

Assessment of the level of muscular strength and volume in physically active English adults

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ABSTRACT

Leyton M, Luis-del-Campo V, Morenas J, Roldán A. Assessment of the level of muscular strength and volume in physically active English adults. *J. Hum. Sport Exerc.* Vol. 7, No. 1, pp. 296-309, 2012. The aim of this study is to describe the muscular volume and strength of different body segments from a sample of 19 English male participants, with a mean age of 43.84 (± 11.62). An isometric dynamometer (Standard type S) has been used for the strength measurements, as well as an isokinetic device (Cibex Norm, Ronkonkama, New York, U.S.A.) and a M.R.I scanner (Esaote G-Scan biomedical, Milan, Italy) for measuring the muscular volume. The Baecke Questionnaire (1982) helped to determine the participants habitual level of physical activity. The results reveal an inverse relationship between age and isometric strength of the biceps muscle ($r=-0.518$; $p<0.05$). In addition, there exists a correlation between the handgrip of the right hand and the left hand ($r=0.788$; $p<0.001$); torque of the knee extensor muscles and the ankle extensor muscles ($r=0.712$; $p<0.01$); time of torque of the knee flexor and extensor muscles ($r=0.773$; $p<0.001$) volume of the biceps and triceps muscles ($r=0.849$; $p<0.001$), as well as several correlations between the different volumes of the quadriceps muscles. As a conclusion, age has a negative influence on the production of isometric strength of the biceps muscle, but not of the knee extensor muscles. As expected, the antagonistic muscle groups actuating around the knee, i.e. the extensor and flexor groups seem to be adapted to each other in terms of volume, strength and rate of force development. **Key words:** AGE, PHYSICAL ACTIVITY, ISOMETRIC STRENGTH, MUSCLE VOLUME.

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INTRODUCTION

From the second or third decade of life onwards, the functional capability of the neuromuscular system of the human being starts to decrease gradually. Age-associated deterioration of the muscular function is one of the main factors that have influence on a person's capability to lead an independent life. Human's capability to generate strength is necessary to carry out many tasks of everyday life such as climbing stairs, sitting up or walking. It is also believed that age-related reduction of the neuromuscular system capability to generate strength increase the risk of falls and slips, which occur more often in this age group. This aspect makes us consider its importance with an increasing interest (Izquierdo, 2007).

The aging process brings along a decrease in the production of maximal strength, which hampers the execution of tasks which we used to carry out easily before (Hakkinen et al., 1995). The loss of this kind of strength decreases significantly as a person grows older, in such a way that between the 30 and 50 years of age it decreases in a 15%, and from that age onward the loss goes up to 30% each decade (Roig, 2003).

Strength is excellent to predict independence and mobility in old people and it can be directly related to the amount of muscular mass (Fronteras et al., 1991; Pearson et al., 1985). The loss of this muscular mass can also be related to the risk of disability in elderly people (Zamboni et al., 1999).

Age also brings along a reduction in the production of explosive strength, due to a decrease in the size and the loss of muscle fibres, notably those of fast contraction (Lexell et al., 1988). It is also related to a reduction in the activity of Adenosine Triphosphatases or ATPase (Ferreti et al., 1987; Ferreti et al., 1994). Also, the hypotheses that states that reduction in explosive strength is associated to a decrease in the capability of the neuromuscular system to quickly activate the muscles - due to a degeneration of motoneurons (Davies et al., 1985) - should not be disregarded (Häkkinen & Häkkinen, 1995). If a muscle becomes slower with age, this will affect not only the capability to develop the strength necessary for everyday activities, but it could also reduce the reaction speed critically. In this way, some instinctive protective movements will not act to avoid unexpected balance problems, thus increasing the number of falls (Vadervoort & Hayes, 2000).

Ageing is also associated with a reduction in muscular mass or sarcopenia (Narici et al., 2003). Sarcopenia is a quantitative reduction of the muscular mass which brings along a decrease in the strength as well as in the tolerance to exercise (Roig, 2003). Other cross-sectional studies suggest that this phenomenon begins to occur towards the end of the fifth decade of life (Janssen et al., 2000) which also corresponds to the beginning of the decrease in muscular mass and strength (Narici et al., 1991).

