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paru dans : International journal of sports medicine, 2009, vol. 30, n°10, oct., pp. 754-759

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ABSTRACT

Knee extensor muscle strength and metabolism were examined in endurance trained young versus master athletes (10 elderly: 63.1 ± 2.3 yr and 10 young : 28.7 ± 3.2 yr). Before and immediately after a resistance strength training (RST) session, subjects performed maximal isometric voluntary contraction (MVC) and a 10-min cycling test at a moderate intensity. During MVC, evoked contractions of the knee extensor muscles were performed to assess neuromuscular properties. Metabolism was assessed using oxygen uptake kinetics model. Before the RST session, master athletes show lower knee extensors MVC than young subjects without any difference in oxygen uptake kinetics. After the RST session, a similar effect of fatigue was observed on muscular properties and oxygen uptake kinetics whatever the group. Our results suggest the ability of master athletes to perform exercise at a given intensity is maintained despite a significant loss in strength with ageing.

Keywords : *Ageing, Endurance Training, Strength, Oxygen uptake kinetics*

INTRODUCTION

In the recent years there has been an increased interest in issues related to the enhancement of the performance of master athletes [12, 26, 37, 39]. Many of the changes in physiological functional capacity related to ageing have been found to be the result of long standing sedentary lifestyle [26]. Studies on master athletes' performance have shown that master athletes are able to maintain high performance as the age related structural adaptations are maintained in masters athletes [26, 36, 37, 39]. The majority of studies working on the effect of age on the muscular function have shown an impairment of the maximal force-generating capacities in elderly compared to young adults and several factors have been identified [5, 20, 27]. For non endurance trained adults, this reduction is generally attributed to a loss of muscle fibres, change in the proportions of muscle fibre types [25, 33], and a reduction in muscle volume and cross-sectional area [15]. Based on results of Coggan et al. [10] confirmed by Tarpenning et al. [38] decreases of strength capacities for masters athletes could be explained by other factors. Indeed, these authors have shown that fibre area and fibre distribution are maintained with aging for master runners. They suggested that the decline in muscle performance may also be the result of neural factors, such as muscle recruitment and/or specific tension. Within this framework, recent studies have highlighted the interest to study age related fatigability during exercise to explain mechanisms underlying the force decline with ageing, but to date contradictory results have been reported mainly related to task dependency of fatigue [2, 14, 19] . Therefore, during the last decade, a great attention has been attributed on the need to identify factors affecting muscle performance decrease and strategies to increase muscle performance in older population [4, 11, 37]. Within this framework (repetition avec ligne 35), it has been demonstrated that resistance training has a significant effect on muscle mass and force whereas endurance training increases oxygen transport and consumption capacities in elderly subjects but little is known on the effect of regular endurance training on muscle performance [11, 38].

Muscular performance alterations can be analyzed with isometric or dynamic maximal voluntary contraction (MVC) performed before and after a fatiguing protocol [21, 22, 23]. In addition, changes in locomotion efficiency can be evaluated during dynamic exercise like cycling by analyzing oxygen uptake [16, 24]. In these last studies efficiency is classically recorded from steady state values of oxygen uptake during a submaximal exercise. During the last decade it has been well documented that the characteristics of VO_2 kinetics could reflect more accurately the aerobic response to exercise and therefore efficiency [4, 7, 18]. During exercises above lactate threshold VO_2 increases with bi-exponential kinetics with a VO_2 slow component [41]. It has been demonstrated that VO_2 kinetics get slower with age indicating a limitation in oxygen delivery or in muscle oxidation activity and that the VO_2 slow component amplitude is lower indicating changes in muscle function [3, 4, 9, 35].

The analysis of ageing on muscular performance or efficiency is difficult to interpret because of the confounding effects of reduction in physical activity levels, changes in body composition and development of clinical diseases [37]. Therefore, the purpose of this study was to examine the age-related alterations in neuromuscular properties and oxygen uptake kinetics in regularly endurance-trained subjects. In this specific population we raised the following questions a) Do endurance-trained master athletes present lower values of muscle strength and slower oxygen uptake kinetics than young adults as classically described in the literature for untrained groups? b) Is this possible difference enhanced by fatiguing exercise?

