Influence of grade of obesity on the achievement of VO2max using an incremental treadmill test in youths

Louis Toulouse^a, Patrick Mucci^b, Thierry Pez^a, Gautier Zunquin^c.

a Unit de Recherche Pluridisciplinaire Sport Sant Socit, ULR 7369 - URePSSS - Univ. Littoral Cte d'Opale, Univ. Lille, Univ. Artois, F-59000 Lille, France

b Unit de Recherche Pluridisciplinaire Sport Sant Socit, Univ. Lille, ULR 7369 - URePSSS - Univ. Littoral Cte d'Opale, Univ. Artois, F-59000 Lille, France

c Laboratoire Mouvement, Equilibre, Performance, Sant. Campus Montaury, EA 4445 - Universit Pau Pays de l'Adour, F-64600 Anglet, France

*Corresponding author: Louis Toulouse, Unit de Recherche Pluridisciplinaire Sport Sant Socit, EA 7369 - URePSSS - Univ. Littoral Cte d'Opale, Univ. Lille, Univ. Artois, F-59000 Lille, France. E-mail: louis.toulouse@etu.univ-littoral.fr

ORCID : 0000-0003-1215-7104

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The purpose of this study was to analyze the influence of grade of obesity on the probability of achieving a VO_2 plateau and threshold secondary criteria for verifying $\text{VO}_{2\text{max}}$ during a treadmill walk test in youths with obesity. Therefore, 72 youths with obesity (aged 8-16) performed an incremental treadmill walk test to exhaustion during which oxygen uptake (VO_2), minute ventilation (VE), heart rate (HR) and rating of perceived exertion were continuously measured. HR corresponding to a “hard” level of perceived exertion was reported and expressed as a percentage of the predicted HR_{max} . The rate of achievement of criteria for validation $\text{VO}_{2\text{max}}$ (VO_2 plateau; $\text{HR} > 95\%$ theoretical HR_{max} ; $\text{RER} > 1.0$; rating of perceived exertion $\geq$ “hard”) was compared between participants with grade I and grade II obesity. 37% of the participants achieved a VO_2 plateau and 23% achieved both an $\text{HR} > 95\%$ and $\text{RER} > 1.0$. Youths with grade II obesity had lower minute ventilation ($p < 0.01$) tended to be more likely to reach an $\text{HR} > 95\%$ ($\text{OR} = 0.33$; $P = 0.06$) and a “hard” rating of perceived exertion than grade I ($\text{OR} = 4.5$; $P = 0.07$). However, there was no influence of grade of obesity on the achievement of VO_2 plateau, and $\text{RER} > 1.0$. A higher grade of obesity was related to a lower peak in minute ventilation normalized by fat-free mass, lower peak heart rates and premature reaching of a “hard” rating of perceived exertion. Therefore, youths with higher grades of obesity might be less likely to display maximal heart rate during an incremental treadmill test, probably due to higher ventilatory constraints and higher ratings of perceived exertion.

Keywords: children ; adolescents ; obesity ; treadmill ; $\text{VO}_{2\text{max}}$

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INTRODUCTION

Cardiorespiratory fitness is one of the best predictors of all-cause mortality in adults¹, especially when it is normalized by fat-free mass². Cardiorespiratory fitness is assessed by the maximal oxygen uptake ($\text{VO}_{2\text{max}}$), which is the highest value of VO_2 clinically attainable during a progressive cycling or treadmill test conducted to exhaustion³. Since walking is more representative of free-living physical activities, treadmill walk tests are mostly used to assess the $\text{VO}_{2\text{max}}$ in youth with obesity⁴⁻⁶. During these tests, the speed is constant and usually between 3.5 and 5 $\text{km}\cdot\text{h}^{-1}$, which is close to the preferred walking speed in this population⁷. The intensity is increased by increasing the slope, amounting to 1 or 2% per minute^{4,5}. To verify the achievement of $\text{VO}_{2\text{max}}$ (i.e., a maximal aerobic effort) during this type of test, it was proposed that youths with obesity should reach at least one of the three following physiological criteria: 1) the presence of a VO_2 plateau; 2) a heart rate $> 200\text{bpm}$ or $95\%\text{HR}_{\text{max}}$; 3) a respiratory exchange ratio > 1.0 . According to these criteria, Gutin et al. found that 66 out of 80 participants ($\sim 83\%$) reached $\text{VO}_{2\text{max}}$ ⁴. Using the same protocol, a study⁶ found that 29% of adolescents with grade II obesity achieved a VO_2 plateau. However, the rates of achievement of secondary threshold criteria were not specified. Finally, one study⁵ did not specify the criteria⁴ used to verify the achievement of $\text{VO}_{2\text{max}}$, which does not allow to determine the extent to which their treadmill protocol elicited a maximal aerobic effort. Since $\text{VO}_{2\text{max}}$ remains the gold standard for monitoring aerobic fitness in youths with obesity⁸, it is necessary to ensure that a maximal aerobic effort has been made during the test. However, there is still a lack of transparency regarding the criteria used to ensure that a maximal aerobic effort has been made during treadmill walk tests in youths with obesity. Furthermore, no study has investigated the influence of grade of obesity on the probability of achieving $\text{VO}_{2\text{max}}$ during this type of protocol. Thus, further studies are

needed to better understand the mechanisms associated with the non-achievement of a VO_2 plateau and secondary threshold criteria for verifying $\text{VO}_{2\text{max}}$ in youth with obesity.

