



**HAL**  
open science

## Relationships between lower limbs fatigability threshold and postural control in obese adults

Wael Maktouf, Cerise Guilherme, S. Boyas, Bruno Beaune, Sylvain Durand

### ► To cite this version:

Wael Maktouf, Cerise Guilherme, S. Boyas, Bruno Beaune, Sylvain Durand. Relationships between lower limbs fatigability threshold and postural control in obese adults. *Journal of Biomechanics*, 2020, 105, pp.109819. 10.1016/j.jbiomech.2020.109819 . hal-02954055

**HAL Id: hal-02954055**

**<https://hal.science/hal-02954055>**

Submitted on 20 May 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

## **Relationships between lower limbs fatigability threshold and postural control in obese adults.**

Wael MAKTOUF, Cerise GUILHEME C Sébastien BOYAS, Bruno BEAUNE and Sylvain  
DURAND

Le Mans University, Movement - Interactions, Performance, MIP, EA 4334  
Faculty of Sciences and Technologies, Avenue Olivier Messiaen, 72000 Le Mans, France

**Keywords:** overweight; fatigue; strength, balance; ankle muscles

### **Corresponding author:**

- **E-mail address:** waelmaktouf1@gmail.com
- **Address:** Avenue Olivier Messiaen, Laboratory “Movement, Interactions, Performance” (EA 4334), Faculty of Sciences and Technologies, Department of Sport Sciences, 72085 Le Mans, France.

### **E-mail addresses:**

- Waelmaktouf1@gmail.com
- Cerise.Guilherme.Etu@univ-lemans.fr
- Sebastien.boyas@univ-lemans.fr
- Bruno.beaune@univ-lemans.fr
- Sylvain.durand@univ-lemans.fr

### **Address:**

Le Mans University, Movement - Interactions, Performance, MIP, EA 4334  
Faculty of Sciences and Technologies, Avenue Olivier Messiaen, 72000 Le Mans, France

### **Acknowledgements**

We would like to thank the patients of the reeducation center François Gallouedec (Le Mans, France) and the students of Le Mans University for their acceptance to participate in this study.

**Abstract:**

The objective of this study was to investigate the effect of obesity on markers of neuromuscular fatigability of ankle muscles and their potential relationships with postural control capacities.

Two groups: non-obese control group (CG; n=15; age =  $40.1 \pm 13.9$  years; BMI =  $23.9 \pm 2.8$  kg/m<sup>2</sup>) and obese group (OG; n=15; age =  $44.2 \pm 12.4$  years; BMI =  $42.2 \pm 5.2$  kg/m<sup>2</sup>), performed two postural tasks with and without vision in order to collect parameters of center of pressure (CoP) displacements; area (cm<sup>2</sup>), velocity (mm/s), length (cm) and the ratio length/area. Fatigability was estimated during 60 repeated maximal voluntary contractions of plantar (PF) and dorsal flexors (DF). The maximal force, critical force ( $F_{cr}$ ) presenting the asymptote of the force-time evolution and rate of the force decrease ( $\tau$ ) were extracted.

Results reported that CoP parameters were higher in OG compared to CG in all postural tasks ( $p < 0.05$ ).  $F_{cr}$  of PF and DF were 39% and 28% lower respectively in OG compared to CG ( $p < 0.05$ ). Only  $\tau$  of PF was 12% lower in OG ( $p < 0.05$ ).  $F_{cr}$  of PF was negatively correlated with the ratio length/area in OG in all postural tasks ( $r = 0.86$  and  $r = 0.85$ , respectively,  $p < 0.05$ ). We concluded that obesity is associated with a decreased  $F_{cr}$  of ankle muscles expressing the intensity threshold above which fatigue develops drastically. We also revealed that decreased fatigability threshold particularly that of PF, could partly explain postural control alterations in obese adults.

# 1 Relationships between lower limbs fatigability threshold and postural 2 control in obese adults.

## 4 1. Introduction

5 A growing body of evidence suggests that obesity affects negatively the postural  
6 control regulation (Cieślińska-Świder and Błaszczyk, 2019; Corbeil et al., 2001; Handrigan et  
7 al., 2017; Hue et al., 2007; Maktouf et al., 2018; Maktouf et al., 2019). Indeed, obesity  
8 induces changes in body geometry (i.e., waist and hip circumferences) due to an excessive  
9 accumulation of adipose tissue in body segments (e.g., waist and hip circumferences). The  
10 distribution of adipose tissue separates obesity into two groups; the android type (i.e., the fat  
11 is localized in the abdominal area) and the gynoidal obesity type (i.e., the fat is localized on  
12 the thighs and buttocks (WHO, 2008). Recently, Cieślińska-Świder et al. (2017) reported that  
13 androidal obesity type exposed to a greater risk of instability than the gynoidal obesity type.  
14 The androidal obesity is characterized by an excessive body fat at the abdominal level which  
15 induces an anterior position of the center of Mass (CoM), and its relative position to the  
16 center of foot pressure (CoP), from the axis of rotation (i.e., ankle joint assuming an inverted  
17 pendulum model, where the CoM is the controlled variable and the CoP is the controlling  
18 variable; Corbeil et al., 2001). This forward position of the CoM causes an increased  
19 gravitational torque accelerating the body forward (Corbeil et al., 2001; Simoneau and  
20 Teasdale, 2015). Consequently, individuals with androidal obesity have to develop an  
21 appropriate ankle torque with a higher rate of force development and velocity than normal  
22 weighted individuals to counteract the gravitational torque in order to restore similar balance  
23 level (Handrigan et al., 2012; Simoneau and Teasdale, 2015). This suggests that the altered  
24 postural control abilities in adults with androidal obesity could be explained by a lack of  
25 strength from the muscles mobilizing the ankle joint (Hue et al., 2007; Matrangola and  
26 Madigan, 2009). However, Maktouf et al. (2018) reported that obese individuals showed

27 similar relative force capacities for the ankle plantar (PF) and dorsal flexors (DF) muscles  
28 compared to normal weighted individuals, indicating that the primary source of imbalance in  
29 obese individuals is rather associated with an increase in muscle activity of the PF than with a  
30 lack of strength. These authors hypothesized that the increased muscle activity might be  
31 responsive for an early fatigue in muscles, leading to postural alteration in obese individuals.  
32 The aforementioned observations question the effects of the lower extremity muscle fatigue  
33 development on postural control regulation in obese individuals.

