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1 **Rate of force development and rapid muscle activation characteristics of knee extensors**
2 **in very old men.**

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17

18 **Abbreviations**

19

KE	knee extensors
F_{\max}	maximal force
RFD	rate of force development
RFD_{\max}	maximal rate of force development
$tRFD_{\max}$	time to maximal rate of force development
RMS	Root Mean Square
RER	rate of EMG rise
MVC	maximal voluntary contraction
VL	vastus lateralis
CV	coefficient of variation

20

21 **Highlights**

- 22 • Rapid force development and activation capacity are reduced in the eighth decade of
23 age.
- 24 • Rate of force development at early (0-50 ms) but not late (100-200 ms) time intervals
25 were lower in very old adults when normalized to the maximal force.
- 26 • Rate of force development capacity decline of knee extensors is mainly affected by
27 age on the early phase of the contraction (first 50 ms from the force onset).

28 **Abstract**

29 The age-related decrease in neuromuscular performance is usually accentuated in very old
30 age (>80 yr) as evidenced by a marked reduction in maximal force production. However,
31 little is known on the ability to rapidly produce force, which limits daily activities and
32 increase the risk of falling. We aimed to assess rapid force production characteristics and rate
33 of muscle activation of the knee extensors in 15 very old (82±1 yr) vs young (24±4 yr) men.
34 Maximal force (F_{\max}) and maximal rate of force development (RFD_{\max}) were determined
35 during separated specific isometric contractions. EMG from the *vastus lateralis* was analyzed
36 to assess the rate of EMG rise (RER). Finally, RFD and RER were examined at time intervals
37 of 0-50, 50-100, 100-200, 0-200 ms and 0-30, 0-50, 0-75 ms, respectively. We reported lower
38 F_{\max} (414±91 N vs. 661±139 N) and absolute RFD_{\max} (8720±2056 N*s⁻¹ vs. 5700±2474 N*s⁻¹)
39 in the very old men compared to young men ($P<0.01$). When normalized to F_{\max} , RFD_{\max}
40 was similar between groups. Normalized RFD at 0-50 and 0-200 ms were lower (-34% and -
41 46%, $P=0.04$) for the very old men, while no difference was observed at 50-100 ms and 100-
42 200 ms. RER values were higher (~346%, $P<0.01$) for the young men at every time interval.
43 These data suggest that the decline in RFD_{\max} is associated to the decrease in F_{\max} .

44 Impairments in RFD were accentuated in the first phase of the contraction, which has been
45 associated in the literature to impairments in neural factors associated with aging.

46

47 Keywords: aging, rate of force development, rate of EMG rise, neuromuscular performance,
48 knee extensors.

49

50 **1. Introduction**

51 The ability to quickly produce a high amount of force is strongly related to the completion of
52 daily activities and can be further associated with the risk of falling in older adults [1,2,3]. A
53 useful tool to assess the capacity to rapidly increase force is the rate of force development
54 (RFD), considered to be more sensitive than maximal isometric force (F_{\max}) to detect changes
55 in neuromuscular function in clinical and old populations [4,5]. Another advantage of RFD is
56 the possibility to differentiate various phases of the force-time curve to better detect
57 performance changes after a training protocol or in clinical *vs* healthy populations [4,6,7].
58 This analysis can be further implemented by studying the rise in the EMG signal. The rate of
59 EMG rise (RER) has been used to evaluate the rate of muscle activation concurrent to the rise
60 in force in order to account for the neural factors that contribute to RFD [8,9,10].

61 Healthy older adults present lower peak RFD than young adults for various upper and lower
62 limb muscle groups, including the knee extensors [11,12], plantar flexors [10], dorsiflexors
63 [2] and elbow extensors [13]. Conflicting results were reported when RFD was normalized to
64 F_{\max} : while some studies showed greater values in young *vs* older adults [2,10,12,14], others
65 did not [1,15]. The discrepancy in the results could be due to different time intervals
66 examined and different techniques used to normalize RFD by F_{\max} (e.g. some author
67 calculated RFD on the force-time curve, while others used %MVC on the x-axis and
68 measured the RFD value at the point when the force reached 10%, 30% or 50% of the MVC
69 [10]). However, it remains unclear whether the age-related decrease in RFD capacity is only
70 due to the decrease in F_{\max} . For instance, RFD may be influenced more than F_{\max} by changes
71 at the motor units level (i.e. loss of fast-type motor units [16]), or neural impairments (i.e.
72 motor unit discharge rate and doublets [2]).

73 Regarding the methodology, it has to be noted that a large part of the available literature
74 measured RFD during maximal isometric voluntary contractions (MVC), asking the

75 participants to exert isometric contractions as strong and as fast as possible (e.g.[10,11,12]).
76 Instead, recent recommendations suggest to perform specific impulsive isometric contractions
77 as fast as possible to investigate RFD separately from F_{\max} [4]. The rigor in the instructions is
78 essential, as Sahaly et al. [17] showed a significant improvement in peak RFD when
79 participants were instructed to push “fast” rather than “hard and fast”. Consequently, RFD
80 analyzed during MVC could be suboptimal and may not represent the maximal capacity to
81 rapidly increase force. Furthermore, considering that older adults exhibit greater variability in
82 force measurements compared to young adults [18], measuring RFD during an MVC may
83 lead to inconsistent results and a misinterpretation of the age-related changes in RFD.