However, not only Sarcopenia causes loss of muscular mass, there also exist other additional factors, such as a reduction in the capacity of activation of motor units (Harridge et al., 1999; Winegard et al., 1996) an increase in the coactivation of antagonist muscles (Klein et al., 2001; Macaluso et al., 2002), and a decrease in the size of type II/ fast twitch fibres (Larsson et al., 1997). Also this loss of muscular mass associated to ageing may be due to structural change in the skeletal muscle system, chronic diseases and their treatments, disuse atrophy or even malnutrition (Evans & Campbell, 1993).

Reduction in quantity and quality of daily physical activity is directly related to age-associated reduction in muscular strength and mass, which can be noticed as a person grows older (Roig, 2003). This strength becomes at some point insufficient to carry out motor tasks such as sitting down and walking at a given speed (Rantanen et al., 1998). For this reason, many organisations such as the World Health Organisation (W.H.O), the International Council of Sport Science and Physical Education (I.C.S.S.P.E), the Centre for Disease Control and Prevention (C.D.C), the American College of Sports Medicine (A.C.S.M), the International Organisation of Sports Medicine (F.I.M.S) and the American Heart Association (A.H.A) recommend an active lifestyle, that is to say, that which includes physical activities in everyday life, at home, at work or in spare time. Going up and down stairs, taking the dog out for a long walk, looking after the garden, washing the car, dancing, pedalling or swimming are some of these activities (Andrade et al., 1996).

Although the loss of muscular mass -an age-related process- entails a lower production of strength (Hugues & Schiaffino, 1999), similar levels of strength production can be reached by both old and young individuals in certain patterns of movement such as race walking (De Vita & Hortobagyi, 2000). This is due to the different redistribution of strength and power on the execution of the exercise, in a way that elders draw on hip extensors to a greater extent, rather than knee extensors or ankle plantar flexors, in comparison with younger participants.

There are several studies that have specifically dealt with the influence of age and muscular strength and volume levels, such as that of Akagi et al. (2009) which measured the torque strength (by means of an isometric dynamometer) and the volume of the biceps muscles (by means of a magnetic resonance), establishing in this way significative differences between age groups, both with regard to muscular volume and strength.

In addition, the above-mentioned authors assert that isometric strength measurements and those of the cross-sectional area are the most useful to evaluate differences in muscular strength and volume depending on the age. In another study, Jeffrey et al., (1997) used a hand dynamometer to establish the isometric strength of the biceps muscle, with which they established that there exists a significative decrease in isometric strength as a person grows older.

Enoka et al., (1992) found that the cross-sectional area in the quadriceps femoris muscle is significantly related to the corresponding individual value of the peak force, in addition to entailing a decrease in the maximum strength in both men and women as they grow older. Häkkinen & Häkkinen (1995) realised later that the value of the cross-sectional area of the quadriceps femoris muscle was notably higher in young adults. A relation was also found between the individual values of the cross-sectional area of the above-mentioned muscle and the individual values of the peak force. These authors conclude that the decrease in the maximum strength may be partly explained, not only by the reduction in muscular mass but also by the decrease in the maximal voluntary nerve activation and the qualitative characteristics of the muscle tissue.

With regard to the knee extensors and flexors Lindle et al., (1997) carried out a research with a wide sample of sedentary men and women, aged between 20 and 93. They measured isometric, eccentric and concentric force with a dynamometer, coming to the conclusion 'that age and strength are inversely related'.

Regarding the plantar flexor Morse et al., (2004) used the dynamometer to determine whether there existed differences in torque strength or muscular activation in these muscles, coming to the conclusion that there are differences in the activation of such muscles depending on the age group.

Establishing the muscular strength in isometric conditions can be a useful evaluation tool to determine the function of the different articulations (Fransen et al., 2003). Although isometric activity is rare in everyday life, the measurement of the isometric strength has a strong predictive relation with the functional capacity (Sapega, 1990). This relation becomes even more obvious in old patients and in those that show considerable functional alterations. The isometric strength is related to a large extent to the muscle volume and the cross-sectional area (Fukunaga et al., 2001; Kanehisa et al., 1994; Klein et al., 2001). Moreover, the analysis of images by means of a MRI scan is used to evaluate the muscular quality (in case of an atrophy or size abnormality), the muscular volume and some other characteristics (Asakawa et al., 2002; Pappas et al., 2002; Tingart et al., 2003).

