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Muscle strength and metabolism in master athletes

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27 ABSTRACT

28 Knee extensor muscle strength and metabolism were examined in endurance trained

29 young versus master athletes (10 elderly: 63.1 ± 2.3 yr and 10 young : 28.7 ± 3.2 yr). Before and

30 immediately after a resistance strength training (RST) session, subjects performed maximal

31 isometric voluntary contraction (MVC) and a 10-min cycling test at a moderate intensity. During

32 MVC, evoked contractions of the knee extensor muscles were performed to assess

33 neuromuscular properties. Metabolism was assessed using oxygen uptake kinetics model.

34 Before the RST session, master athletes show lower knee extensors MVC than young subjects

35 without any difference in oxygen uptake kinetics. After the RST session, a similar effect of

36 fatigue was observed on muscular properties and oxygen uptake kinetics whatever the group.

37 Our results suggest the ability of master athletes to perform exercise at a given intensity is

38 maintained despite a significant loss in strength with ageing.

39

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

41 INTRODUCTION

42 In the recent years there has been an increased interest in issues related to the enhancement of the
43 performance of master athletes [12, 26, 37, 39]. Many of the changes in physiological functional
44 capacity related to ageing have been found to be the result of long standing sedentary lifestyle
45 [26]. Studies on master athletes' performance have shown that master athletes are able to
46 maintain high performance as the age related structural adaptations are maintained in masters
47 athletes [26, 36, 37, 39]. The majority of studies working on the effect of age on the muscular
48 function have shown an impairment of the maximal force-generating capacities in elderly
49 compared to young adults and several factors have been identified [5, 20, 27]. For non endurance
50 trained adults, this reduction is generally attributed to a loss of muscle fibres, change in the
51 proportions of muscle fibre types [25, 33], and a reduction in muscle volume and cross-sectional
52 area [15]. Based on results of Coggan et al. [10] confirmed by Tarpenning et al. [38] decreases of
53 strength capacities for masters athletes could be explained by other factors. Indeed, these authors
54 have shown that fibre area and fibre distribution are maintained with aging for master runners.
55 They suggested that the decline in muscle performance may also be the result of neural factors,
56 such as muscle recruitment and/or specific tension. Within this framework, recent studies have
57 highlighted the interest to study age related fatigability during exercise to explain mechanisms
58 underlying the force decline with ageing, but to date contradictory results have been reported
59 mainly related to task dependency of fatigue [2, 14, 19] . Therefore, during the last decade, a
60 great attention has been attributed on the need to identify factors affecting muscle performance
61 decrease and strategies to increase muscle performance in older population [4, 11, 37]. Within
62 this framework (repetition avec ligne 35), it has been demonstrated that resistance training has a

63 significant effect on muscle mass and force whereas endurance training increases oxygen
64 transport and consumption capacities in elderly subjects but little is known on the effect of
65 regular endurance training on muscle performance [11, 38].

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

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

85 MATERIALS AND METHODS

86 *SUBJECTS AND OVERALL DESIGN.* – The investigation was conducted on 10 masters (Age, $62.5 \pm$
87 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
88 young men (Age, 26.2 ± 2.4 yr , height, 1.82 ± 0.05 m; body mass, 74.4 ± 5.2 kg, free fat mass,
89 $15.3 \pm 1.2\%$). All subjects had to be free from present or past neuromuscular conditions that
90 could affect motor function. Subjects were fully informed about the protocol, and informed
91 consent was obtained prior to all testing. This study was approved by a local research ethics
92 committee. The individuals selected were regularly trained subjects engaged in cycling and
93 running long distance competitions (minimum training time per week: 6hr cycling and 1hr
94 running). In both groups, all subjects were selected to have a similar training volume to avoid a
95 possible training volume effect on the comparison between groups. Each subject completed three
96 laboratory-based testing sessions separated by at least a 48 hour rest period (figure 1).