84 In this scenario, also the age group of participants is determinant: several cross-sectional and
85 longitudinal studies focusing on the advanced stages of human life documented a sudden
86 acceleration in the decline of neuromuscular function starting from the ninth decade [19,20].
87 However, RFD has been mainly studied in individuals aged between 60 and 80 years and
88 only one study focused on the RFD performance in octogenarians [13]. In their study,
89 Bellumori, Jaric, & Knight [13] analyzed the absolute peak RFD from MVC of the elbow
90 extensors and index finger abductors in very old adults and observed a ~50% reduction in
91 RFD compared to young adults. Considering that the age-related impairments in
92 neuromuscular performance are typically greater in the lower limb compared to upper limb
93 muscles [19,21] with functional repercussions on balance and autonomy [22], investigating
94 the capacity to rapidly increase force of the lower limb muscles is particularly relevant in
95 very old adults. Identifying the mechanisms of the possible impairment in RFD may help to
96 design specific interventions to preserve the neuromuscular function in very old age.

97 In the present study, we aimed to investigate the age-related changes in RFD
98 characteristics and RER of knee extensors (KE) between healthy young (<30 years) and
99 active very old men (>80 years). We hypothesized that 1) both absolute and relative (to F_{\max})

100 RFD characteristics of the KE would be considerably reduced in the octogenarians compared
101 to the young adults during specific impulsive contractions and 2) RER of the *vastus lateralis*
102 would be lower in very old adults.

103 **2. Methods**

104 *2.1. Participants*

105 Twelve recreationally active males of 24 ± 4 years (range 20 - 33 yr, 182 ± 6 cm, 76 ± 8 kg) and
106 fifteen active very old men of 82 ± 1 years (range 80 - 83 yr, 168 ± 6 cm, 71 ± 9 kg) volunteered
107 to participate in the experiment and gave their written consent. Very old participants were
108 selected from the PROgnostic indicator OF cardiovascular and cerebrovascular events
109 (PROOF) cohort, which is a prospective longitudinal cohort of old adults started in 2001 [23].
110 Individual physical activity of the participants from this cohort is regularly assessed using a
111 wrist wearable accelerometer (wGT3X-BT, ActiGraph, Pensacola, USA) and analyzed using
112 ActiLife software (v6.13.4, ActiGraph, Pensacola, USA). Considering those data, all the very
113 old men were considered as physically active (8840 ± 1972 steps.day⁻¹, [24]). All participants
114 were free from musculoskeletal or neurological disorders. Before the experimental session,
115 participants were asked to avoid strenuous exercises for at least 24 hours. All the
116 experimental procedures were approved by the Comité de Protection des Personnes Sud-Est 1
117 (France), and the Agence Nationale Sanitaire et du Médicament (ANSM-France) and was
118 performed in accordance with the Declaration of Helsinki (ClinicalTrials.gov, Identifier:
119 NCT02675192).

120 *2.2. Mechanical recording and electromyography*

121 Participants were seated upright on a custom-built chair with hip angle set at 120° (180°
122 corresponds to full extension) and knee angles set at 90° of flexion (Figure 1A). Knee
123 extensors force of the right leg was assessed using a calibrated force transducer (Omega
124 Engineering Inc., Stamford, CT, USA). Extraneous movements of the upper body were

125 minimized by three belts across the thorax and waist. The force transducer was firmly
126 attached above the malleoli. Force was sampled at 2 kHz and recorded without analogical or
127 digital filter using a Power-Lab data acquisition system (16/30-ML880/P, ADInstruments,
128 Bella Vista, Australia). Passive resting force was subtracted from the signal so that the
129 baseline was set at 0 N. Electromyographic (EMG) activity was recorded from the *vastus*
130 *lateralis* (VL) muscle of the right leg using pairs of self-adhesive Ag/AgCl surface electrodes
131 (recording diameter = 10 mm, Kendall MediTrace foam electrode, MA) placed in bipolar
132 configuration over the muscle belly with an interelectrode (center to center) distance of 30
133 mm. Electrodes were placed following the SENIAM project recommendations. A reference
134 electrode was placed on the right patella. Prior to electrode placement, the skin was shaved,
135 abraded and cleaned with alcohol swab to lower the impedance (<5 k Ω , 87v, Fluke Corp.,
136 Everett, WA, USA). EMG and force signals were digitized simultaneously at the same
137 sampling rate (2 kHz) by PowerLab System (16/30- ML880/P, AD Instruments, Bella Vista,
138 Australia). Force and EMG data were analyzed offline using Labchart 8 software
139 (ADInstruments). EMG signals were amplified (gain = 500) using an octal bio-amplifier
140 (ML138, AD Instruments) with a bandwidth frequency range of 10-500 Hz obtained through
141 a band-pass filter. Prior to analysis, data were rectified and smoothed using a moving root-
142 mean-square (RMS) with a time constant interval of 50 ms [8].