34         Several studies focused on fatigue development of the upper extremity muscles in  
35 obese adults, showing that obesity was associated with an early fatigue and a delayed  
36 recovery from isometric endurance exercise (Cavuoto and Nussbaum, 2014; Eksioglu, 2011;  
37 Pajoutan et al., 2017). To our knowledge, only the study of Pajoutan et al. (2016) focused on  
38 the fatigue development of the lower extremity muscles in obese adults. They reported that  
39 increased body mass index altered endurance and central activation during maximal voluntary  
40 isometric contraction (MVC) of the tibialis anterior (TA) after a sustained isometric fatiguing  
41 task (60% of MVC). However, they did not investigate the relationship between the early  
42 fatigue development and altered postural control parameters in obese adults, nor the  
43 fatigability threshold of PF that are considered as the primary muscles responsible for the  
44 forward balance recovery in obese adults (Loram et al., 2004). Moreover, it is well established  
45 that a percentage of MVC did not refer to metabolic exercise intensity domains and thus to  
46 fatigue development (Kent-Braun et al., 1993; Saugen et al., 1997). The critical force ( $F_{cr}$ ),  
47 which corresponds to the maximal exercise that still results in metabolic steady state, is  
48 considered as a potential alternative approach that allows identifying a threshold above which  
49 the fatigability is critically developed in healthy and pathological individuals (Poole et al.,  
50 2016; Veni et al., 2019). Thus,  $F_{cr}$  is the intensity threshold above which fatigue develops

51 when performing isometric contractions of single agonist muscle (Poole et al., 2016).  
52 However, to the best of our knowledge, no study has examined the effect of obesity on  $F_{cr}$  of  
53 muscles mobilizing ankle joint in order to identify the fatigability threshold.

54 Therefore, the main objective of this study was to investigate the effect of obesity on  
55 the markers of neuromuscular fatigability of ankle muscles in order to better understand the  
56 neuromuscular fatigability threshold in obese adults. Second, we aim to examine the  
57 relationships between markers of the neuromuscular fatigability and postural control  
58 parameters to provide indications about the underlying mechanisms of postural control  
59 alterations in individuals with androidal obesity. We hypothesize that obese adults have a  
60 decreased fatigability threshold and an earlier fatigue development compared to normal  
61 weighted adults and that  $F_{cr}$  is negatively correlated with altered postural control parameters  
62 in obese adults.

## 63 2. Methods

### 64 2.1. Participants

65 Thirty men, recruited from our university and from an obesity treatment center, were  
66 divided into two groups (**Table 1**) according to their body mass index (BMI, kg/m<sup>2</sup>): the non-  
67 obese control group (CG; n=15; age = 40.1(13.9) years; BMI = 23.9(2.8) kg/m<sup>2</sup>) and the obese  
68 group (OG; n=15; age = 44.2(12.4) years; BMI = 42.2(5.2) kg/m<sup>2</sup>). Only adults with androidal  
69 obesity type (i.e., obese individuals with the waist to hip ratio greater or equal to 0.85;  
70 Cieślińska-Świder et al., 2017). Participants were excluded from the study if they had a  
71 history of cardiovascular disorders, diabetes, uncorrected vision problems, severe  
72 musculoskeletal deformities, or injuries to their lower extremities that would interfere with  
73 testing. All participants were informed about the purpose and protocol of the study and gave

74 their written consent. The study was conducted according the Declaration of Helsinki 2004  
75 and was approved by the local ethics committee on human research.

## 76 **2.2.Experimental protocol**

### 77 **2.2.1. Anthropometric measurements**

78 Height, waist and hip circumferences were obtained using a measuring tape. Body  
79 mass and percentage of body fat were measured using an impedance-meter (Tanita; SC 240-  
80 Class III; Tanita Europe B. V., Amsterdam, The Netherlands). Fat body mass (FBM) and lean  
81 body mass (LBM) were calculated using the equations from Gartner et al. (2004).

### 82 **2.2.2. Static postural control testing**

83 Postural control during quiet standing was measured using a force platform (Zebris  
84 FDM-S; sampling rate: 100 Hz; Zebris Medical GmbH, Isny, Germany). Participants were  
85 instructed to stand barefoot on the platform with their feet together and their arms hanging  
86 alongside their bodies and to sway as little as possible with eyes opened (EO) and with eyes  
87 closed (EC). In each experimental condition, participants performed three postural trials (30 s  
88 per trial) with rest intervals of 30 s to prevent fatigue or boredom. The six trials were  
89 randomly presented to eliminate any order effects.

90 The raw center-of-pressure (CoP) signal of each trial was filtered by a Butterworth's  
91 low-pass filter ( $n = 4$ ; cut-off frequency = 5Hz) in order to overcome the problems associated  
92 with the clean cut transition (Paillard and Noé, 2015). Then, the signal of CoP displacements  
93 was pre-processed by a three-channel Analogic-to-Digital converter (100/16). Finally, data of  
94 CoP displacements was used to extract three postural parameters: the area of the 95%-  
95 confidence ellipse (area,  $\text{cm}^2$ ), the velocity (velocity,  $\text{mm/s}$ ) and length (length,  $\text{cm}$ ) of the  
96 CoP displacements (Donath et al., 2012; Paillard and Noé, 2015; Schubert and Kirchner,  
97 2014). The average recorded measurements of the three trials for each condition were used in  
98 this study. The ratio between length and area of the CoP (L/A) for each condition was also

99 calculated in order to investigate the energy spend indicated by the length of CoP versus the  
100 accuracy of the postural system indicated by the area (Paillard and Noé, 2015).

