force output was displayed on a computer screen visible to the subject.

Three maximal voluntary contractions (MVCs) were performed and held for 5 s with visual and verbal feedback. Rest periods of 15 s were given between each attempt. In the rare event of a force plateau not having occurred after three attempts, further attempts were allowed. The MVC of both legs was measured and entered into the analysis. The force signals were A to D converted [Cambridge Electronic Devices (CED), UK] and recorded on a PC for subsequent analysis.

Isometric quadriceps steadiness

Visual targets representing forces of 10, 25 and 50% MVC were displayed on the PC monitor in front of the subjects. The subject was asked to perform an isometric contraction at each force level and maintain the contraction as steadily as possible for 10 s. Fifteen second rest periods were given between contractions.

Two readings were taken for each level. Each leg was tested separately for all of the tests. An average of the two legs is reported here.

Power output

The maximal explosive leg extensor power was measured with the Nottingham Power Rig (Bassey and Short 1990). Briefly, the subjects sat on a seat which was adjusted to their leg length. The foot to be tested rested on a flat pedal and at the start the hip and knee were flexed. They were asked to push the pedal away from them in a forward direction as fast as possible and made a movement of 220 mm to finish with their knee almost fully extended. This caused a flywheel to turn via a lever. The velocity of the flywheel was measured by an optoswitch and used to calculate the average leg extensor power. Initially the brake of the flywheel prevented movement until released just after the subject was asked to push as fast and hard as possible. The other leg rested on the ground and subjects kept their arms folded.

This was repeated six times, or until the power output reached a plateau. The average power achieved was recorded for each leg.

Data analysis

Isometric force and steadiness

Analysis was performed using Signal software (Version 2.10, CED). For measurement of steadiness the coefficient of force variation (CV = SD/mean × 100) was used to indicate fluctuation of the force around the target level.

The middle 1 s period of the MVC and 6 s for each sub-maximal level were analysed. The time periods that were analysed differed between MVC and sub-maximal levels because subjects were unable to hold their MVC for more than a few seconds. The central period of each contraction was measured. An average of the two attempts at each target level was taken.

Statistical analysis

A one-way ANOVA was used to compare the dependent variable between the three subject groups (SPSS version 10.1). Tukey post-hoc comparisons were used to determine specific differences.

A power calculation revealed that seven subjects were required in each group to detect a difference of 2.4 in isometric steadiness with a power of 90% and an alpha of 0.05.

Unless stated otherwise, data are presented as mean ± SEM.

Results

All three groups were of similar body mass; young 62.6 ± 5.9 kg (mean ± SD); HRT− 67.7 ± 10.7 kg and HRT+ 66.6 ± 12.9 kg. There was no significant difference between the ages of the two older groups (HRT+ 68.1 ± 5.3 years and HRT− 70.5 ± 5.8 years).

No significant differences were seen between the results of the women taking different types of HRT for any of the parameters studied and therefore their data have been combined.

Power output

The HRT+ group generated more power than the HRT− one (136.5 ± 10.9 W vs. 110.2 ± 7.2 W, $P = 0.027$). The young group (136.2 ± 5.8 W) were more powerful than the HRT− subjects ($P = 0.027$). There was no significant difference between the young and HRT+ subjects (Fig. 1a).

MVC (Fig. 1b)

There was no difference between the two older groups. The young group (297.7 ± 13.0 N) were stronger than the HRT− subjects (241.3 ± 14.0 N, $P = 0.006$), but similar to the HRT+ group (255.5 ± 12.9 N).

Isometric steadiness

There was considerable individual variation in the amount of steadiness in all groups. Typical traces are shown in Fig. 2. In Fig. 2b the first attempt was so poor that it was not used for analysis and a second attempt was made

When the fluctuations were normalised relative to the mean force level (CV) there was a tendency for all subject groups to be most steady at MVC (Fig. 3). Young

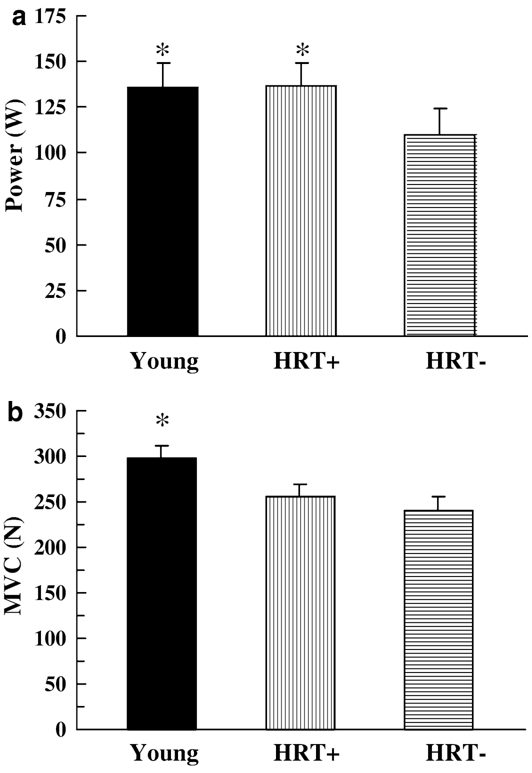


Fig. 1 Quadriceps leg extension power (**a**) and MVC (**b**) in the three groups. *Significantly greater than HRT− ($P = 0.027$ for power and 0.006 for MVC)