143 *2.3. Experimental protocol*

144 All the participants were clearly informed on the modality of the test, and an experimenter
145 provided practical demonstration if required. Participants performed a standardized warm-up
146 consisting in 10 isometric contractions of the knee extensors at increasing intensities until
147 reaching 90% of their perceived F_{max} . Warm-up was followed by familiarization with the
148 experimental procedures: participants were instructed to extend their knee (in isometric
149 condition) “as fast as possible” in order to assess the RFD variables [4]. Familiarization

150 consisted in 5 to 10 non-successive impulsive contractions, allowing participant to feel
151 comfortable with the procedures. Successively, 5-min of rest were allowed before asking
152 participants to perform two 5-s MVC separated by at least 60 s of rest. If the difference
153 between the two MVCs was greater than 5%, participants performed a third MVC. In order to
154 perform MVC, participants were asked to contract “as hard as possible”, strong verbal
155 encouragements and visual feedback were provided. After a 3-min rest, participants
156 performed a series of eight isometric contractions (0.5-1.5 s; Figure 1B) separated by 30 s of
157 rest. Strong verbal encouragement was provided. In case of countermovement, i.e. quick
158 flexion prior to the knee extension, determined from a force drop of 2 N below the baseline,
159 or if the force attained was less than 70% of the F_{max} [7,25], the trial was repeated again in
160 order to obtain eight reliable contractions.

161 *2.4.Data analysis*

162 All data were analyzed offline using Labchart 8 Software (ADInstruments). The F_{max} and
163 associated RMS-EMG signal (EMG_{max}) were defined as the average of the highest 0.5-s
164 window among the best MVC. Repeatability of MVC was tested using a bivariate correlation.
165 The maximal rate of force development (RFD_{max}) was determined as the maximal value of
166 the force-time derivative curve for each RFD contraction. Absolute RFD_{max} was used to
167 identify the best five impulsive contractions retained and then averaged for further analysis,
168 while the others were discarded (Figure 1B). To assess the influence of within-subject
169 variability among young and very old adults, the coefficient of variation (CV) was calculated
170 for each participant and compared between groups.

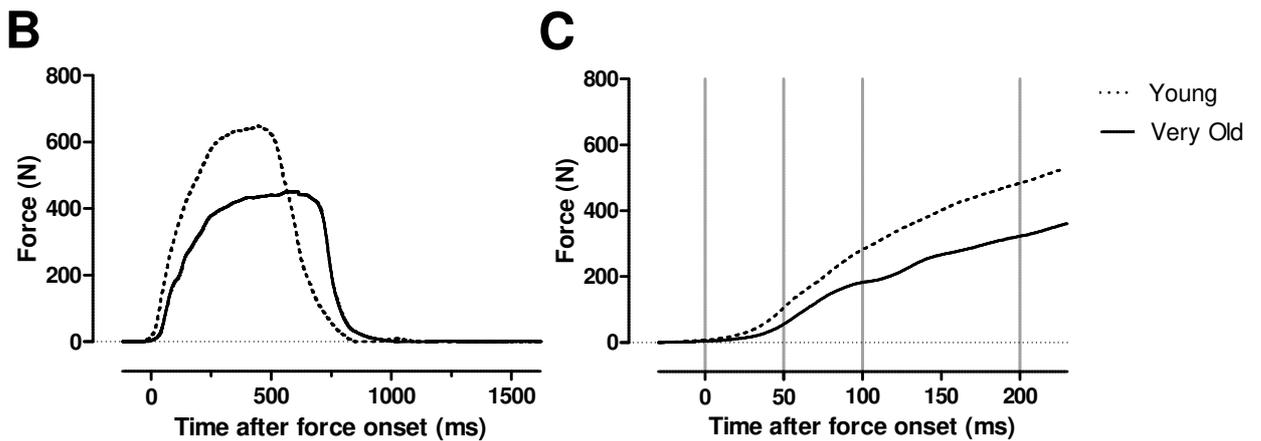
171 Time to RFD_{max} ($tRFD_{max}$) and force level at 25, 50, 100 and 200 ms from the onset of the
172 force (see below) were identified. Then, the mean RFD was calculated at three time intervals
173 of 0-50 ms (RFD_{0-50}), 50-100 ms (RFD_{50-100}), 100-200 ms ($RFD_{100-200}$) and 0-200 ms
174 (RFD_{0-200}) from the linear slope of the force-time curve [8] (Figure 1C). The onset of the

175 force development was defined automatically as the point at which the level of force
176 exceeded three standard deviations over the average resting baseline [25]. This method has
177 been chosen because it provides a valid and reliable method to determine the onset of the
178 contraction when low-noise dynamometers (~1 N) are used [4]. All RFD parameters are
179 presented in both absolute values and expressed as percentage of F_{\max} .