### 101 **2.2.3. Muscle evaluations**

102 The force of the ankle plantar flexor (PF) and dorsal flexor (DF) muscles of the  
103 dominant leg were measured using a dynamometer (Sauter FL1K; Type: Force Gauge; Sauter  
104 GmbH, Balingen, Germany). For each muscle group, a 20-min experimental session was  
105 dedicated as follows: (1) Familiarization and maximal voluntary contraction (MVC) testing in  
106 order to determine the warm up intensity, (2) warm up (10 contractions at 25% of the pre-  
107 warm up MVC, five at 50% and two at 70%), (3) two-MVC with one-min rest between, (4)  
108 three-min of recovery, (5) exercise fatigability testing. The recovery between both muscle-  
109 specific experimental sessions lasted 10 minutes.

110 For PF testing, participants were instructed to keep their back, buttock and thigh in  
111 contact with a height-adjustable chair, to keep their leg stretched horizontally and to push  
112 with the tips of the foot on the dynamometer. A strap was placed around the dominant leg to  
113 secure it firmly to the foot plane (Maktouf et al., 2018). For DF, participants were asked to  
114 stand up, to keep their ankle at 90° and push up with the foot on the dynamometer (Nagai et  
115 al., 2013).

#### 116 **2.2.3.1. Maximal voluntary contraction testing**

117 Prior to exercise fatigability measurement, two maximal voluntary contractions trials  
118 were performed with a two-min rest in-between. Only the best trial was considered (absolute  
119 force, N) and then normalized to LBM (relative force, N/kg).

#### 120 **2.2.3.2. Fatigability intervention**

121 During the muscle fatigability testing, participants were invited to repeat 4-s maximal  
122 contractions interspersed by 1 s for up to 5 min (i.e., 60 contractions). The follow-up was  
123 assured by a smartphone's application which displayed a red color for contraction and green



124 color for recovery with an according audio signal. Strong verbal encouragement was given  
125 during every contraction to promote maximal effort. In order to avoid pacing strategies,  
126 participants were unaware of the precise duration of the test or of the remaining time (Tucker,  
127 2009). The peak force ( $F_{peak}$ , expressed in percentage of MVC) of each contraction was used  
128 in this study (**Fig. 1**).

129 -----**Fig. 1**-----

#### 130 2.2.4. Data analysis

131 The kinetics analysis of  $F_{peak}$  of both DF and PF was processed using Matlab (Matlab  
132 R2013a, MathWorks, Natick, USA). The non-linear regression technique was used to trace  
133 the exponential model of the kinetic of  $F_{peak}$  over the time of each participant and to extract  
134 markers of fatigability according to Veni et al., (2019):

$$135 \quad F_{peak} = F_{cr} + (100 - F_{cr}) \times e^{-\frac{t}{\tau}}$$

136 Where  $F_{peak}$  is the maximal force expressed in percentage of the MVC,  $t$  is the  
137 time of contraction,  $\tau$  is the curvature constant in number of contraction  
138 corresponding to the rate of the force decrease and  $F_{cr}$  is the force-time  
139 asymptote relationship corresponding to the intensity threshold above which  
140 fatigue develops.

141 The index of variability (RMSSD) was calculated for each participant using the following  
142 equation:

$$143 \quad \sqrt{\frac{\sum_{i=1}^{n-1} (F_{peak}(i) - F_{peak}(i+1))^2}{n-1}}$$

144 Where  $n$  is the number of contractions (i.e., 60 contractions),  $F_{peak}(i)$  is the  
145 maximal force expressed in percentage of the MVC at  $t$  instant and  $F_{peak}$   
146 ( $i+1$ ) is the  $F_{peak}$  at  $t+1$  instant.

148

149 **3. Result**

150 **3.1. Statistical analysis**

151 Statistical analysis was performed using Statistica Software 13.0 (Software, Inc.,  
152 Tulsa, USA). The normality and homogeneity of variance were respectively determined using  
153 the Shapiro-wilk and Levene tests. The assumption of normality and homogeneity of variance  
154 was confirmed for all parameters. The student's t-test was used for markers of fatigability and  
155 anthropometric parameters, and the two-way ANOVA (obesity × postural task) for postural  
156 parameters with the Bonferroni post-hoc procedures were performed. Relationships between  
157 the postural parameters and markers of fatigability were evaluated using Pearson's  
158 correlations analysis. Values were expressed as means (standard deviation). The level of  
159 significance was set at the 5% critical level ( $p < 0.05$ ).

160 **3.2. Anthropometric measurements**

161  
162 Participants' characteristics are shown in **Table 1**. Body mass, BMI, body fat, hip and  
163 waist circumferences and the ratio waist/hip were higher in OG compared to CG ( $p < 0.05$ ).  
164 There are no significant differences concerning LBM, age and body height between groups.

165 -----**Table 1**-----

166 **3.3. Static postural control testing**

167 The two-way ANOVA showed a significant obesity × postural task interaction effect  
168 on area ( $F_{(1,56)} = 11.1$ ,  $p < 0.05$ ,  $\alpha^2 = 0.15$ ,  $\beta = 0.98$ ), velocity ( $F_{(1,56)} = 60.2$ ,  $p < 0.01$ ,  $\alpha^2 = 0.71$ ,  $\beta$   
169  $= 1$ ), CoP length ( $F_{(1,56)} = 25.2$ ,  $p < 0.01$ ,  $\alpha^2 = 0.54$ ,  $\beta = 1$ ) and L/A ration ( $F_{(2,56)} = 15.9$ ,  $p < 0.05$ ,  
170  $\alpha^2 = 0.27$ ,  $\beta = 0.98$ ) (**Table 2**). Post hoc analysis revealed that OG exhibited significantly  
171 greater area, velocity, CoP length and L/A ratio than CG in all conditions ( $p < 0.05$ ). In the  
172 two groups, area, velocity and CoP length were greater in EC than EO condition ( $p < 0.05$ ).  
173 The L/A ratio was higher in EC than EO condition only in OG ( $p < 0.05$ ).

### 3.4. Muscle evaluations

The parameters of the neuromuscular fatigability are presented in **Table 3**. The absolute and the relative of PF and DF were not significantly different between OG and CG.