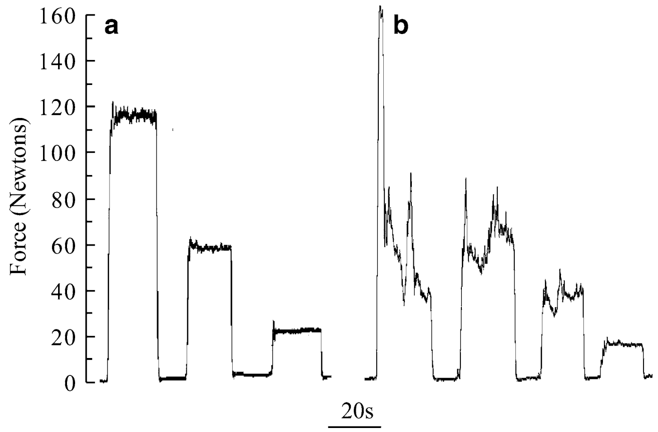


Fig. 2 Force traces from a more (**a**) and a less (**b**) steady subject during trials at 50, 25 and 10% MVC. Subject **b** made two attempts at the 50% level. Examples of both of these were found in all the three groups studied

subjects appeared to decline in steadiness with decreasing target force, however there was no clear relationship between force and steadiness for the older women. There were no significant differences between the three groups at any of the force levels.

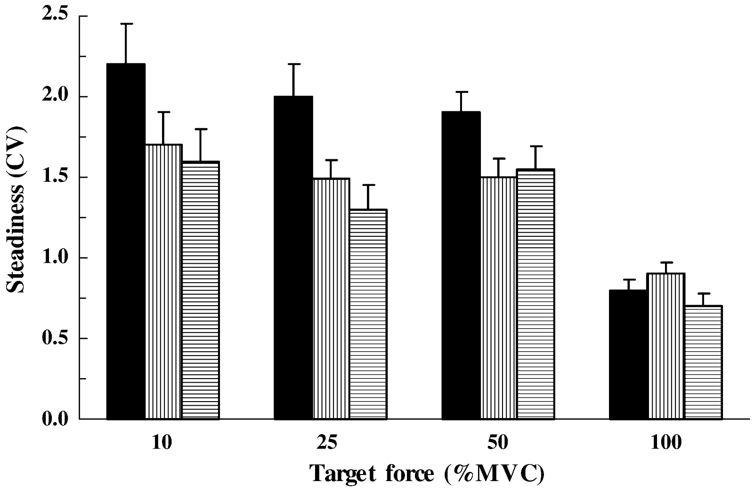
Discussion

These results indicate that HRT has a greater effect on power output than strength. The HRT+ group had similar strength and power output to the young subjects and also had a higher power output than the HRT− group. The younger subjects were the stronger than the older women who had never received HRT, in agreement with previous studies (Jubrias et al. 1997; Phillips et al. 1992, 1998; Klein et al. 2001; Greeves et al. 1999; Skelton et al. 1999; Onambele et al. 2001; Sipila et al. 2001). A similar pattern was found for explosive leg extension power generation (Whipple et al. 1987; Martin et al. 2000).

The finding that the HRT+ group generated more power but produced similar forces than the HRT− group suggests that HRT may have an effect on contractile speed and particularly on functional performance. This might be due to a relative preservation of fast twitch, type II muscle fibres, but we are unaware of any data on this. From our data we are unable to measure contractile speed, but it would be useful to do this in future studies. Since it has been suggested previously that ageing affects power output more than isometric force generation (Skelton et al. 1994; Vandervoort et al. 1990; Bassey et al. 1992), HRT may maintain power output either by an effect on contractile speed or on the central nervous system (McEwen and Alves 1999; Hampson 1990; Smith 1998). Our finding that isometric steadiness was similar in all three groups does not support the latter. However our older subjects were relatively active, and had similar levels of physical activity to the younger subjects and it would be interesting to investigate this in a more frail elderly population.

The greater effect on power output than isometric force might be due to the older subjects being able to achieve higher levels of voluntary activation during the more functional leg extension test. While the majority of young subjects appear to be able to achieve virtually full voluntary activation in the unfatigued quadriceps, there is some debate about whether older people are able to achieve similar levels. There are reports that similar levels of voluntary activation are found in young and old subjects (Roos et al. 1999; Jakobi and Rice 2002) while others find reduced activation in older people in the order of 5–10% (Harridge et al. 1999; Stevens et al. 2001, 2003). Although voluntary activation was not measured in this group of subjects, we have examined this in other young and older people and in currently unpublished results have found no differences between the two age groups. Another possible explanation could be different levels of activity in antagonistic muscle activity with age and also between the two groups. It has

Fig. 3 Steadiness (CV) for the three groups at the force levels studied. The higher values show greater fluctuation around the target level and therefore greater unsteadiness. There were no significant differences between the groups. *Solid bars* represent young subjects; *vertical stripes* represent HRT+ and *horizontal stripes* HRT−



been suggested that older people have greater activity of antagonist muscles during isometric contractions (e.g. Macaluso et al. 2002) but whether this also occurs during dynamic and more functional movements is not clear.