97 *DETERMINATION OF VO_{2MAX}* – On their first visit to the laboratory the subjects underwent an
98 incremental cycling test at a self-selected cadence on an electromagnetically braked ergocycle
99 (Excalibur sport, Lode, Gröningen, The Nederland). The test began with a warm-up lasting 6 min
100 of 100 W for young and 70 W for masters, after which the power output was increased by 30 W
101 each minute until the subjects were exhausted. The criteria used for the determination of VO_{2max}
102 were a plateau in VO_2 despite an increase in workrate and a respiratory exchange ratio (RER)
103 above 1.1. V_E (minute ventilation) and VO_2 were recorded using the Cosmed K4b² telemetric
104 system (Rome, Italy). Ventilatory thresholds (VT_1 and VT_2) were assessed from the graph of
105 VE/VO_2 relative to VO_2 [34, 40]

106 *CONTROL EXERCISE AND 1RM KNEE EXTENSION EVALUATION* – On their second visit to the
107 laboratory the subjects underwent a 10 min control cycling test (CTRL) at a self-selected
108 cadence on the same ergocycle at a load corresponding to: $P_{\text{exercise}} = [\text{Power output corresponding}$
109 $\text{to } VT_1 (P_{VT_1}) + \text{Power output corresponding to the } VT_2 (P_{VT_2})] / 2$. Immediately before
110 (MVC_{Ctrl}) and after ($MVC_{\text{Ctrl Post}}$) the control cycling test, subjects were placed in a seated
111 position and were securely strapped into the test chair to perform maximal voluntary isometric
112 (MVC) knee extension of their dominant leg using an isometric ergometer (Type: Schnell
113 Trainingsgeräte GmbH, Peutenhausen, Germany). Subjects performed three MVC of short
114 duration (2-3 sec) of the knee flexor and extensor muscles. A 60 sec period of rest was imposed
115 between each contraction. The best performance of to the three trials was selected as the
116 maximal isometric voluntary contraction (MVC, in Newton).

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

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

128 90-s. The exercise consisted of a 3 sec concentric contraction followed by a 3 sec eccentric
129 contraction. After resistance strength training session, all subjects performed 10 min of cycling
130 on the electromagnetically braked ergocycle at intensity equal to that of the control test.

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

134 *OXYGEN UPTAKE KINETICS.*

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

138

$$139 \quad Y(t) = Y(b) + A_1 * [1 - e^{-(t-TD_1/\tau_1)}] + A_2 * [1 - e^{-(t-TD_2/\tau_2)}]$$

140

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

145 *EVOKED CONTRACTIONS*

146 The contractile properties (muscular twitch) of the quadriceps muscle were studied using
147 electrically evoked contractions. Electrical stimulation was applied to the femoral nerve of the
148 dominant leg according to the methodology previously described by Place et al [10]. The

149 following parameters were obtained before the control exercise and after the resistance strength
150 training session: (a) peak twitch (Pt), i.e. the highest value of twitch tension production; (b)
151 contraction time (Ct), i.e. the time from the origin of the mechanical response to Pt; (c) half-
152 relaxation time (HRt), i.e. the time to obtain half of the decline in twitch maximal force.

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

167

168 *STATISTICAL ANALYSIS.* – All data were expressed as mean \pm standard deviation (SD). A two-way
169 analysis of variance (group x session) for repeated measures was performed to analyze the effect
170 of groups and the strength training session using MVC, contractile properties, cadence and,

171 oxygen uptake kinetics parameters as dependent variables. Tukey post-hoc test was used to
172 determine any differences among the Pre and Post fatiguing exercise and groups.