For PF, the relative  $F_{cr}$  to MVC was 21% lower in obese group ( $p < 0.01$ ). The  $F_{cr}$  in Newton per body mass was significantly 39% lower in OG ( $p < 0.01$ ). The  $\tau$  value was 12% lower ( $p < 0.05$ ) and the RMSSD was 47% higher in OG ( $p < 0.001$ ). For FD, only the  $F_{cr}$  in Newton per body mass ( $p < 0.05$ ) and the  $\tau$  ( $p < 0.05$ ) remained significantly lower in OG.

### 3.5. Correlations analyses

Pearson correlation's analysis revealed significant correlations between the (L/A) ratio of CoP displacements and the  $F_{cr}$  PF expressed in percentage of MVC in EO ( $r = 0.86$ ,  $p < 0.05$ ) and EC ( $r = 0.85$ ,  $p < 0.05$ ) in OG (**Fig. 2**).

## 4. Discussion

Results point out that obesity decreases the  $F_{cr}$  expressing the intensity threshold above which fatigue develops drastically, and an early fatigue development in ankle muscles. Moreover, results indicate that  $F_{cr}$  of PF was negatively correlated with altered postural control parameters in obese adults.

The absolute and relative maximal forces during the MVC testing are statistically similar in CG and OG (**Table 3**). This observation provides evidence that obesity does not affect maximal force production capacities at the ankle level and suggests that obese and non-obese adults have similar neuromuscular functioning characteristics (e.g., function of cross-section area, muscle typology, motor recruitment) during MVC. However, the MVC evaluation alone cannot inform about the mechanisms of muscles fatigability in obese adults. Consequently, we focused on the  $F_{cr}$  concepts in this study. Physiologically,  $F_{cr}$  can be

198 determined to discriminate poor and heavy intensities and is defined as an intensity threshold  
199 above which fatigue develops drastically (Burnley et al., 2012; Ferguson et al., 2007).  
200 Interestingly,  $F_{cr}$  expressed in percentage of the MVC and  $F_{cr}$  expressed in Newton per  
201 kilogram of body mass of the PF were 21% and 39% lower in OG than CG, respectively. This  
202 reveals that obesity lowers the fatigability threshold of ankle muscles promoting an early  
203 fatigue development. Obese adults may thus often exceed their  $F_{cr}$  even during daily living  
204 activities especially when ankle muscles are considerably solicited (e.g., walking, balance...).  
205 In the same way, the curvature of the force-time relationship of the PF was 12% lower in OG  
206 confirming that obesity causes not only a reduced fatigability threshold but also an earlier  
207 fatigue at the ankle level compared to non-obese adults. These neuromuscular alterations may  
208 contribute to the development and persistence of chronic fatigue in this population (Veni et  
209 al., 2019).

210 It has been also reported that older adults have greater peak force variability (RMSSD)  
211 than young adults (Poole et al., 2016) due to a decreased of maximal force (Sosnoff and  
212 Newell, 2006). The present study shows that despite obese adults develop similar relative  
213 force to non-obese ones, they have higher peak force variability of PF (+47%). Hence, the  
214 force variability seems to be independent of the maximal force level in obese adults. It is  
215 possible that the high force variability observed in obese adults is related to an altered central  
216 mechanisms driving motor behavior (Lorist et al., 2002). This hypothesis is in accordance  
217 with the findings of Pajoutan et al. (2017) reporting that fatigue in obese adults originates  
218 rather from the central level than the peripheral level. The precise nature of this interference  
219 and the level it occurs need further investigations.

220 Otherwise, only the  $F_{cr}$  of DF normalized to body mass was lower in OG compared to  
221 CG. This may be surprising since obese adults present the same relative MVC of DF. It is

222 likely that DF and PF do not present the same neuromuscular mechanisms of fatigability.  
223 Indeed, DF contains approximately 27% of fast twitch fibers characterized by their low  
224 fatigue resistance (Wåhlin Larsson et al., 2008), while PF, particularly gastrocnemius  
225 muscles, contains over 43% of fast twitch fibers (Gollnick et al., 1974). For all these reasons,  
226 we can assume that obesity decreases the fatigability threshold and induces an early fatigue  
227 development, particularly at PF level. This observation confirms results of Maffiuletti et al.  
228 (2007) pointed out that obese individuals demonstrated lower fatigue resistance during  
229 voluntary extensions of quadriceps muscle.

230           Otherwise, Pajoutan et al. (2016) showed a significant effect of obesity on central  
231 activation failure of dorsiflexor muscles of the ankle after a fatiguing tasks suggesting that  
232 obese individuals may be at higher risk of falls due to weaker ankle dorsiflexor as the prime  
233 controllers of the balance recovery. In this context, results of this study reported a strong  
234 linear correlation has been evidenced between the ratio ( $L/A$ ), i.e. the level of the energy  
235 spend versus the accuracy of the postural system (Paillard and Noé, 2015), and the  $F_{cr}$   
236 expressed in percentage of MVC in EO and EC conditions (**Fig.2**). The more patients reported  
237 higher energy spent to regulate balance, the lower  $F_{cr}$  were found. This observation suggests  
238 that postural control alterations in obese adults could be partly explained by a decreased  
239 fatigability threshold. Similar relationship has previously been observed between increased  
240 fatigability and poor functional mobility and balance in obese subjects. (Ercan et al., 2019;  
241 Resnick et al., 2006). A possible explanation is related to mechanical changes in obese  
242 individuals caused by their wide body mass per se. Indeed, a non-negligible proportion of  
243 body mass, particularly in individuals with androidal obesity, is further away from the axis of  
244 rotation. This might cause a greater gravitational torque that accelerates the body in the  
245 anteroposterior axis (Corbeil et al., 2001). To maintain upright stance, this gravitational

246 torque must be countered by increasing muscular torque (Handrigan et al., 2012; Teasdale et  
247 al., 2007). Consequently, obese individuals need to generate greater muscle force at the ankle  
248 level to reach a level of balance similar to non-obese individuals. However, results of this  
249 study point out that the relative strength produced by obese adults at the ankle level is similar  
250 to non-obese adults confirming that altered postural control capacities in obese individuals are  
251 not related to an insufficient ankle muscle force production but rather to an increase in PF  
252 muscle activity (Maktouf et al., 2018). Thus, the high level of muscle activity may increase  
253 the development of an early extremity muscle fatigue (Pajoutan et al., 2017). Therefore, our  
254 results fit with the hypothesis made by Maktouf et al. (2018) suggesting that the postural  
255 control instability in obese adults can be explained by the neuromuscular fatigability of ankle  
256 muscles. We also reveal that postural control alterations are not mainly related to an early  
257 fatigue but rather to a decreased fatigability threshold of PF (i.e. decreased Fcr). In fact, the  
258 higher muscle activity of PF needed to counteract obesity related constraints (i.e., mechanical  
259 and/or proprioceptive) could be responsive for a higher energy cost (Marques et al., 2013) and  
260 consequently lower extremity muscle fatigue development (Pajoutan et al., 2016).