MATERIALS AND METHODS

SUBJECTS AND OVERALL DESIGN. – The investigation was conducted on 10 masters (Age, 62.5 ± 4.1 yr yr; height, 1.70 ± 0.02 m; body mass, 70.2 ± 1.5 kg, free fat mass, 22.4 ± 0.8 %) and on 10 young men (Age, 26.2 ± 2.4 yr , height, 1.82 ± 0.05 m; body mass, 74.4 ± 5.2 kg, free fat mass, 15.3 ± 1.2%). All subjects had to be free from present or past neuromuscular conditions that could affect motor function. Subjects were fully informed about the protocol, and informed consent was obtained prior to all testing. This study was approved by a local research ethics committee. The individuals selected were regularly trained subjects engaged in cycling and running long distance competitions (minimum training time per week: 6hr cycling and 1hr running). In both groups, all subjects were selected to have a similar training volume to avoid a possible training volume effect on the comparison between groups. Each subject completed three laboratory-based testing sessions separated by at least a 48 hour rest period (figure 1).

DETERMINATION OF VO_{2MAX} – On their first visit to the laboratory the subjects underwent an incremental cycling test at a self-selected cadence on an electromagnetically braked ergocycle (Excalibur sport, Lode, Gröningen, The Nederland). The test began with a warm-up lasting 6 min of 100 W for young and 70 W for masters, after which the power output was increased by 30 W each minute until the subjects were exhausted. The criteria used for the determination of VO_{2max} were a plateau in VO_2 despite an increase in workrate and a respiratory exchange ratio (RER) above 1.1. V_E (minute ventilation) and VO_2 were recorded using the Cosmed K4b^2 telemetric system (Rome, Italy). Ventilatory thresholds (VT_1 and VT_2) were assessed from the graph of VE/VO_2 relative to VO_2 [34, 40]

CONTROL EXERCISE AND 1RM KNEE EXTENSION EVALUATION – On their second visit to the laboratory the subjects underwent a 10 min control cycling test (CTRL) at a self-selected cadence on the same ergocycle at a load corresponding to: $P_{exercise}$ = [Power output corresponding to VT_1 (P_{VT_1}) + Power output corresponding to the VT_2 (P_{VT_2})] / 2. Immediately before (MVC_{Ctrl}) and after ($MVC_{Ctrl\ Post}$) the control cycling test, subjects were placed in a seated position and were securely strapped into the test chair to perform maximal voluntary isometric (MVC) knee extension of their dominant leg using an isometric ergometer (Type: Schnell Trainingsgeräte GmbH, Peutenhausen, Germany). Subjects performed three MVC of short duration (2-3 sec) of the knee flexor and extensor muscles. A 60 sec period of rest was imposed between each contraction. The best performance of to the three trials was selected as the maximal isometric voluntary contraction (MVC, in Newton).

One hour after end of the previous test, subjects were evaluated for their 1RM during inertial knee extension exercise on a leg ergometer (Type: Schnell Trainingsgesäte GmbH, Peutenhausen, Deutschland) The one repetition maximum (1RM), is defined as the load for which only one full repetition, i.e., a sequence of movements ending back in the starting position, can be performed. Determination of 1RM proceeds over subsequent trials in which the amount of weight to be lifted is increased stepwise until the subject fails to produce a full-range movement using method described by Bishop et al. [6]

RESISTANCE STRENGTH TRAINING SESSION AND CYCLING EXERCISE – On their third visit to the laboratory the subjects had to perform a classical resistance strength training session composed of 10 sets of 10 repetitions on a horizontal leg press (Technogym, Gambettola, Italy), at an intensity of 70% of the individual one repetition maximum (1 RM). The rest between sets was

90-s. The exercise consisted of a 3 sec concentric contraction followed by a 3 sec eccentric contraction. After resistance strength training session, all subjects performed 10 min of cycling on the electromagnetically braked ergocycle at intensity equal to that of the control test.

Before ($MVC_{Fatigue\ Pre}$) and after ($MVC_{Fatigue\ Post}$) the resistance strength training session, and after the cycling exercise ($MVC_{10\text{-}min\ Post}$), subjects performed three MVC of the knee extensor muscles.

OXYGEN UPTAKE KINETICS .

For each subject and each session, breath-by-breath data were time-aligned. Resting data were obtained by averaging the values recorded over the 3 min rest period prior to exercise. VO_2 kinetics were determined by the use of a bi-exponential model of the form

$$Y (t) = Y(b) + A_1*[1-e-^{(t-TD1/\tau1)}]+ A_2*[1-e-(^{t-TD2/\tau2)}]$$

where Y represents VO_2 at any time (t), b is the baseline value of Y (VO_{2b}), A_1 and A_2 represent the primary and slow component amplitudes, τ_1 and τ_2 the time constants defined as the duration of time through which Y increase to a value equivalent to 63% of A_1 and A_2 , and TD_1 or TD_2 are the time delays [7].