180 The rate of EMG rise (RER) was calculated as the linear slope of the RMS EMG-time curve
181 from two different onsets: the first onset was set 70 ms prior to the force onset as suggested
182 by Aagaard et al. [8], and the second onset was visually identified from the rise in the RMS
183 EMG-time curve. RER was analyzed at time intervals of 0-30 ms (RER30), 0-50 ms (RER50)
184 and 0-75ms (RER75). All EMG signals were normalized to EMG_{\max} [10]. Electromechanical
185 delay was measured from the RMS EMG onset visually identified to the force signal onset.



186



187

188

189 (2-column fitting image)

190 Figure 1. Example of the force recording during the isometric impulsive contraction for two
 191 representative participants. A: Schematic of the experimental setup.

192 B: Rapid force development of the knee extensors between young (dotted line) and very old
 193 men (solid line). C: Rapid force development at different time intervals: 0-50 ms, 50-100 ms,
 194 100-200 ms and 0-200 ms.

195

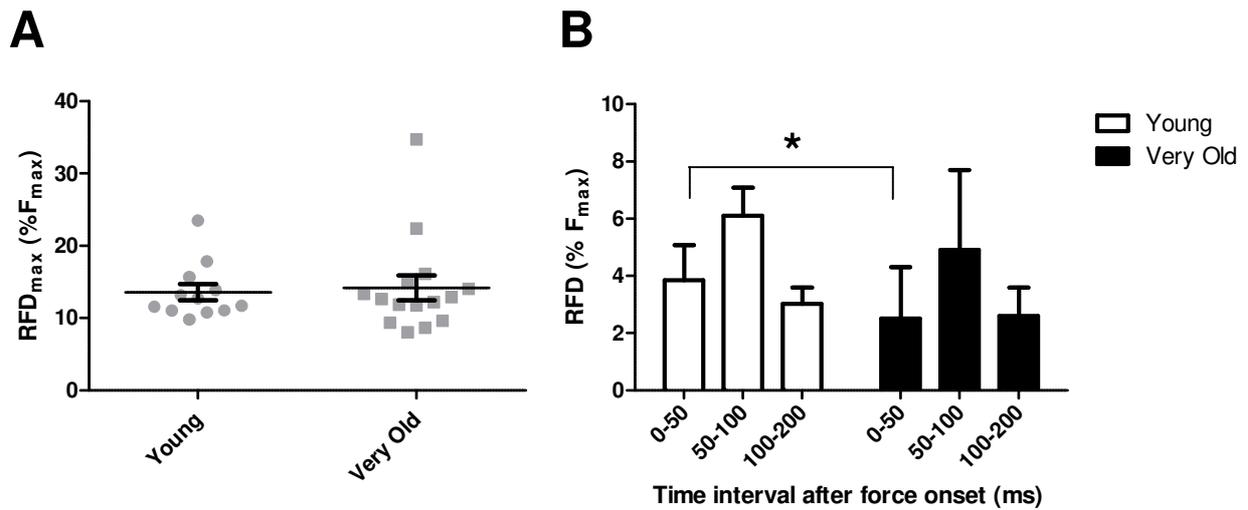
196 2.5. *Statistical analysis*

197 Data are reported as mean \pm SD in the text, the table and the figures. Assumption of
198 normality (Shapiro-Wilk test) was tested for all variables and outliers were determined using
199 a step of 1.5 x Interquartile range from the Turkey's Hinges. Intraclass correlation coefficient
200 (ICC, Two-way mixed model), standard error of the measurement (SEM), average CV and
201 repeated-measure analysis of variance (ANOVA) were used to assess reliability of RFD
202 measures [26] on both groups pooled together and separated. Independent samples T-tests
203 were used to compare F_{\max} , EMG_{\max} , and CV between groups. Mann-Whitney U Tests were
204 used to compare time to RFD_{\max} , absolute and relative RFD_{\max} . Two-way ANOVAs were
205 performed with age as between-subjects factor and time as within-subjects factor for all the
206 remaining force and EMG-derived variables. Sphericity (Mauchly test) were tested for all
207 dependent variables. If the assumption of sphericity was violated, the correction of
208 Greenhouse-Geisser was applied. When significant main effects were observed, Bonferroni's
209 test was used for post-hoc analysis. Significance was set as $P < .05$ for all tests. Statistical
210 analysis was conducted using IBM SPSS software (Version 23.0, SPSS, Inc, Chicago, IL).