261 Accordingly, it is evident that the more the fatigability threshold of PF is decreased, the  
262 higher risk of instability could be observed in obese adults. Moreover, it is possible that the  
263 lower fatigability threshold in obese individuals, when combined with age-related  
264 neuromuscular changes, may increase the risk of fall in obese elderly (Handrigan et al., 2017;  
265 Maktouf et al., 2018; Melzer and Oddsson, 2016). Further investigations are needed to clarify  
266 the interactions between obesity and age-related effects on the fatigability threshold and the  
267 relationship between lower limbs fatigability and altered postural control regulation in obese  
268 elderly (Maktouf et al., 2018).

## 269 **Limits of study**

270 The present study provides interesting information about the possible links between  
271 markers of the neuromuscular fatigability and postural parameters in obese adults but it is  
272 worth noting that there are limitations. First of all, only individuals with android obesity  
273 type were taken into account. Nevertheless, the android obesity type exposed to a greater  
274 risk of instability than the gynoidal obesity type (Cieślińska-Świder et al., 2017). This choice  
275 allows us to provide indications about the underlying mechanisms of postural control  
276 alterations in obese most exposed to risk of instability. Furthermore, we are aware that the  
277 standardized position of the feet during postural control test in this study (feet together) may  
278 influence the test results, since healthy young obese show a stable position when standing  
279 naturally (Cieślińska-Świder and Błaszczyk, 2019). However, the effects of muscle fatigue  
280 noticed in the present work during an unnatural position can also be manifested in everyday  
281 life, where regaining stability requires more effort in the obese. Moreover, we used the  
282 standardized position described by Maktouf et al. (2018) in order to check their hypothesis  
283 regarding the relationship between neuromuscular fatigability and postural instability

## 284 **Conclusion**

285 Obesity decreased fatigability threshold and induces an early fatigue development at the ankle  
286 level in obese adults. Decreased fatigability threshold could partly explain postural control  
287 instability in this population when exposed to difficult standing. This also confirms that  
288 altered postural control regulation during difficult tasks of daily living is not related to an  
289 insufficient ankle muscle force production but rather to a decreased  $F_{cr}$  expressing the  
290 intensity threshold above which fatigue develops drastically in obese adults. Finally,  $F_{cr}$  could  
291 be a relevant indicator to detect symptoms of fatigue in obese adults that clinician should  
292 strongly consider in order to prevent functional limitations that may develop at an advanced  
293 age. This possibility should be explored in future research.

294

## 295 **Acknowledgements**

296 We would like to thank patients of the reeducation center François Gallouedec (Le Mans,  
297 France) for their acceptance to participate in this study. We also thank the managers of this  
298 institution for their collaborations.

299

## 300 **Conflict of interest**

301 The authors declare no conflict of interest.

302

## 303 **References**

- 304 Burnley, M., Vanhatalo, A., Jones, A.M., 2012. Distinct profiles of neuromuscular fatigue  
305 during muscle contractions below and above the critical torque in humans. *J. Appl.*  
306 *Physiol.* 113, 215–23.
- 307 Cavuoto, L.A., Nussbaum, M.A., 2014. The influences of obesity and age on functional  
308 performance during intermittent upper extremity tasks. *J. Occup. Environ. Hyg.* 11(9),  
309 583-590.
- 310 Cieślińska-Świder, J., Furmanek, M.P., Błaszczuk, J.W., 2017. The influence of adipose  
311 tissue location on postural control. *J. Biomech.* 60 162-169.
- 312 Cieślińska-Świder, J.M., Błaszczuk, J.W., 2019. Posturographic characteristics of the standing  
313 posture and the effects of the treatment of obesity on obese young women. *PLoS One.*  
314 14(9), e0220962.
- 315 Corbeil, P., Simoneau, M., Rancourt, D., Tremblay, A., Teasdale, N., 2001. Increased risk for  
316 falling associated with obesity: mathematical modeling of postural control. *IEEE Trans.*  
317 *Neural Syst. Rehabil. Eng.* 9, 126–136.
- 318 Donath, L., Roth, R., Zahner, L., Faude, O., 2012. Testing single and double limb standing  
319 balance performance: Comparison of COP path length evaluation between two devices.  
320 *Gait Posture.* 36(3), 439-443.
- 321 Eksioglu, M., 2011. Endurance time of grip-force as a function of grip-span, posture and  
322 anthropometric variables. *Int. J. Ind. Ergon.* 41(5), 401-409.
- 323 Ercan, S., Başkurt, F., Başkurt, Z., Çetin, C., 2019. Effect of self-perceived fatigue on balance  
324 and functional mobility in middle-aged obese women. *Acta Med. Okayama* 73, 95–100.