Finally, the assessment of the quality of life carried out by the questionnaires can inform us, both qualitatively and quantitatively, which aspects of the patient's quality of life are affected in comparison to the general population -which is the reference in these questionnaires- and the effect that other diseases produce on the quality of life (Sanjuás, 2005). One of these generic questionnaires is that of Baecke et al. (1982), whose aim is to measure the quality of life of the people, taking into account the level of physical activity at work and in their spare time. The kind of people that have undergone such a questionnaire of physical activity are those who suffer from diabetes (Baecke et al., 1982), those with an obstructive lung disease (Vilaro et al., 2007), and old people (Mora et al., 2004). A variation of the questionnaire has also been carried out (Guirao et al., 2009) for its application to individual patients and the identification of light physical activities.

In summary, this research aims to describe the neuromuscular capacity of the upper and lower body muscles, as well as their volume, by means of an isometric dynamometry (upper body), isokinetic dynamometry (lower body) and a M.R.I from a small sample of physically active adult men from the city of Manchester.

MATERIAL AND METHODS

To measure the moment of force or torque in Newton metres (Nm) of the knee extensor and flexor muscles, as well as that of the plantar extensors and flexors, an isokinetic dynamometer (Cybex Norm, Ronkonkama, New York, U.S.A.) was used. The dynamometer was connected to a computer containing the software MP100 Manager Acqknowledge, version 3.7.3 (Biopac System) for collecting and analysing the results of the moment of force or torque.

For the measurement of isometric strength of the biceps brachii muscle, an isometric dynamometer attached to a quilted holder -for easier measuring and more comfortability for the participants- was used. The dynamometer was a standard type S, widely used, both in research and industrial processes. This kind of dynamometers works with both traction and compressibility, which grants a great versatility in measuring processes of static loads. This dynamometer was made and validated in the Physical Activity Laboratory of the IRM. This dynamometer was connected as well to the computer containing the software MP100 Manager Acqknowledge version 3.7.3 (Biopac System), which enabled us to collect and analyse the results of the isometric strength.

For the imaging of the cross-sectional area of the muscles and their subsequent analysis for the volume calculation, a MRI scan [Esaote G-Scan Biomedical (Genoa, Italy)] was used.

To determine the physical activity of the subject, the Baecke et al. (1982) questionnaire was used.

Participants

The sample is composed by 19 voluntary English participants, from the city of Manchester, all of them male and with a mean age of 43.84 years, (± 11.62), average weight of 78.57 kg (± 12.51) and average height of 172.95 cm (± 0.65).

The measurements were carried out in the physical activity laboratory of the Institute for Biomedical Research into Human Movement and Health (IRM), in Manchester Metropolitan University. Before the start of the research, all participants had given their written informed consent, and the study was approved by the local ethics committee. In addition, participants were asked to fill in the Baecke et al. (1982) questionnaire so that we could have full knowledge of their lifestyle in terms of work, sport and spare time.

Measured dependent variables

The dependent variables of our research are:

- Moment of force or torque (Nm) of the knee extensor muscles.
- Moment of force or torque (Nm) of the knee flexor muscles.
- Moment of force or torque (Nm) of the ankle extensor muscles.
- Moment of force or torque (Nm) of the ankle flexor muscles.
- Isometric strength (N) of the biceps brachii muscle.
- Volume (cm^3) of the quadriceps femoris muscles (rectus femoris, vastus lateralis, vastus medialis and vastus intermedius).
- Volume (cm^3) of the biceps and triceps muscles.

Procedure

The order of the measurement in each of the participants was: a) register of the cross-sectional area of the quadriceps femoris muscles, b) cross-sectional area of the biceps and triceps muscles, c) moment of force or torque of the knee extensor and flexor muscles, d) moment of force or torque of the plantar extensor and flexor muscles and, finally, the isometric strength of the biceps muscle. Altogether, the tests took approximately 2 hours.