211 **3. Results**

212 Due to technical issues, the EMG signals for two very old men were unusable and thus
213 discarded. Thus, EMG parameters are presented for 13 very old men. Absolute values for
214 F_{\max} , EMG_{\max} , RFD, RFD_{\max} and $tRFD_{\max}$ are presented in Table 1. Reliability of RFD
215 measurement was excellent either when both groups were pooled together (ICC=0.98,
216 CI=0.97-0.99; SEM=893.87 $N \cdot s^{-1}$; CV=11 \pm 6%; ANOVA: $F_{(4,104)}=0.84$, $P=.50$) and when the
217 young (ICC=0.96, CI=0.91-0.98; SEM=998.78 $N \cdot s^{-1}$; CV=12 \pm 6%; ANOVA: $F_{(4,44)}=2.10$,
218 $P=.10$) and very old men (ICC=0.98, CI=0.96-0.99; SEM=810.80 $N \cdot s^{-1}$; CV=9 \pm 6%;
219 ANOVA: $F_{(4,56)}=0.27$, $P=.90$) were analyzed separately. F_{\max} was consistent between
220 measures ($r = 0.98$, $P < 0.001$) and significantly lower (37%) for the very old men compared to

221 the young men ($P < 0.001$). The associated EMG_{max} was also lower for the older adults (27%,
 222 $P = 0.42$). Absolute RFD_{max} was greater in the young men (35%, $P < 0.001$), however the age-
 223 related difference was not observed when normalized to the maximal force (Figure 2A,
 224 $P = 0.78$). Normalized RFD was not influenced by the between-subject variability, as CV was
 225 similar between young ($9 \pm 6\%$) and very old men ($12 \pm 6\%$, $P = 0.21$).



226
 227 (2-column fitting image)

228 Figure 2. Normalized RFD performance of young vs very old adults. A: Differences in the
 229 RFD_{max} normalized to the F_{max} . B: The ratio of the RFD and F_{max} at three time intervals of 0-
 230 50 ms, 50-100 ms and 100-200 ms after the force onset between young men (white) and very
 231 old men (black). $* = P < 0.05$.

232 It can be noticed on Figure 2A that two outliers from the very old group may have influenced
 233 the mean. Nevertheless, the statistical analysis was also performed without these two
 234 participants and the results remained unchanged. Finally, no age-related differences were
 235 observed for the $tRFD_{max}$ ($P = 0.25$).

236 Of those two outliers, one very old man showed higher F_{max} (554 N) and RFD ($12409 \text{ N} \cdot \text{s}^{-1}$)
 237 than some young men.

238 Table 1. Absolute force, RFD and EMG data.

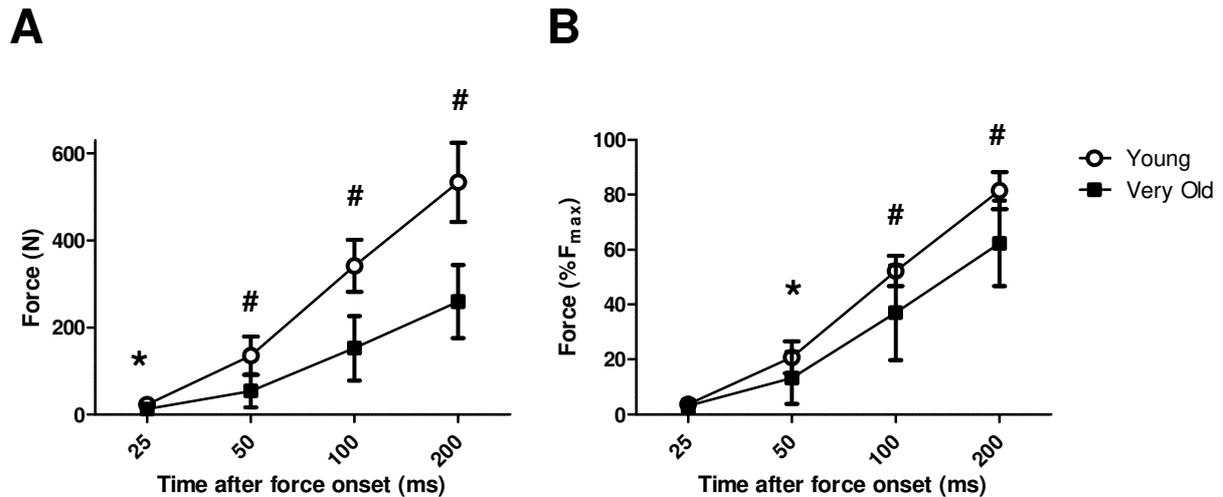
	Young Men	Range (min. – max.)	Very Old Men	Range (min. – max.)
F_{\max} (N)	660.9±139.1	455.0 – 911.0	414.3±90.8 #	268.0 – 554.0
EMG_{\max} (mV)	0.62±0.22	0.24 – 1.09	0.45±0.16 *	0.26 – 0.80
RFD_{\max} (N*s ⁻¹)	8719.7±2055.9	6278.0 – 11625.0	5700.5±2473.9 #	3262.0 – 12409.0 ^a
$tRFD_{\max}$ (s)	70.3±36.1	40.9 – 168.5	85.8±33.1	45.0 – 127.0
RFD 0-50 ms (N*s ⁻¹)	2494.7±877.7	1543.0 – 4684.0 ^a	1034.4±738.4 #	222.0 – 2470.0
RFD 50-100 ms (N*s ⁻¹)	3992.7±929.8	2885.0 – 6033.0	2040.2±1258.7 #	568.0 – 4035.0
RFD 100-200 ms (N*s ⁻¹)	1986.6±513	1283.0 – 3071.0 ^a	1101.6±544.2 #	379.0 – 1925.0
RFD 0-200 ms (N*s ⁻¹)	2725.2±410.8	2097.7 – 3441.85	1470.5±503.3 #	618.38 – 2241.95