The equipment used to measure leg extension power was specifically designed for use with elderly people. It is not weight bearing and does not require the subjects to control their posture and balance, therefore it is not valid to translate these results to steadiness during functional activities. The fact that body mass does not feature in the equation of power and also that average, rather than peak, power was calculated means that our power values are lower than those where different equipment and protocols have been used. However the values reported here are similar to those reported for the same equipment for older people (Bassey et al. 1994, 2002). Equally our strength measurements are similar to those reported previously for healthy but untrained young (Edwards et al. 1977; Young et al. 1984; Rutherford and Jones 1992) and older (Young et al. 1984; Rutherford and Jones 1992; Schiffman and Luchies 2001; Hortobágyi et al. 2002; Tracy and Enoka 2002; Skelton et al. 1994, 2002) subjects.

Although there was a tendency for the younger subjects to have higher force variations during sub-maximal contractions there were no significant differences between the two age groups. This is in contrast to previous studies that have reported decreased steadiness with ageing in the first dorsal interosseous (FDI) and quadriceps (Galganski et al. 1993; Tracy and Enoka 2002). Two studies on the quadriceps however have also failed to find this (Hortobágyi et al. 2001; Schiffman et al. 2002). The discrepancy may be accounted for by differences in individual muscle groups, although this is not obvious. Another possibility is that of methodological differences; in some cases the absolute force variance (SD) has been measured which does not take into account any difference in strength with ageing.

Differences in the results of studies on different muscles could be due also to their composition and functional role. Postural weight bearing muscles such as the quadriceps consist of larger motor units and therefore are less capable of fine control. Differences in steadiness may be masked by the larger motor units being recruited at low levels of force in all age groups when the greatest differences in steadiness are usually observed (Schiffman et al. 2002). Hortobágyi et al. (2001) used absolute force targets and therefore the older and weaker people were working at a higher proportion of their MVC. Muscle mass is known to be affected variably by ageing in different parts of the body (Janssen et al. 2000).

Different results could also be accounted for by differing levels of physical activity of subjects in the studies since one effect of repeated activity is to improve the skill and precision of movement. However the activity levels of the two older groups in our study were similar. Strength training has been reported to increase force steadiness in older people (Tracy et al. 2004), and it may be that our older population were more active and therefore trained than those studied by other workers.

The younger subjects in the present study had comparable isometric steadiness values to those in other studies (or were more steady) although the older women were considerably steadier (Tracy and Enoka 2002), suggesting that there are populations of ‘steady’ and ‘unsteady’ older individuals. The older subjects were recruited through advertisements and therefore were highly motivated. In the older HRT− group physical activity level was significantly correlated with isometric steadiness at 25 and 50% MVC, lending support to the possibility that activity level and ability to hold a steady isometric contraction force may be linked. There was considerable individual variation in the steadiness of the older subjects.

The effect of HRT on muscle contraction steadiness has not been studied previously. This study provided no evidence to suggest that HRT affects force steadiness. However, it has been reported that HRT helps to restore strength lost at the menopause, but does not increase it beyond baseline levels (Skelton et al. 1999), while the greatest strength gains are seen in the weakest people (Heikkinen et al. 1997). It may be that the strength and steadiness have to drop below a critical value before intervention strategies have an effect.

The mechanism behind strength increasing with HRT and when oestrogen is at its highest during the menstrual cycle is not known, although HRT has been claimed to increase muscle cross-sectional area (Kent-Braun et al. 2000). Direct action may be due to muscle oestrogen receptors, or female sex hormones may also interact with the receptors of other hormones (Sipila and Poutamo 2003). Alternatively these hormones may have an effect on the CNS and therefore motor control. Increased oestrogen levels have been shown to improve fine motor skills and co-ordination (McEwen and Alves 1999; Hampson 1990) and effect oscillatory output of neurones (Smith 1998); all these suggest that HRT could have beneficial effects on steadiness of movement if this were impaired.

In conclusion, these findings indicate that HRT offers greater protection against the age-related changes in power output than isometric strength. The generation of power is of particular importance for functional activities where relatively rapid movements are needed to maintain and restore balance since ageing is associated with an increased incidence of falling. Although some studies have reported that the ability of muscles to hold a steady force isometric contraction is reduced with age, we have not found this in the quadriceps, and steadiness was unaffected by the use of HRT.

Further work is required to determine the effects of ageing on steadiness in different muscle groups in people with differing levels of physical activity and to compare differences between older people who do and do not fall regularly.

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