Therefore, this study aimed to assess the influence of grade of obesity on the probability of achieving a VO_2 plateau and secondary threshold criteria for verifying $\text{VO}_{2\text{max}}$ during an incremental treadmill walk test in youth with obesity.

METHODS

Participants

72 youths with obesity were included in this study. The inclusion criteria were an age between 8 and 16 years old and a BMI superior to the 85th percentile of the IOTF standards for BMI, defining grade I obesity in youths⁹. These youths are oriented by their practitioner towards obesity management networks (including the hospital center and associations) where they are offered to follow care adapted to their needs. During their inclusion appointment to the program, the youths participants and their parents received an oral and written explanation of the experimental procedure and the objectives of the study. For youths, the information notice was written in a language adapted to their level of understanding. After a reflection time of at least one week following the inclusion visit, the youths and the voluntary parents signed a written consent summarizing the information relating to the study.

General procedure

The experiments took place in the department of pulmonary medicine of the hospital center in the presence of a specialist doctor. Participants were called in the morning between 10 a.m. and 12 p.m. or in the afternoon between 3 p.m. and 7 p.m., at least two

92 hours after their last food intake to avoid digestive discomfort during the test. Parents
 93 were asked to make sure that their youths did not exercise intensively during the 48
 94 hours preceding the appointment. Before the experiments, the participants were
 95 measured in standing and seated positions using a stadiometer. Then, the body weight
 96 and composition were measured using bioimpedance-analysis (Tanita DC-360, Japan).
 97 These measurements allowed us to obtain an estimate of their body composition (fat-
 98 free mass and fat mass) and to calculate their BMI z-score based on the IOTF⁹ and
 99 WHO¹⁰ standards. Participants who had a BMI z-score between 1 and 2 (not included)
 100 according to the IOTF standards were categorized into "grade I obesity", whereas those
 101 who had a BMI z-score > 2 were categorized into "grade II obesity". From the
 102 anthropometrical measurements, the Age of Peak Height Velocity – age of PHV (also
 103 called “Maturity Offset”) was estimated using the following sex-specific equations
 104 provided by Mirwald et al.¹¹ :

$$\text{Eq. 1 : Maturity Offset (boys)} = -9.236$$

$$\begin{aligned} &+ 0.0002708 \cdot \text{Leg Length and Sitting Height interaction} \\ &- 0.001663 \cdot \text{Age and Leg Length interaction} \\ &+ 0.007216 \cdot \text{Age and Sitting Height interaction} \\ &+ 0.02292 \cdot \text{Weight by Height ratio} \end{aligned}$$

105

$$\text{Eq. 2 : Maturity Offset (girls)} = -9.376$$

$$\begin{aligned} &+ 0.0001882 \cdot \text{Leg Length and Sitting Height interaction} \\ &+ 0.0022 \cdot \text{Age and Leg Length interaction} \\ &+ 0.005841 \cdot \text{Age and Sitting Height interaction} \\ &- 0.002658 \cdot \text{Age and Weight interaction} \\ &+ 0.07693 \cdot \text{Weight by Height ratio} \end{aligned}$$

Then, age from the peak height velocity (age from PHV) was estimated by subtracting the estimated age of PHV by the chronological age. A negative value indicates that the PHV has not occurred yet¹¹. The maturity offset and age from PHV were used as an indicator of the maturity of the participants.

Incremental exercise

The incremental treadmill protocol consisted of performing a 3-minute warm-up at 0% slope and a speed between 3.0 to 4.5 $\text{km}\cdot\text{h}^{-1}$ so that the participant reached a heart-rate (HR) steady-state at $60 \pm 5\%$ (110-130 bpm) of the predicted maximum HR estimated with the formula of Tanaka¹² [$\text{HR}_{\text{max}} = 208 - 0.7 * \text{age}$]. Normalizing the starting speed by the HR was intended to ensure an equitable starting intensity between individuals and optimal exercise duration (> 5 minutes excluding warm-up) for all participants¹³. During the first 5 minutes, the slope increased by 2% per minute and the speed was kept constant. From the sixth minute, the slope was maintained at 10% and the speed increased by 0.3 $\text{km}\cdot\text{h}^{-1}$ for a starting speed between 3.0 $\text{km}\cdot\text{h}^{-1}$ and 3.7 $\text{km}\cdot\text{h}^{-1}$ or by 0.4 $\text{km}\cdot\text{h}^{-1}$ for a starting speed between 3.7 and 4.5 $\text{km}\cdot\text{h}^{-1}$. This protocol was selected because high treadmill grades would be associated with an increased failure to achieve $\text{VO}_{2\text{max}}$ ¹⁴. The test ended when the participant declared that he was no longer able to continue the test despite the encouragement of the experimenter.