239

240 F_{\max} = maximal force; EMG_{\max} : maximal EMG; RFD= rate of force development;
241 RFD_{\max} =maximal rate of force development; $tRFD_{\max}$ = time to the maximal rate of force
242 development. ^a= from an outlier; *= $P<0.05$; # = $P<0.01$.

243

244 From the onset of the contraction, there were significant age-related differences in the
245 absolute force level at every time point and were 23.1±8.5 N vs 12.6±10.5 N (25-ms,
246 $P=0.01$), 135.2±43.8 N vs 53.8±38.4 N (50-ms, $P<0.001$), 340.7±59.6 N vs 152.4±73.5 N
247 (100-ms, $P<0.001$) and 533.3±91.1 N vs 258.9±84.2 N (200-ms, $P<0.001$) for young and
248 very old men, respectively (Figure 3A). When normalized to F_{\max} , the differences between
249 groups were less pronounced. Normalized force values were 3.6±1.3% vs 3.1± 2.3% (25-ms,
250 $P=0.49$), 20.7±5.8% vs 13.3±9.3% (50-ms, $P=0.02$), 52.1±5.5% vs 36.9±17.3% (100-ms,
251 $P=0.007$) and 81.5±6.7% vs 62.2±15.6% (200-ms, $P=0.001$) for young vs very old men,
252 respectively (Figure 3B).



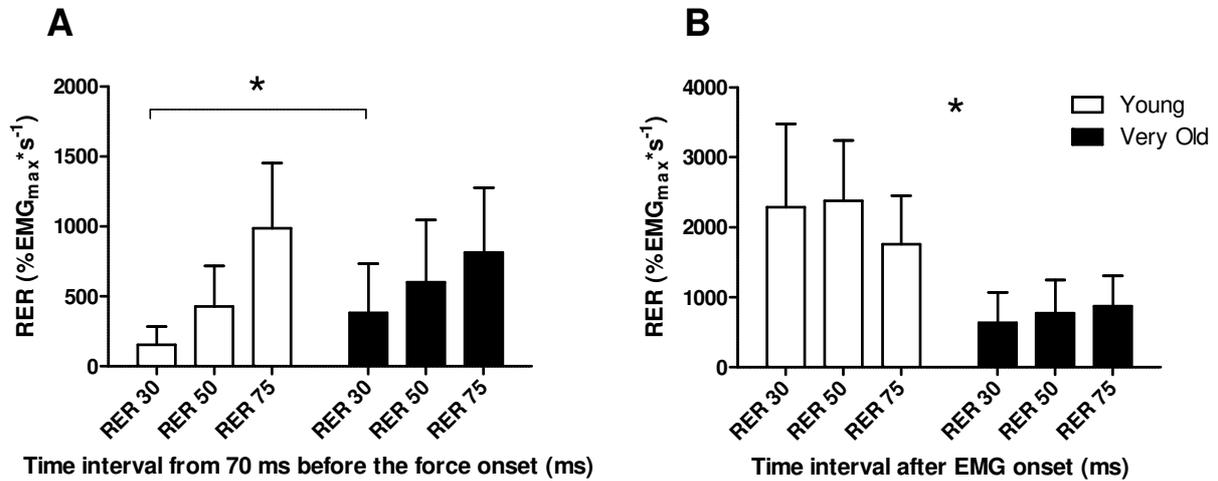
253
254 (2-column fitting image)

255 Figure 3. Differences between young men (empty circles) and very old men (black squares)
256 at four time points after the force onset. A: Difference in absolute force level. B: Difference
257 in force level normalized to the F_{max} . $*$ = $P<0.05$; $\#$ = $P<0.01$.

258
259 Average RFD were greater for the young than the very old men at every time interval (Table
260 1). When normalized to the F_{max} , average RFD were $3.8\pm 1.2\%$ (0-50 ms), $6.1\pm 0.9\%$ (50-100
261 ms) and $3.0\pm 0.5\%$ (100-200 ms) for young men and $2.5\pm 1.7\%$ (0-50 ms), $4.8\pm 2.7\%$ (50-100
262 ms) and $2.5\pm 1.0\%$ (100-200 ms) for very old men (Figure 2B). Significance was found only
263 at the 0-50 ms time interval ($P=0.04$), while no differences were observed at 50-100 ms
264 ($P=0.16$) and 100-200 ms ($P=0.20$). Finally, significant difference was found at the 0-200 ms
265 time interval between young ($4.2\pm 0.7\%$) and very old men ($3.5\pm 0.9\%$; $P=0.04$).