- 325 Ferguson, C., Whipp, B.J., Cathcart, A.J., Rossiter, H.B., Turner, A.P., Ward, S.A., 2007.  
326 Effects of prior very-heavy intensity exercise on indices of aerobic function and high-  
327 intensity exercise tolerance. *J. Appl. Physiol.* 103, 812–22.
- 328 Gartner, A., Dioum, A., Delpeuch, F., Maire, B., Schutz, Y., 2004. Use of hand-to-hand  
329 impedancemetry to predict body composition of African women as measured by air  
330 displacement plethysmography. *Eur. J. Clin. Nutr.* 58, 523–531.
- 331 Gollnick, P.D., Sjödin, B., Karlsson, J., Jansson, E., Saltin, B., 1974. Human soleus muscle: A  
332 comparison of fiber composition and enzyme activities with other leg muscles. *Pflügers*  
333 *Arch. Eur. J. Physiol.* 348(3), 247-255.
- 334 Handrigan, G.A., Berrigan, F., Hue, O., Simoneau, M., Corbeil, P., Tremblay, A., Teasdale,  
335 N., 2012. Gait & Posture The effects of muscle strength on center of pressure-based  
336 measures of postural sway in obese and heavy athletic individuals. *Gait Posture* 35, 88–  
337 91.
- 338 Handrigan, G. A., Maltais, N., Gagné, M., Lamontagne, P., Hamel, D., Teasdale, N., Hue, O.,  
339 Corbeil, P., Brown, J.P., Jean, S., 2017. Sex-specific association between obesity and  
340 self-reported falls and injuries among community-dwelling Canadians aged 65 years and  
341 older. *Osteoporos. Int.* 28, 483–494.
- 342 Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Doré, J., Marceau, P., Marceau, S.,  
343 Tremblay, A., Teasdale, N., 2007. Body weight is a strong predictor of postural stability.  
344 *Gait Posture* 26, 32–38.
- 345 Kent-Braun, J.A., Miller, R.G., Weiner, M.W., 1993. Phases of metabolism during  
346 progressive exercise to fatigue in human skeletal muscle. *J. Appl. Physiol.* 75(2), 573-  
347 580.
- 348 Loram, I.D., Maganaris, C.N., Lakie, M., 2004. Paradoxical muscle movement in human  
349 standing. *J. Physiol.* 556, 683–689.
- 350 Lorist, M.M., Kernell, D., Meijman, T.F., Zijdwind, I., 2002. Motor fatigue and cognitive  
351 task performance in humans. *J. Physiol.* 545, 313–9.
- 352 Maffiuletti, N.A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., Lafortuna,  
353 C.L., Sartorio, A., 2007. Differences in quadriceps muscle strength and fatigue between  
354 lean and obese subjects. *Eur J Appl Physiol* 101, 51–59.
- 355 Maktouf, W., Durand, S., Beaune, B., Boyas, S., 2019. Influence of Obesity and Impact of a  
356 Physical Activity Program on Postural Control and Functional and Physical Capacities in  
357 Institutionalized Older Adults: A Pilot Study. *J. Phys. Act. Heal.* 17, 169–176.
- 358 Maktouf, W., Durand, S., Boyas, S., Pouliquen, C., Beaune, B., 2018. Combined effects of  
359 aging and obesity on postural control, muscle activity and maximal voluntary force of  
360 muscles mobilizing ankle joint. *J. Biomech.* 79, 198-206.
- 361 Marques, N.R., Laroche, D.P., Hallal, C.Z., Crozara, L.F., Morcelli, M.H., Karuka, A.H.,  
362 Navega, M.T., Gonçalves, M., 2013. Association between energy cost of walking,  
363 muscle activation, and biomechanical parameters in older female fallers and non-fallers.

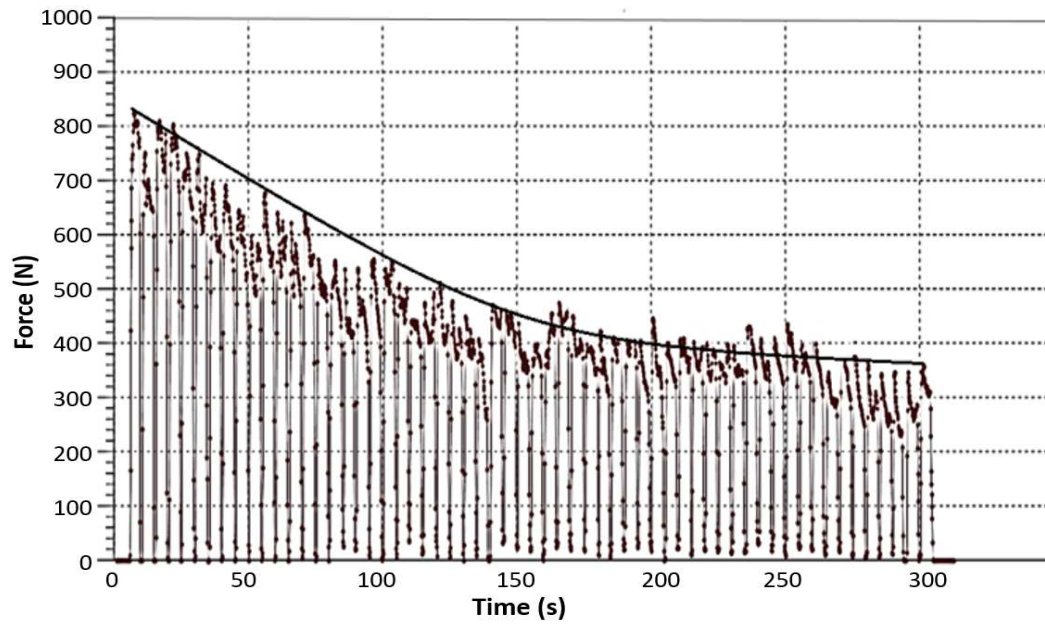
- 364 Clin. Biomech. 28, 330–336.
- 365 Matrangola, S.L., Madigan, M.L., 2009. Relative effects of weight loss and strength training  
366 on balance recovery. *Med. Sci. Sports Exerc.* 41, 1488–1493.
- 367 Melzer, I., Oddsson, L.I.E., 2016. Altered characteristics of balance control in obese older  
368 adults. *Obes. Res. Clin. Pract.* 10, 151–158.
- 369 Nagai, K., Yamada, M., Mori, S., Tanaka, B., Uemura, K., Aoyama, T., Ichihashi, N.,  
370 Tsuboyama, T., 2013. Effect of the muscle coactivation during quiet standing on  
371 dynamic postural control in older adults. *Arch. Gerontol. Geriatr.* 56, 129–133.
- 372 Paillard, T., Noé, F., 2015. Techniques and Methods for Testing the Postural Function in  
373 Healthy and Pathological Subjects. *Biomed. Res. Int.* 891390.
- 374 Pajoutan, M., Ghesmaty Sangachin, M., Cavuoto, L.A., 2017. Central and peripheral fatigue  
375 development in the shoulder muscle with obesity during an isometric endurance task.  
376 *BMC Musculoskelet. Disord.* 18, 314.
- 377 Pajoutan, M., Mehta, R.K., Cavuoto, L.A., 2016. The effect of obesity on central activation  
378 failure during ankle fatigue: a pilot investigation. *Fatigue Biomed. Heal. Behav.* 4, 115–  
379 126.
- 380 Poole, D.C., Burnley, M., Vanhatalo, A., Rossiter, H.B., Jones, A.M., 2016. Critical power:  
381 An important fatigue threshold in exercise physiology. *Med. Sci. Sports Exerc.* 48,  
382 2320–2334.
- 383 Resnick, H.E., Carter, E.A., Aloia, M., Phillips, B., 2006. Cross-sectional relationship of  
384 reported fatigue to obesity, diet, and physical activity: Results from the Third National  
385 Health and Nutrition Examination Survey. *J. Clin. Sleep Med.*
- 386 Saugen, E., Vøllestad, N.K., Gibson, H., Martin, P.A., Edwards, R.H.T., 1997. Dissociation  
387 between metabolic and contractile responses during intermittent isometric exercise in  
388 man. *Exp. Physiol.* 2(2), 163-169.
- 389 Schubert, P., Kirchner, M., 2014. Ellipse area calculations and their applicability in  
390 posturography. *Gait Posture.* 39(1), 518-522.
- 391 Simoneau, M., Teasdale, N., 2015. Balance control impairment in obese individuals is caused  
392 by larger balance motor commands variability. *Gait Posture* 41, 203–208.
- 393 Sosnoff, J.J., Newell, K.M., 2006. Are age-related increases in force variability due to  
394 decrements in strength? *Exp. brain Res.* 174, 86–94.
- 395 Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Dore, J., Marceau, P.,  
396 Marceau, S., Tremblay, A., 2007. Reducing weight increases postural stability in obese  
397 and morbid obese men. *Int. J. Obes.* 31, 153–160.
- 398 Tucker, R., 2009. The anticipatory regulation of performance: The physiological basis for  
399 pacing strategies and the development of a perception-based model for exercise  
400 performance. *Br. J. Sports Med.* 43(6), 392-400.