For the measurement of the cross-sectional area of the upper and lower body muscles, the MRI was used. For the measurement of the quadriceps femoris muscles and the biceps a specific programme was used. In the first case, 16 images were obtained in each measurement, with a distance of 10 mm between each image, images in the transverse plane in two dimensions (2D) and a resolution of 256*192 pixels. In the second case, 16 images were obtained in each measurement, with a distance of 3 mm between each image, images in the transverse plane in two dimensions (2D) and a resolution of 288*200 pixels. In both situations, the subject was supine with the dominant arm inside a holder. For all the leg muscles, three measurements were carried out, starting from the knee and finishing in the hip, obtaining a total of 48 images, whereas to measure all arm muscles, two measurements were carried out, starting from the elbow and finishing in the shoulder, obtaining a total of 32 images (Figure 1).

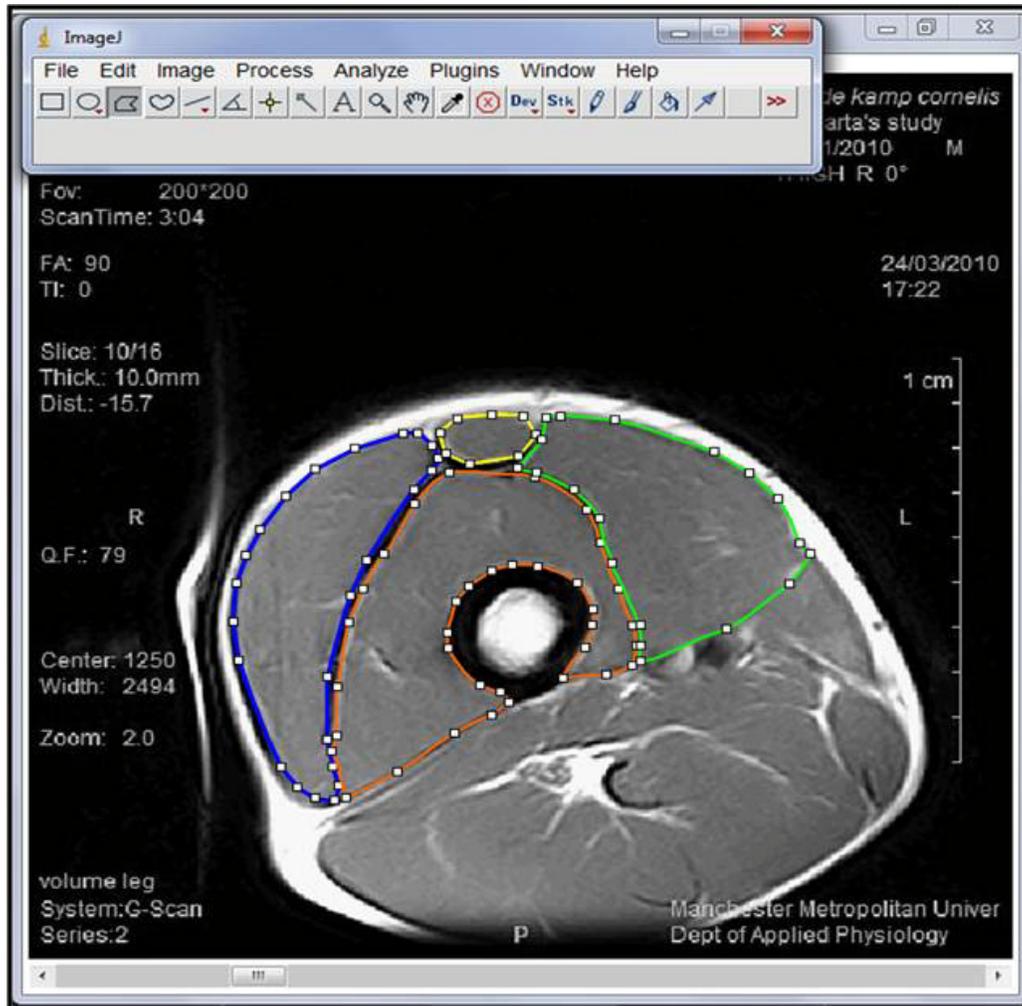


Figure 1. Example of the selection of the area of the different quadriceps femoris muscles, being the yellow outline the rectus femoris; the blue outline, the vastus lateralis; the orange outline, the vastus intermedius; and the green outline, the vastus medialis.