EVOKED CONTRCATIONS

The contractile properties (muscular twitch) of the quadriceps muscle were studied using electrically evoked contractions. Electrical stimulation was applied to the femoral nerve of the dominant leg according to the methodology previously described by Place et al [10]. The following parameters were obtained before the control exercise and after the resistance strength training session: (a) peak twitch (Pt), i.e. the highest value of twitch tension production; (b) contraction time (Ct), i.e. the time from the origin of the mechanical response to Pt; (c) half-relaxation time (HRt), i.e. the time to obtain half of the decline in twitch maximal force.

Electromyographic activity of the right vastus lateralis (VL) muscle was monitored with surface EMG during the single twitch. The subjects were prepared for placement of EMG electrodes by shaving the skin of each electrode site, cleaning it carefully with alcohol wipe and lightly abrading it to maintain a low inter-electrode resistance of <1000 Ω. Pairs of Ag/AgCl pre-gelled surface electrodes (Medicotest, type Blue Sensor, Q-00-S, Denmark) of 40 mm diameter with a center to center distance of 25 mm were placed on the VL muscle for EMG data acquisition. According to SENIAM recommendations, the location of the electrode was place at the distal 2/3 point on the line from the anterior spina iliaca superior to the lateral side of the patella. A ground electrode was placed on a bony site over the right anterior superior spine of the iliac crest. Peak-to-peak amplitude (PPA), peak-to-peak duration (PPD) of the M-wave were determined for the VL muscle during the control twitches performed before the MVC. Amplitude was defined as the sum of absolute values for maximum and minimum points of the biphasic (one positive and one negative deflection) M wave. Duration was defined as the time from maximum to minimum points of the biphasic M wave.

STATISTICAL ANALYSIS. – All data were expressed as mean ± standard deviation (SD). A two-way analysis of variance (group x session) for repeated measures was performed to analyze the effect of groups and the strength training session using MVC, contractile properties, cadence and, oxygen uptake kinetics parameters as dependent variables. Tukey post-hoc test was used to determine any differences among the Pre and Post fatiguing exercise and groups.

RESULTS

MVC FORCE AND CONTRACTILE PROPERTIES – No significant effect of 10 min cycling was observed on the MVC in non-fatiguing (Ctrl) and fatiguing conditions for the two groups.

A significant effect of ageing was observed on MVC with lower MVC values for masters than young athletes ($MVC_{Fatigue\ pre}$: -30,2 % and $MVC_{Fatigue\ Post}$: -27.4 %). The difference between young and master was also significant when MVC was expressed per unit free fat mass (respectively for young and elderly $MVC_{fatigue\ pre}$: 6.9 ± 1.2 *vs.* 5.2 ± 1.5N.kg^{-1} free fat mass, $p<0.05$). A significant decrease in MVC was measured after fatiguing exercise ($p<0.01$) without any difference between groups: - 13.4 % for elderly adults and - 15.9 % for young (figure 2).

A significant effect of ageing was observed on contractile properties before the heavy-fatiguing exercise with a slower Ct and HRt for masters when compared to young athletes (for young and elderly respectively; Ct: 55 ± 15 *vs.* 82 ± 21 ms and HRt : 62 ± 11 *vs.* 82 ± 18 ms, $p<0.05$). After fatigue a decrease in Pt was observed whatever the group without any changes in CT or HRt (-24.5± 3.8% and -33± 5.1% respectively for young and master athletes). No effects of group or fatigue were observed on M-wave amplitude or duration (Table 1).

CADENCE – No effect of ageing was observed on the freely chosen cadence (FCC) during cycling exercises before or after the strength training session exercise. After the strength training session a significant increase in cadence was observed for both groups (respectively for young and master athletes: pre *vs.* post fatigue: 79.8 ± 10.5rpm vs. 88.4 ± 8.5rpm and 80.2 ± 11.2rpm vs. 89.5 ± 12.5rpm) .