173 RESULTS

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

176 A significant effect of ageing was observed on MVC with lower MVC values for masters than
177 young athletes ($MVC_{\text{Fatigue pre:}} -30,2\%$ and $MVC_{\text{Fatigue Post:}} -27.4\%$). The difference between
178 young and master was also significant when MVC was expressed per unit free fat mass
179 (respectively for young and elderly $MVC_{\text{fatigue pre:}} 6.9 \pm 1.2$ vs. $5.2 \pm 1.5 N \cdot kg^{-1}$ free fat mass,
180 $p < 0.05$). A significant decrease in MVC was measured after fatiguing exercise ($p < 0.01$) without
181 any difference between groups: -13.4% for elderly adults and -15.9% for young (figure 2).

182 A significant effect of ageing was observed on contractile properties before the heavy-fatiguing
183 exercise with a slower Ct and HRt for masters when compared to young athletes (for young and
184 elderly respectively; Ct: 55 ± 15 vs. 82 ± 21 ms and HRt : 62 ± 11 vs. 82 ± 18 ms, $p < 0.05$). After
185 fatigue a decrease in Pt was observed whatever the group without any changes in CT or HRt ($-$
186 $24.5 \pm 3.8\%$ and $-33 \pm 5.1\%$ respectively for young and master athletes). No effects of group or
187 fatigue were observed on M-wave amplitude or duration (Table 1).

188 *CADENCE* – No effect of ageing was observed on the freely chosen cadence (FCC) during cycling
189 exercises before or after the strength training session exercise. After the strength training session
190 a significant increase in cadence was observed for both groups (respectively for young and

191 master athletes: pre vs. post fatigue: 79.8 ± 10.5 rpm vs. 88.4 ± 8.5 rpm and 80.2 ± 11.2 rpm vs.
192 89.5 ± 12.5 rpm) .

193 *OXYGEN UPTAKE KINETICS*- Maximal oxygen uptake values were statistically higher in young
194 when compared with masters whatever the mode of expression (*i.e.* per unit body mass vs. per
195 unit fat free mass). When expressed per unit body mass, these values were respectively for
196 young and master athletes: 67 ± 4 ml.min⁻¹.kg⁻¹ and 56 ± 1 ml.min⁻¹.kg⁻¹. For the master group
197 these values were significantly higher than those previously reported in the literature in healthy
198 but untrained subjects [22]. No effect of ageing was observed on oxygen uptake kinetics
199 parameters during the control exercise. After fatigue a significant increase in oxygen slow
200 component and a decrease in time constant of the primary phase (τ_1) were observed in both
201 groups. (Table 2)

202

203 DISCUSSION

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

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

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

226 In this study we have observed a similar reduction in the maximal strength capacity for master
227 and young athletes after the strength training session, with a decrease in maximal strength of -
228 15.9 % for young and - 13.4 % for older. In the literature the analysis of the effect of fatigue on
229 muscular properties has led to contradictory results. [27, 2]. For example during sustained
230 submaximal contractions, in healthy, but untrained subjects, Hunter et al [17] have compared
231 time to task failure for a sustained isometric contraction performed at a submaximal intensity
232 with elbow flexor muscles by young and old men who were matched for strength. They have
233 reported that time to task failure was longer for the old men compared with the strength-matched

234 young men. On the opposite Baudry et al [2] have showed that the fatigability of the ankle
235 dorsiflexor muscles during repeated eccentric or concentric contractions was greater in untrained
236 elderly subjects than in young subjects. During repeated maximal contractions Petrella et al [10]
237 have reported that older adults are less capable of sustaining maximum concentric velocity
238 during repetitive contractions, indicating the role of contraction velocity in this impairment. In
239 our study we did not find any effect of ageing on contraction time or MVC reduction after
240 fatigue. These results suggest that fatigue is similar following exercise for both groups and
241 indicates that in regularly endurance-trained subjects the effect of ageing on force decrease is not
242 potentiated by fatigue.