The images obtained by means of a MRI were subsequently analysed with the programme Image J 1.42q. The procedure for the calculation of the volume of the quadriceps femoris, biceps and triceps muscles is described hereafter: once the areas of all the images composing a muscle were calculated, each area was multiplied by the distance between the images converted into centimetres (in the case of the quadriceps femoris each area was multiplied by 1, and in the case of the biceps and triceps, by 0.3) and subsequently, all areas were added up, being the result the volume of the muscle in question in cubic centimetres. This can be expressed with the following formula:

$$\text{Volume (cm}^3\text{)} = \Sigma \text{ cross-sectional area} \times (\text{distance between images in cm}).$$

For the measurement of the moments of force or torque of the knee and plantar extensors and flexors as well as that of the isometric strength of the biceps muscle, the specific software MP100 Manager Acqknowledge version 3.7.3 (Biopac System) was used. This programme collected the data of the moments of force or torque, with a sampling frequency of 200 Hz and an external voltage of 10 V.

For the measurement of the moments of force or torque of the knee extensors and flexors, the subject sat on the chair of the isokinetic dynamometer and had to carry out 3 maximum voluntary contractions, 3 isometric extensions and 3 isometric flexions for 3 seconds. There was an interval of 10 seconds between each repetition. The greatest registered moments of force for both knee flexion and extension were selected for analysis.

For the measurement of the moments of force or torque of the plantar extensors and flexors, the same procedure was used, except that the subject lay on his stomach, with his foot inside a holder or lever arm.

For the measurement of the isometric strength of the biceps, the subject sat on an adjustable chair, inserting his dominant arm into the dynamometer. The arm was placed in such a way that the biceps muscle and the forearm made an angle of 90°. The subject was asked to carry out 3 isometric flexions, holding the strength for 3 seconds, with an interval of 10 seconds between each repetition.

Statistical analysis

A descriptive, exploratory analysis was carried out to determine the muscular behaviour of the sample with regard to the dependant variables. A correlational analysis was carried out as well. The statistical processing of data was carried out with the Statistical Package for the Social Sciences 15.0 (© 2008 SPSS Inc.).

RESULTS

The participants responses to the questionnaire showed that they were physically active, since they achieved the following scores: 2.38 points (sport), 2.71 (spare time) and 2.36 (work). The final score was 7.46, out of a maximum of 10. In addition, the questionnaire ruled out the possibility of health problems among the participants.

Hereafter is the data regarding the variables measured in the sample of participants (Table 1). It is to be remarked that grip strength is very similar between both hands, although being slightly higher in the right hand (44.01 kgf). The torque of the knee extensors (199.75 Nm) is almost three times greater than the exerted by the flexors (67.85 Nm). The same occurs with the plantar flexors (103.79 Nm), which reach also much greater figures than the foot dorsiflexors (39.52 Nm). Both in the actions of extending and flexing, in knee and ankle, the time it takes to reach the maximum moment of force is approximately 3 seconds. As for the muscular volumes, that of the triceps muscle (242.55 cm³) is slightly greater than that of the biceps brachii (218.61 cm³) whereas the volume of the rectus femoris muscle is the smallest (150.03 cm³) and that of the vastus lateralis muscle the greatest (299.58 cm³) among the muscles of the quadriceps femoris.

Table 1. Statistical data of the sample under study.