266 RER of the VL, expressed as %EMGmax, exhibited different results depending on the onset
267 considered (Figure 4). Data obtained with the RER onset 70 ms prior to the force onset
268 showed significantly lower RER during the 0-30 ms time interval in the young men ($P=0.04$),
269 while no age-related differences were observed during the 0-50 ms ($P=0.26$) and 0-75 ms
270 time intervals ($P=0.36$; Figure 4A). The opposite trend was observed when RER onset was
271 visually set at the point of RMS EMG rise, RER was greater for the young than the very old

272 men for every time interval (RER30: $P=0.003$; RER50: $P<0.001$; RER75: $P=0.007$; Figure
 273 4B). Electromechanical delay was longer in the very old men (76.8 ± 27.5 ms) than in the
 274 young men (37.4 ± 0.9 ms; $P<0.001$).



275
 276 Figure 4. Comparison between young (white) and very old (black) men in the RER
 277 normalized to the maximal EMG at three time intervals of 0-30 ms, 0-50 ms and 0-75ms. A:
 278 onset was automatically set 70 ms prior to the force onset. B: onset was visually set at the rise
 279 in RMS EMG-time curve. $*=P<0.05$.

280
 281 **4. Discussion**

282 The aim of the present study was to assess the age-related impairments in rapid force
 283 production capacity and rate of muscle activation of the KE. We reported reduced F_{max} and
 284 absolute RFD_{max} in active octogenarians compared to young men. For every time interval of
 285 the force-time curve, absolute force and RFD values were considerably lower in very old
 286 men, as initially hypothesized. Contrary to our hypothesis, no age-related difference in
 287 RFD_{max} was observed when normalized to F_{max} . However, normalized RFD values in the
 288 early phase of the contractions (0-50 ms) were lower in very old compared to young men.
 289 This age-related difference disappeared in the successive phases of the contraction.

290 Regarding RER, when the onset was defined manually on the RMS EMG-time curve, RER
291 was significantly lower for very old men at every time intervals.

292 Although investigating the capacities of the KE is functionally relevant in old and very old
293 age [19,27], the literature regarding RFD performance with aging for this muscle group is
294 limited. Thompson and colleagues [1] observed ~28% lower F_{\max} and absolute RFD_{\max}
295 measured during isometric KE MVC in old (67 yr) compared to young adults (25 yr), while
296 Mau Moeller et al. [12] reported even greater age-related impairments (F_{\max} , ~40%; RFD_{\max} ,
297 ~65%) between young (25 yr) and old (70 yr) men during the same task. In agreement with
298 the previous studies, we reported a ~36% lower absolute F_{\max} and RFD_{\max} in very old men
299 compared to young men. During the rapid isometric contractions, the absolute force level of
300 very old men was significantly lower than the young men at every time point, and this
301 difference persisted when normalized to F_{\max} . These results confirm the marked impairment
302 in the capacity to rapidly increase the level of force with very old age that accompany the
303 decline in maximal force production capacity [20].

304 Interestingly, no age-related differences were observed in RFD_{\max} when normalized to F_{\max} ,
305 which could indicate similar factors are responsible for the decline of those two parameters.
306 Maximal force and rapid force development are both affected by sarcopenia and the
307 consequent muscle remodeling process with aging [28]. Only one very old man was more
308 performant in both F_{\max} and RFD_{\max} than some young men. This is in agreement with
309 previous investigations showing no age-related change in normalized RFD in plantar flexors
310 [15], dorsiflexors [15], leg extensors [1] and leg flexors [1]. However, other studies reported
311 a reduction in the relative RFD_{\max} of plantar flexors [10], dorsiflexors [2] and leg extensors
312 [12,14]. In contrast with the previous investigations, in the present study F_{\max} and RFD were
313 obtained during different contractions and giving specific instructions, according to the most
314 recent recommendations [4,5], obtaining good within-subject reliability of the RFD measures

315 in both groups. Consequently, different muscles involved, data analysis and protocols
316 adopted may partially explain the discrepancies in the literature. The majority of the studies
317 analyzed RFD during MVC, while we used specific impulsive isometric contractions. As we
318 asked our participants to push “as hard as possible” during MVC rather than “hard and fast”,
319 we could not compare RFD during MVC and the impulsive contractions. Other than
320 methodological factors, the high level of physical activity of our participants may influenced
321 age-related differences in RFD. In the present study, the very old participants were healthy
322 community-dwelling volunteers, and classified as “active” according to the number of
323 steps/day measured (threshold defined at 7000 steps/day between active and sedentary very
324 old men [29]). These healthy individuals may not represent the overall population over 80
325 years, but rather those with greater lifespan physical activity behaviors and/or with biological
326 superiority [30]. The natural selection bias of healthy participants over 80 years (alive,
327 autonomous, without motor or neural impairments, etc...) could also explain why the age-
328 related declines in performance observed in previous cross-sectional and longitudinal studies
329 were less important than what expected in the ninth decade from linear extrapolation models
330 [31,32]. Moreover, physical activity has important implications in the age-related changes in
331 RFD. For example, Aagaard et al. [3] showed that chronic exposure to strength training
332 preserves RFD_{max} at a similar level in young and old individuals, and Caserotti et al. [33]
333 reported similar performances after 12-weeks of heavy-resistance training in old (60-65
334 years) and very old women (80-89 years). Further investigations should compare normalized
335 RFD of very old men with different levels of physical activity to clarify the relative
336 contribution of maximal force decline, aging and physical activity level in RFD performance.
337 The normalized 0-200 ms time interval was used to provide a more representative indicator of
338 the age-related RFD changes, and was significantly lower in the very old men. This reflects
339 an overall impairment in the capacity of rapid force generation with aging that has been