OXYGEN UPTAKE KINETICS- Maximal oxygen uptake values were statistically higher in young when compared with masters whatever the mode of expression (*i.e.* per unit body mass *vs.* per unit fat free mass). When expressed per unit body mass, these values were respectively for young and master athletes: 67± 4 $ml.min^{-1}.kg^{-1}$ and 56 ± 1 $ml.min^{-1}.kg^{-1}$. For the master group these values were significantly higher than those previously reported in the literature in healthy but untrained subjects [22]. No effect of ageing was observed on oxygen uptake kinetics parameters during the control exercise. After fatigue a significant increase in oxygen slow component and a decrease in time constant of the primary phase ($\square_1$) were observed in both groups. (Table 2)

DISCUSSION

The present study aimed to analyze the age-related alteration of the knee extensor muscle strength and oxygen uptake kinetics during cycling before and after a strength training session in regularly endurance-trained subjects.

Main findings were 1) The maximal muscle strength capacity of endurance-trained masters was lower than young athletes, but no significant effect was observed on oxygen uptake kinetics 2) Following the resistance strength training session a significant effect of fatigue was observed on muscle force and oxygen uptake kinetics in both groups, but no significant further effect of ageing was observed on these alterations.

MVC FORCE AND CONTRACTILE PROPERTIES - At rest in non-fatiguing condition, master athletes generated ~ 29 % less voluntary isometric force compared to the young. This first result is in accordance with the literature where a ~15 % to ~35 % decrease with age is classically observed for trained and untrained subjects [1, 19, 20], indicating that regular endurance training does not allow to maintain the maximal muscular performance of elderly adults. In the literature, 60 years old is generally the age where the decrease of maximal isometric strength capacity of the quadriceps muscle is observed [33]. Reasons of this decrease are multi factorial and could be linked to a reduction in muscle volume and cross-sectional area [29] or/and a change in size numbers and proportions of muscle fiber type [25, 33]. These observations are supported by our results on the twitch properties. In agreement with previous studies [5, 25], our data show a slowing of the contraction time (Ct) and half-relaxation time (HRt) of the master compared with young athletes (Ct: +33 %; HRt: +43 %). If many hypotheses have been suggested to explain this slowing, the main explanation attributed this results to an age-related shift toward a higher percentage of type I fiber, a loss of muscle fiber and motor units [12].

In this study we have observed a similar reduction in the maximal strength capacity for master and young athletes after the strength training session, with a decrease in maximal strength of -15.9 % for young and - 13.4 % for older. In the literature the analysis of the effect of fatigue on muscular properties has leaded to contradictory results. [27, 2]. For example during sustained submaximal contractions, in healthy, but untrained subjects, Hunter et al [17] have compared time to task failure for a sustained isometric contraction performed at a submaximal intensity with elbow flexor muscles by young and old men who were matched for strength. They have reported that time to task failure was longer for the old men compared with the strength-matched young men. On the opposite Baudry et al [2] have showed that the fatigability of the ankle dorsiflexor muscles during repeated eccentric or concentric contractions was greater in untrained elderly subjects than in young subjects. During repeated maximal contractions Petrella et al [10] have reported that older adults are less capable of sustaining maximum concentric velocity during repetitive contractions, indicating the role of contraction velocity in this impairment. In our study we did not find any effect of ageing on contraction time or MVC reduction after fatigue. These results suggest that fatigue is similar following exercise for both groups and indicates that in regularly endurance-trained subjects the effect of ageing on force decrease is not potentiated by fatigue.