	Mean	SD
Isometric strength of the manual prehension (right hand)	44.01 kgf.	±7.12
Isometric strength of the manual prehension (left hand)	43.26 kgf.	±6.58
Isometric strength (Biceps)	283.56 N.	±59.22
Time to reach the maximum moment of force (isometric strength, biceps)	3.68 sec.	±.64
Torque of the knee extensor muscles	199.75 Nm.	3.794
Time to reach the torque (knee extensor muscles)	3.08 sec.	±.77
Torque of the knee flexor muscles	67.85 Nm.	±14.57
Time to reach the torque (knee flexor muscles)	2.78 sec.	±.74
Torque of the plantar extensor muscles	103.79 Nm.	±46.75
Time to reach the torque (plantar extensor muscles)	2.98 sec.	±.64
Torque of the plantar flexor muscles	39.52 N.	±25.64
Volume of the biceps muscle	218.61 cm ³	±57.39
Volume of the triceps muscle	242.55 cm ³	±76.20
Volume of the rectus femoris muscle	150.03 cm ³	±48.70
Volume of the vastus lateralis muscle	299.58 cm ³	7.254
Volume of the vastus medialis muscle	275.67 cm ³	±102.65
Volume of the vastus intermedius muscle	288.53 cm ³	±70.87

SD=standard deviation.

With regard to correlations, there exists a negative correlation between the variable age ($r=-0.52$; $p<0.05$) and the variable isometric strength of the biceps. It is also noticeable that the manual pretension of the right hand is positively correlated to the manual pretension of the left hand ($r=0.788$; $p<0.001$) and the isometric strength of the biceps ($r=0.562$; $p<0.05$).

In addition, the moment of force or torque of the leg extensor muscles is positively correlated to the moment of force or torque of the plantar extensor muscles ($r=0.712$; $p<0.01$). The time of the torque of the leg flexor muscles is positively correlated to the time of the moment of force or torque of the leg extensor muscles ($r=0.773$; $p<0.001$) and the time of the moment of force or torque of the plantar flexor muscles ($r=0.626$; $p<0.01$).

As for the volumes, the volume of the biceps is correlated to the volume of the triceps ($r=0.849$; $p<0.001$), and with regard to the quadriceps femoris muscles, the volume of the rectus femoris is correlated to the volume of the vastus lateralis ($r=0.724$; $p<0.001$), the volume of the vastus medialis ($r=0.718$; $p<0.01$) and the volume of the vastus intermedius ($r=0.743$; $p<0.001$). Similarly, the volume of the vastus lateralis is correlated to the volume of the vastus medialis ($r=0.796$; $p<0.001$) and the volume of the vastus intermedius ($r=0.782$; $p<0.001$); and the volume of the vastus medialis is correlated to the volume of the vastus intermedius ($r=0.864$; $p<0.001$).

DISCUSSION

Firstly, it is to be remarked that there exists a positive correlation between the isometric strength of the manual prehension of the right hand (dominant hand for all participants) and that of the left hand. This suggests that the sample of participants did not carry out hard manual activities or asymmetric physical activities. That negative relation we have found in the sample of participants between the variable age and the variable isometric strength of the biceps coincides with the conclusions of Akagi et al. (2009), Goodpaster et al. (2006), Jeffrey et al. (1997), Pearson et al. (1985), who determine a significant involution of the isometric strength of the biceps muscle with advancing age. Therefore, this relation that has been found reinforces the statements of Baldini et al., (2006), who assert that the manual prehension strength is a common measurement to determine the strength of the upper body. Other authors also came to the conclusion that the leg musculature suffers the loss of isometric strength with advancing age (Enoka, et al., 1992; Lindle et al., 1997).

It is also to be remarked that the sample of participants reached a greater moment of force through the extensor muscles than through the flexor muscles in the articulation of the knee and the ankle. Both actions of flexing and extending, in the respective articulations, need about 3 seconds to reach the maximum moment of force. These results are similar to those found by Candow and Chilibeck (2005), who stated that both young and old people exert a greater strength with the knee extensor muscles.

These differences between the actions of flexing and extending were also found in a group of athletes; the degree of coactivation of their hamstring muscles was greater when they carried out an extension with an isokinetic dynamometer (Osterning et al., 1986; Sale, 1988). The cause of this behaviour could be the following: the coactivation of the antagonist muscles is very common, especially when the contraction of the antagonists is very intense and/or fast, and when the tasks requires accuracy or when the subject is not trained for a particular task, generating in this way less strength in the action of flexing (Sobel, 1986; Popescue, 1974; Renstrom, 1994).