340 evidenced at every time point on the force-time curve. To better illustrate RFD differences
341 between groups, different time epochs were analyzed and normalized to F_{max} .

342 The average normalized RFD values were significantly lower only in the early phase of the
343 contraction (0-50 ms), but not in the successive time intervals (50-100 ms and 100-200 ms),
344 contrary to the absolute RFD values and the normalized force values. The non-significant
345 difference in the middle time epochs regarding RFD data could be explained by the higher
346 between-subject variability in very old men. Despite higher variability, the difference at 0-50
347 ms was great enough to reach statistical significance. In other words, the force increment in
348 this short time period (50 ms) was greater for the young men, which determined a difference
349 in the relative RFD between groups. This could suggest that different neural strategies could
350 be adopted during aging to compensate the progressive loss in RFD capacity, still evident in
351 the 0-50 ms time interval. This could be partially supported by our results on time to reach
352 RFD_{max} , which was similar between groups. Similar results were obtained by Thompson et al.
353 [10] and Mau-Moeller et al. [12]. Thompson et al. [10] found a difference between young and
354 old adults in the plantar flexors at time intervals of 0-50 ms and 100-200 ms. However, these
355 authors didn't report the time interval 50-100 ms. Thus, it seems that the early phase of the
356 contraction is determinant for the age-related impairment in absolute RFD capacity of the leg
357 extensors. Previous investigations associated the first phase of the contraction (0-50 ms) to
358 the rate of muscle activation. For instance, a recent study of Gerstner et al. [34] on the plantar
359 flexors found similar rate of torque development capacity between young and old men (~69
360 yr) in the firsts 50 ms of contraction, while it was reduced in the late interval (100-200 ms).

361 These authors suggested that while factors like poorer muscle quality, the inability to sustain
362 a high rate of muscle activation and reduced level of physical activity could influence the late
363 interval of contraction in old men, muscle activation could reflect changes in the early time
364 interval. To provide further insight, we quantified using the rate of EMG rise (RER). We set

365 two different RMS EMG onset for the RER analysis. With the EMG onset fixed 70 ms prior
366 to force onset [8], RER was significantly higher in very old compared to young men only in
367 the early phase of the contraction (0-30ms), while no age-related differences were observed at
368 0-50 ms and 0-75ms. However, the electromechanical delay was significantly different
369 between groups, and only the electromechanical delay of the very old men was close to the
370 fixed value of 70 ms suggested by Aagaard et al. [8]. Thus, setting the onset visually on the
371 RMS EMG-time curve seems to be the best option when two different populations are
372 compared. In the present study, when the RMS EMG onset was set manually, RER was
373 significantly lower for very old men for all the time intervals considered. The longer
374 electromechanical delay in the very old group compared to the young, despite in small part
375 dependent from the electrode placement, indicate a deficit in the transmission and conversion
376 of the voluntary drive to force. The reduced capacity to rapidly activate the muscle suggests
377 that impairments occur also in the voluntary drive, e.g. the generation of doublet discharge,
378 the decrease in discharge frequency and/or the inability to maintain high discharge
379 frequencies, leading to different or less efficient activation pattern with aging [2,35]. To
380 interpret those results, it has been shown that the age-related slowing of muscle contractile
381 kinetics, the progressive reduction in type II muscle fibers [19] and changes in the muscle
382 architecture [34] are muscle dependent and could influence the EMG signal. Limiting our
383 analysis to the VL and recognizing the limitations of surface EMG measurements [36],
384 further evidences are needed to clarify the specific role of neural *vs* contractile mechanisms
385 involved in the loss of RFD across different muscles.

386

387 **5. Conclusions**

388 The present study demonstrated that rapid force development capacity is impaired in active
389 octogenarians. However, the age-related difference is minimized when RFD is normalized by

390 the maximal force of each individual. The results suggest that muscle force and RFD have
391 common mechanisms determining neuromuscular changes associated with healthy aging. The
392 impairments in RFD are accentuated in the early phase of the contraction, which has been
393 associated in the literature with the rate of muscle activation. Further studies are needed to
394 establish whether similar levels of Fmax or RFDmax are related to similar motor function in
395 very old age.

396

397 **Conflicts of interest**

398 No conflicts of interests, financial or otherwise are declared by the authors.

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402

403 **References**

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