401 Veni, T., Boyas, S., Beaune, B., Bourgeois, H., Rahmani, A., Landry, S., Bochereau, A.,  
402 Durand, S., Morel, B., 2019. Handgrip fatiguing exercise can provide objective  
403 assessment of cancer-related fatigue: a pilot study. *Support. Care Cancer* 27, 229–238.

404 Wåhlin Larsson, B., Kadi, F., Ulfberg, J., Piehl Aulin, K., 2008. Skeletal muscle morphology  
405 and aerobic capacity in patients with obstructive sleep apnoea syndrome. *Respiration*.  
406 76(1), 21-27.

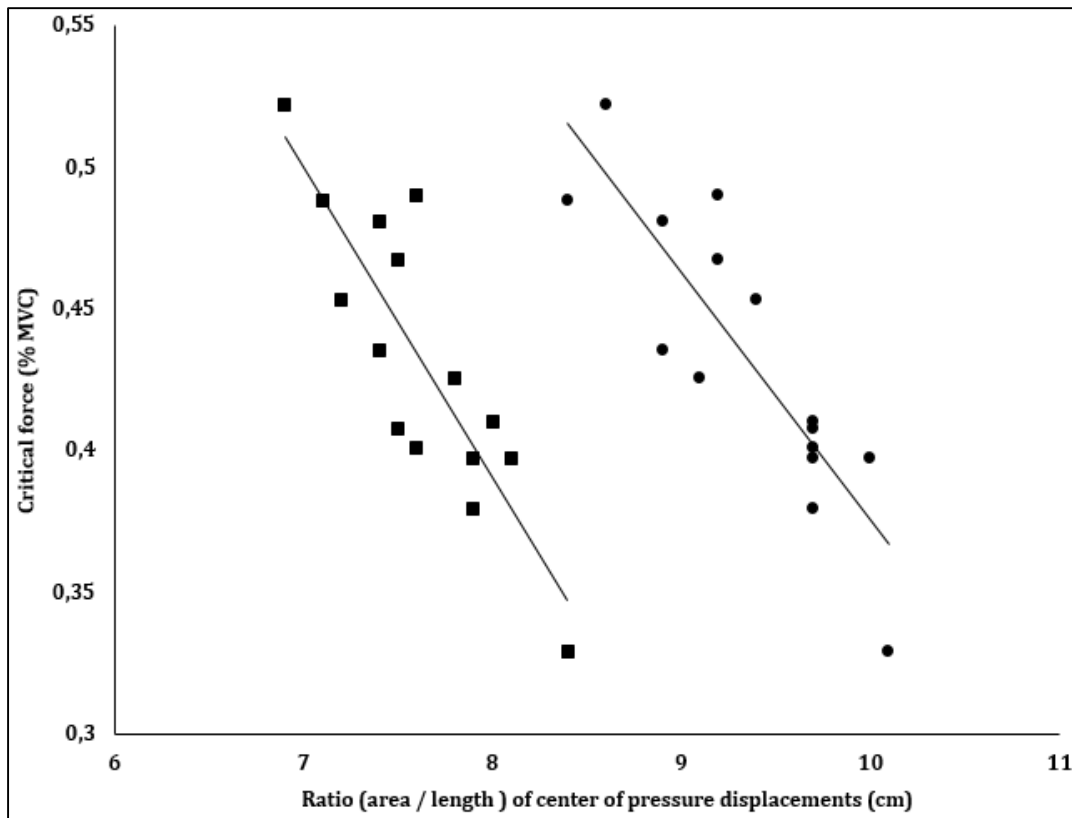
407 WHO, 2008. Waist Circumference and Waist-Hip Ratio: Report of a WHO Expert  
408 Consultation. World Heal. Organ.