The moment of force or torque of the leg extensor muscles is positively correlated to the moment of force or torque of the plantar extensor muscles, in the same way that the time of torque of the leg flexor muscles is positively correlated to the time of the moment of force or torque of the leg extensor muscles.

These relations may indicate a certain coordinated muscular behaviour of the flexor and extensor musculature of the articulations of the knee and the ankle, mainly due to the fact that the participants had regularly engaged in physical activity in their everyday life. This minimal muscular exercising that takes place at work, leisure or while doing sport could favour the adequate coactivation of the agonist and antagonist muscles in the above-mentioned articulations, thus facilitating the control of the movement (García et al., 2006).

Moreover, no relation has been found between the handgrip of both hands and the muscular volume of the biceps brachii and triceps muscles. This result does not coincide with the contributions of Fukunaga et al., (2001), Kanehisa et al., (1994) and Klein et al., (2001), who state that the isometric strength is correlated to a large extent with the muscle volume and the cross-sectional area, or the conclusions of Holzbaur et al., (2007), who establish a relation between the isometric strength and the volume of the arm muscles. Neither has been found, with regard to the lower body, a relation between the variable isometric strength and the variable muscular volume, even though age-related decrease in isometric strength is associated as well to a decrease in the muscular volume, due to a decrease in: level of urinary creatinine (Roig, 2003), cross-sectional area of the muscle (Häkkinen & Häkkinen, 1991), activation of the motor units (Harridge et al., 1999; Winegard et al., 1996), fast-twitch fibres (Larsson et al., 1997); increase in the coactivation of antagonist muscles (Klein et al., 2001; Macaluso et al., 2002), decrease in the protein synthesis (Balagopal et al., 1997) or owing to changes in the contractile capacity of the muscles (Sargent, 1996).

It is probable that regular engagement in physical activity would prevent to a considerable extent the loss of muscular strength and volume with advancing age, thus preventing such a relation between strength and volume. This statement is supported by Sipila (1996), who concludes that old female athletes obtain a greater muscular mass than sedentary old women, or by Evans and Campbell (1993), who suggest that inactivity atrophy could be one of the causes of the loss of muscular volume with advancing age. Also Häkkinen & Häkkinen (1995) and Lexell et al., (1988) suggest that the percentage of type II/fast twitch fibres decrease considerably with advancing age, and this affects the capacity to generate strength, but not necessarily the muscle volume.

Nevertheless, we did find a positive correlation between the volume of the biceps and the volume of the triceps. This relation could indicate a compensated exercising of the flexor and extensor musculature of the arm while at work, during leisure time or on engaging in physical activity. This compensated exercising could be the cause of the relations found between pairs of muscles of the quadriceps femoris muscle. These relations resemble the findings of other studies like that of Morse et al., (2007), who state that the rectus femoris is the muscle with the smallest volume, followed by the vastus medialis, the vastus intermedius and the vastus lateralis. The same occurs with the results obtained with regard to the volume of the muscles of the upper body, since the volume of the triceps was found to be greater than the volume of the biceps, as in the study carried out by Popadic et al., (2009).

Therefore, these descriptive results may indicate a generic and global exercising of the musculature of the upper and lower body, not local nor specific, in which isolated, repetitive or asymmetric movements are not carried out regularly. That is to say, the muscular actions carried out by the sample of participants in their everyday life, could, according to these results, indicate a synergic exercising of the agonist and antagonist musculature.

CONCLUSION

This research, unlike other studies that link the level of muscular strength and volume to the age of the participants, provides an own, specific description of a sample of adults, physically active according to the Baecke et al. (1982) questionnaire.

The sample of participants is characterised by the following elements: a negative relation between the age and the isometric strength of the biceps, a positive relation of volumes between the muscles of the quadriceps femoris, and a positive relation between the time to reach the maximum moment of force per unit of time in the actions of flexing and extending the leg.

In the future, it would be interesting to broaden the sample under study with persons of both sexes, active and sedentary, and carrying out the analysis by segmented groups of age and level of physical activity, in order to determine -taking the age and the level of physical activity into account- when and under which circumstances the strength and muscular volume decrease significantly.

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