OXYGEN UPTAKE KINETICS – One interesting result of this study is that in non-fatigued condition no significant differences in oxygen uptake kinetics temporal parameters was observed between our two groups. This observation seems to demonstrate that regular training could counterbalance the well described slowing of oxygen uptake kinetics with ageing [3]. Pulmonary oxygen uptake kinetics reflects the kinetics of adjustment of oxidative metabolism at the skeletal level; therefore a decrease in this rate of adjustment would lead to a decrease in exercise capacity and fatigue appearance. Relatively few studies have investigated the effect of training on oxygen uptake kinetics in old subjects. A recent comparative study in master athletes has indicated that oxygen uptake kinetics are faster in long distance runners than in middle distance or sprint runners [4] suggesting an increase in oxidative capacity with endurance training. Moreover, in middle age subjects (51 ±3 years) Fukoka et al., [13] have observed that oxygen uptake kinetics are sensitive to a short endurance training program whereas effects on peak physiological variables such as oxygen peak or hear rate peak appears later in the training program. Therefore the lack of any difference in primary time constant (τ_1) values between young and master athletes in our study is in agreement with these previous results and give an indirect evidence that factors controlling oxygen uptake kinetics could be preserved by regular endurance training. The second interesting result concerning oxygen uptake kinetics is that after fatigue the amplitude of slow component was increased in both groups. The VO_2 slow component indicates that the efficiency with which the body uses oxygen to produce energy is progressively lost while exercise continues at exactly the same speed and thus the VO_2 slow component has been described to be an important determinant of exercise tolerance [8]. To date only three studies has compared oxygen slow component between young and old adults [3, 9, 35]. They have reported an attenuation of the slow component amplitude in older compared to young untrained subjects. One difficulty when interpreting these results between old and young subjects is that the smaller slow component amplitude may be due to lower power in the older group. In our study we have calculated the power output used for exercise relatively to each individual's ventilatory thresholds. These values are similar in both groups and represents respectively for young and elderly subjects: 81.4 ± 1.6 and 82.5 ± 1.1 % VO_2 peak. In non-fatigued or fatigued condition, our results differ from previous studies since no differences in amplitude or time constant of the slow component was observed between groups. Jones and Poole [18] have indicated that 86% of the VO2 slow component is attributed to the exercising limbs and that the major contributor is likely within the exercising muscle itself. In our study we found a similar alteration in muscular performance after the strength training session in both groups. Thus the increase in VO_2 slow component could be mainly attributed to the muscular fatigue induced by exercise with an additional recruitment of muscle fibres to maintain the same power output during cycling. Since the trained status of our subjects does not seems to protect the skeletal muscles from the decrease in strength classically described with ageing, one surprising result of this study is that the slow component increase after fatigue was not affected by ageing. This observation suggests a positive effect of regular endurance training on exercise tolerance in master athletes. Further longitudinal studies investigating muscular function in master athletes are necessary to explain this beneficial effect.

CONCLUSION

Despite difference in maximal strength level and contractile properties between young and master athletes, a similar effect of fatigue following the resistance strength training session was observed in both groups. Furthermore no significant difference in oxygen uptake kinetics was observed during cycling exercise between groups in control or fatigue condition. The present study gives indirect evidence that regular endurance training could contribute to improve exercise tolerance.

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Table 1 Muscular twitch and vastus lateralis muscle M-wave characteristics (peak twitch, *i.e.* Pt; contraction time, *i.e.* Ct; half-relaxation time, *i.e.* HRt; peak to peak amplitude, *i.e.* PPA; peak to peak duration, *i.e.* PPD) before and after the fatiguing exercise for masters and young groups.

		Twitch			M-Wave	
Groups	Period	Pt (N)	Ct (ms)	HRt (ms)	PPA (mV)	PPD (ms)
Young	before	50.6 ± 12.6	55 ± 15	62 ± 11	14.6 ± 4.5	5.7 ± 1.4
	after	38.2 ± 21.2*	49 ± 18	56 ± 14	13.6 ± 5.2	5.3 ± 1.8
Elderly	before	46.2 ± 8.6	82 ± 21 †	82 ± 18 †	16.6 ± 9.7	6.2 ± 1.2
	after	33.6 ± 12.4 *	73 ± 15 †	78 ± 21 †	17.1 ± 10.2	6.3 ± 1.8

Values are mean ± SD. * when a difference between the two periods was significant at $p< 0.05$; † when a difference between the two groups was significant at $p<0.05$.

Table 2 Parameters of oxygen kinetics before and after fatiguing exercise in young and master athletes.

Groups	Period	τ1 (s)	A1 (ml.min-1)	τ2 (s)	A2 (ml.min-1)
Young	before	25.1 ± 12	2622 ± 365	188 ± 68	214 ± 54
	after	21.6 ± 13*	2805 ± 495*	198 ± 34	295 ± 48*
Elderly	before	27.8 ± 10.2	2384 ± 321	218 ± 52	231 ± 74
	after	23.5 ± 11.5*	2698 ± 424*	201 ± 44	256 ± 64*

Values are mean ± SD. * when a difference between the two periods was significant at $p < 0.05$;

A1 and A2 represent the primary and slow component amplitudes, τ1 and τ2 the time constants of the kinetics

Figure 1 – Graphic representation of the experimental protocol. CTRL, Control cycling session; VO2max, maximal oxygen uptake test; MVC, maximal voluntary contraction; 1RM, one more-Repetition-Maximal ; R, rest