409



**Figure 1.** Peak force decrease over the time during fatiguing exercise of the plantar flexor muscles.

The black line represents the exponential model of the kinetic of  $F_{\text{peak}}$  over the time.



**Figure 2.** Correlations between Ratio (length/area) of center of pressure displacements and the critical force of plantar flexors expressed in percentage of MVC.

Black squares present the linear relationship between the ration (length/area) and critical force in eyes opened condition. The equation of the linear regression:  $Fcr (\%MVC) = -0.08 \times Ratio (\text{length/area}) + 1.25$  ( $R^2 = 0.75$ ,  $r = 0.86$ ,  $p < 0.05$ ).

Black circles present the linear relationship between the ration (length/ area) and critical force in eyes closed condition. The equation of the linear regression:  $Fcr (\%MVC) = -0.11 \times Ratio (\text{length/area}) + 1.26$  ( $R^2 = 0.74$ ,  $r = 0.85$ ,  $p < 0.05$ ).

**Table 1.** Participants' physical characteristics.

Characteristics	CG	OG	<i>p</i> - level
	(n = 15) Mean(SD)	(n = 15) Mean(SD)	
Age (years)	<b>40.1(13.9)</b>	<b>44.2(12.4)</b>	NS
Body height (m)	<b>1.79(0.13)</b>	<b>1.70(0.09)</b>	NS
Body mass (kg)	<b>68.1(13.5)</b>	<b>118.2(22.6)</b>	p<0.001
BMI (kg/m <sup>2</sup> )	<b>21.3(2.8)</b>	<b>39.1(5.2)</b>	p<0.001
Body fat (%)	<b>23.6(5.1)</b>	<b>49.2(7.1)</b>	p<0.001
Lean body mass (kg)	<b>54.0(11.8)</b>	<b>60.2(15.1)</b>	NS
Fat body mass (kg)	<b>16.0(3.9)</b>	<b>58.0(13.1)</b>	p<0.001
Waist circumference (cm)	<b>95.4(11.5)</b>	<b>138.1(11.8)</b>	p<0.001
Hip circumference (cm)	<b>94.7(6.2)</b>	<b>122.8(10.9)</b>	p<0.001
Ratio Waist / hip	<b>1.0(0.1)</b>	<b>1.1(0.1)</b>	p<0.05

Comparison between two groups based on the student's t-test for each parameter. CG: control group, OG: obese group, BMI: body mass index, NS: not significant.

**Table 2.** Postural parameters of participants during postural control testing.

	CG	OG	<i>Obesity effect</i>		<i>Postural task effect</i>		<i>Obesity × Postural task</i>	
	Mean(SD)	Mean(SD)	<i>F-values</i>	<i>p-Level</i>	<i>F-values</i>	<i>p-level</i>	<i>F-values</i>	<i>p-level</i>
Area EO (cm <sup>2</sup> )	2.9(1.5)	3.7(1.9)*						
Area EC (cm <sup>2</sup> )	3.8(1.9)+	5.9(2.1)*+	F <sub>(1,56)</sub> = 56.9	p<0.01	F <sub>(1,56)</sub> = 200.1	p<0.001	F <sub>(1,56)</sub> = 11.1	p<0.05
Velocity EO (mm/s)	6.2(2.2)	11.3(3.1)*						
Velocity EC (mm/s)	9.1(3.1)+	15.1(3.4)*+	F <sub>(1,56)</sub> = 170.2	p<0.001	F <sub>(1,56)</sub> = 473.5	p<0.001	F <sub>(1,56)</sub> = 60.2	p<0.01
Length EO (cm)	18.7(4.2)	34.0(5.1)*						
Length EC (cm)	27.2(6.4)+	45.4(9.2)*+	F <sub>(1,56)</sub> = 155.2	p<0.001	F <sub>(1,56)</sub> = 273.9	p<0.001	F <sub>(1,56)</sub> = 25.2	p<0.01
Ratio L/A EO (cm)	6.5(1.4)	9.2(2.6)*						
Ratio L/A EC (cm)	7.2(2.4)	7.7(2.1)*+	F <sub>(1,56)</sub> = 24.2	p<0.05	-	-	F <sub>(2,56)</sub> = 15.9	p<0.05

Comparison between two groups based on two-way ANOVA (group × postural task) for each parameter with additional post hoc analysis where there is a main effect of Obesity, Postural task and an interaction (Obesity × Postural task). CG: control group, OG: obese group, EO: eyes opened, EC: eyes closed, Ratio L/A: length/area

\* Significant difference between CG and OG (p<0.05).

+ Significant difference between EO and EC conditions (p<0.05).

**Table 3.** Parameters of the neuromuscular fatigability during fatiguing exercise.

	CG Mean(SD)	OG Mean(SD)	<i>p-Level</i>
<b>PF</b>			
Absolute Force (N)	626.6(193.6)	683.0(115.6)	NS
Relative Force (N/kg)	11.6(2.0)	11.3(2.0)	NS
Fcr (%)	56.2(5.5)	44.4(6.6)	p<0.01
Fcr (N/kg)	7.0(1.6)	4.3(1.0)	p<0.01
RMSSD (N)	45.8(5.5)	67.3(9.2)	p<0.001
$\tau$ (s)	96.0(8.1)	84.7(8.1)	p<0.05
<b>DF</b>			
Absolute Force (N)	209.5(66.2)	237.8(60.8)	NS
Relative Force (N/kg)	3.9(0.9)	3.9(0.5)	NS
Fcr (%)	65.9(17.6)	54.4(9.6)	NS
Fcr (N/kg)	2.5(0.4)	1.8(0.3)	p<0.05
RMSSD (N)	19.3(2.4)	18.1(2.0)	NS
$\tau$ (s)	78.0(4.0)	58.4(4.3)	P<0.05

Comparison between two groups based on t-student's test for each parameter.

CG: control group, OG: obese group, Fcr (%): critical force relative to maximal voluntary contraction, Fcr (N/kg): critical force in Newton per body mass, RMSSD: index of variability,  $\tau$ : rate of force decrease, NS: not significant.