243 *OXYGEN UPTAKE KINETICS* – One interesting result of this study is that in non-fatigued condition
244 no significant differences in oxygen uptake kinetics temporal parameters was observed between
245 our two groups. This observation seems to demonstrate that regular training could
246 counterbalance the well described slowing of oxygen uptake kinetics with ageing [3]. Pulmonary
247 oxygen uptake kinetics reflects the kinetics of adjustment of oxidative metabolism at the skeletal
248 level; therefore a decrease in this rate of adjustment would lead to a decrease in exercise capacity
249 and fatigue appearance. Relatively few studies have investigated the effect of training on oxygen
250 uptake kinetics in old subjects. A recent comparative study in master athletes has indicated that
251 oxygen uptake kinetics are faster in long distance runners than in middle distance or sprint
252 runners [4] suggesting an increase in oxidative capacity with endurance training. Moreover, in
253 middle age subjects (51 \pm 3 years) Fukoka et al., [13] have observed that oxygen uptake kinetics
254 are sensitive to a short endurance training program whereas effects on peak physiological
255 variables such as oxygen peak or hear rate peak appears later in the training program. Therefore

256 the lack of any difference in primary time constant (τ_1) values between young and master
257 athletes in our study is in agreement with these previous results and give an indirect evidence
258 that factors controlling oxygen uptake kinetics could be preserved by regular endurance training.
259 The second interesting result concerning oxygen uptake kinetics is that after fatigue the
260 amplitude of slow component was increased in both groups. The VO_2 slow component indicates
261 that the efficiency with which the body uses oxygen to produce energy is progressively lost
262 while exercise continues at exactly the same speed and thus the VO_2 slow component has been
263 described to be an important determinant of exercise tolerance [8]. To date only three studies has
264 compared oxygen slow component between young and old adults [3, 9, 35]. They have reported
265 an attenuation of the slow component amplitude in older compared to young untrained subjects.
266 One difficulty when interpreting these results between old and young subjects is that the smaller
267 slow component amplitude may be due to lower power in the older group. In our study we have
268 calculated the power output used for exercise relatively to each individual's ventilatory
269 thresholds. These values are similar in both groups and represents respectively for young and
270 elderly subjects: 81.4 ± 1.6 and 82.5 ± 1.1 % VO_2 peak. In non-fatigued or fatigued condition,
271 our results differ from previous studies since no differences in amplitude or time constant of the
272 slow component was observed between groups. Jones and Poole [18] have indicated that 86% of
273 the VO_2 slow component is attributed to the exercising limbs and that the major contributor is
274 likely within the exercising muscle itself. In our study we found a similar alteration in muscular
275 performance after the strength training session in both groups. Thus the increase in VO_2 slow
276 component could be mainly attributed to the muscular fatigue induced by exercise with an
277 additional recruitment of muscle fibres to maintain the same power output during cycling. Since

278 the trained status of our subjects does not seem to protect the skeletal muscles from the decrease
279 in strength classically described with ageing, one surprising result of this study is that the slow
280 component increase after fatigue was not affected by ageing. This observation suggests a positive
281 effect of regular endurance training on exercise tolerance in master athletes. Further longitudinal
282 studies investigating muscular function in master athletes are necessary to explain this beneficial
283 effect.

284

285 CONCLUSION

286 Despite difference in maximal strength level and contractile properties between young
287 and master athletes, a similar effect of fatigue following the resistance strength training session
288 was observed in both groups. Furthermore no significant difference in oxygen uptake kinetics
289 was observed during cycling exercise between groups in control or fatigue condition. The present
290 study gives indirect evidence that regular endurance training could contribute to improve
291 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.