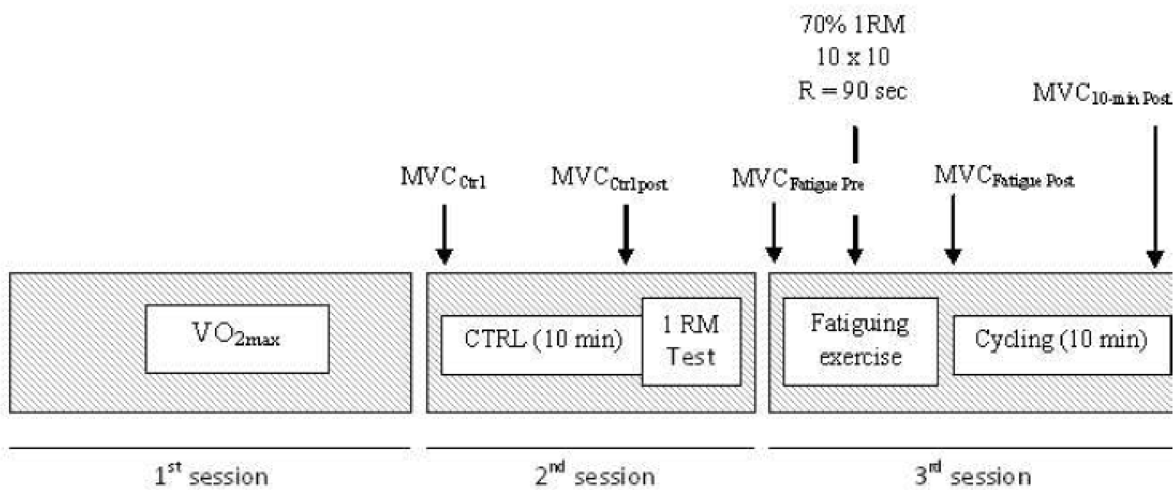
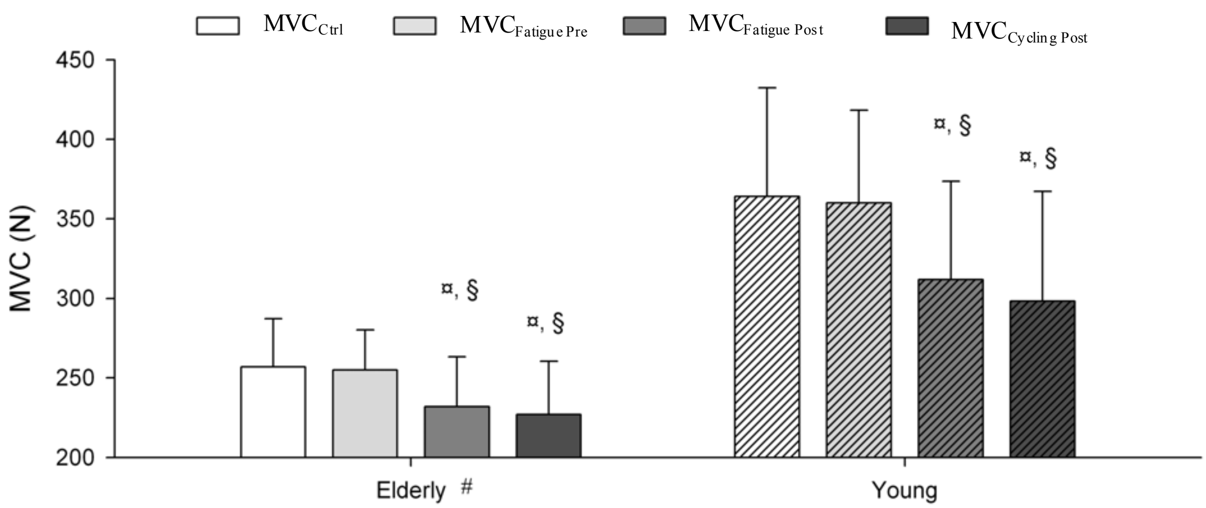


Figure 2 – MVC of the knee extensors measured immediately before (MVC_{Ctrl}) the control cycling test, before ($MVC_{Fatigue\ Pre}$) and after the fatiguing exercise ($MVC_{Fatigue\ Post}$) and after the cycling exercise ($MVC_{Cycling\ Post}$). Values expressed are means ± SE.



¤, significantly different from MVC_{Ctrl} ($p<0.05$)

§, significantly different from $MVC_{Fatigue\ pre}$ ($p<0.05$)

#, significantly different from Young subjects ($p<0.05$)