Groups	Period	Twitch			M-Wave	
		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	τ_1 (s)	A1 (ml.min ⁻¹)	τ_2 (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, τ_1 and τ_2 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

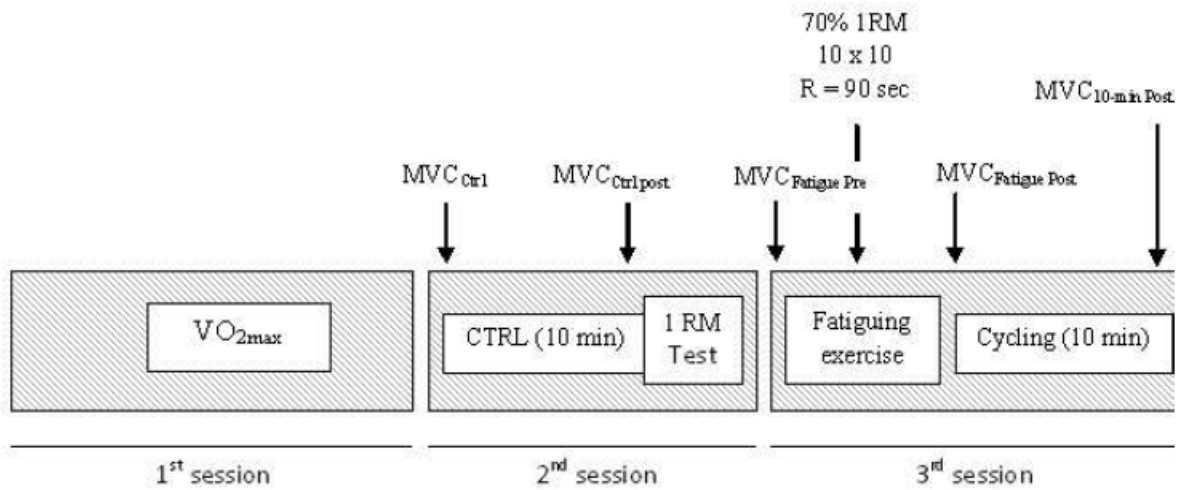
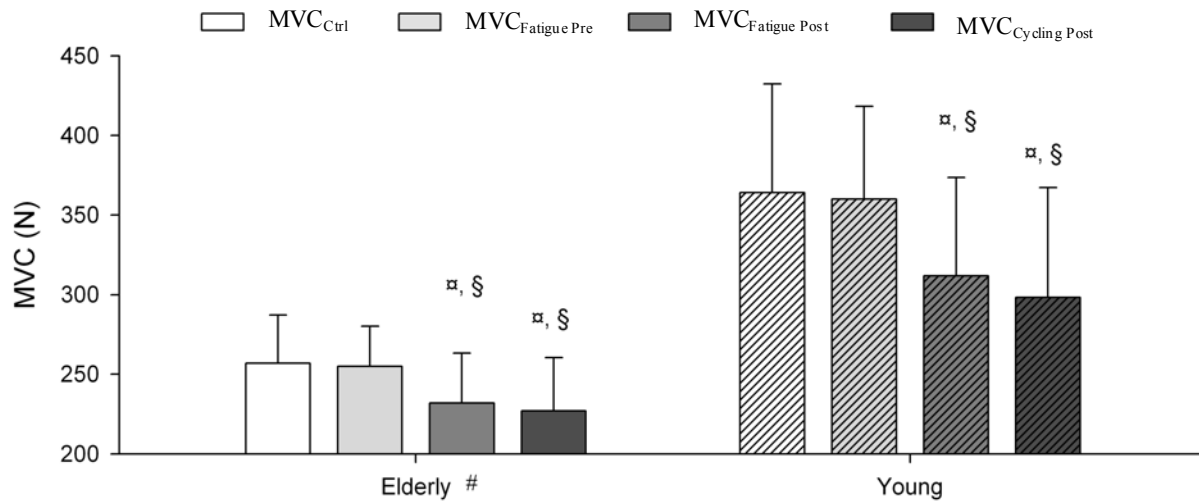


Figure 2 – MVC of the knee extensors measured immediately before (MVC_{Ctrl}) the control cycling test, before ($MVC_{Fatigue\ Pre}$) and after the fatiguing exercise ($MVC_{Fatigue\ Post}$) and after the cycling exercise ($MVC_{Cycling\ Post}$). Values expressed are means \pm SE.



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

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

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