Measurement and processing of data

During exercise, HR was measured using a recently validated optical heart rate monitor (Polar OH1, Finland)¹⁵ positioned at the left wrist. The peak heart rate (HR_{peak}) observed during the test was the highest value averaged on 3 points. The VO_2 was measured breath-by-breath using a portable respiratory gas analyzer (Cosmed K4b2,

Italy) calibrated before the exercises following the manufacturer's recommendations. The $\text{VO}_{2\text{peak}}$ and peak in minute ventilation ($\text{VE}_{\text{peakBM}}$) were reported as the highest values over a 30s moving-averaged interval, as recently recommended in youths¹⁶. Rating of perceived exertion (RPE) was continuously assessed using the CR-10 Borg scale previously used in youths with obesity⁵. This scale describes the difficulties of breathing from level 1 ("not at all") to 10 ("maximal"). The HR measured when the participant declared a level of 5/10 on the scale - corresponding to the "hard" item ($\text{HR}_{\text{RPEhard}}$) - was reported and expressed as a percentage of the individual predicted HR_{max} . We chose this indicator to get information about the level of physiological stress that each participant was able to tolerate before the effort was "hard", a term that has more clinically significance in youths¹⁷.

Criteria for verifying $\text{VO}_{2\text{max}}$

Following previous studies in youths with obesity^{4,6}, the present cardiorespiratory-based criteria for verifying $\text{VO}_{2\text{max}}$ were used: primary criterion = presence of a VO_2 plateau; secondary threshold criteria = $\text{HR} > 95\%$ of theoretical maximal HR and $\text{RER} > 1.0$. Participants were considered as $\text{VO}_{2\text{max}}$ achievers when at least the VO_2 plateau or both the secondary threshold criteria were met. The presence of a VO_2 plateau was characterized when the increase in VO_2 during the last completed minute of effort was strictly less than 50% of the increase observable during the penultimate minute of effort. This method based on the individual workload/ VO_2 relationship was recently recommended¹⁸ and used to detect VO_2 plateaus in adults with obesity¹⁹. A fourth criterion based on the achievement of an $\text{RPE} \geq 5$ (item "hard") was also used. This criterion was used as a measurement of the psychological tolerance to the treadmill test. Conversely, the criteria based on volitional exhaustion was not used because the latter is

determined rather by the experimenter than the participant, limiting the possibilities of inter-study comparisons.

Statistical analysis

The data were analyzed on the R software (version 3.6.2). The normality and homogeneity of the distributions were checked respectively with the Shapiro-Wilk test and the F test of Snedecor. Firstly, the clinical characteristics and peak exercise data of participants were compared between those who had grade I and those who had grade II obesity using Student t-tests and Cohen's *d*. Secondly, the number and rate of participants who met the criteria for verifying $\text{VO}_{2\text{max}}$ were calculated and reported according to the grade of obesity. Chi-Square tests were performed to analyze the differences in the rate of achievement of each criterion according to the grade of obesity. If significant differences were found, logistic regression analysis was performed to examine the association between the grade of obesity and the achievement of each criterion. The significance threshold was set at $P < 0.05$.

Results

Participants' characteristics, cardiorespiratory, and perceptual responses are shown in table 1. Youths with grade II obesity were less mature ($P < 0.05$, $d = 0.5$), heavier ($d = 1.25$) and had a higher BMI z-score ($d = 4.47$) and percentage of body fat ($d = 2.38$) than grade I ($P < 0.001$ for each parameter). VE_{peak} divided by body mass ($P < 0.001$, $d = 1.34$), fat-free mass ($P < 0.05$, $d = 0.72$) and $\text{VO}_{2\text{peak}}$ divided by body mass ($P < 0.01$, $d = 1.03$) were lower in youths with grade II obesity than grade I. Conversely, no

between-groups significant differences were found regarding HR_{peak} , $\text{HR}_{\text{RPEhard}}$, and RER_{peak} .

*** Table 1 here ***

Table 2 summarizes results regarding the achievement of both primary and secondary threshold criteria for verifying $\text{VO}_{2\text{max}}$ in grade II vs. grade I obesity. A VO_2 plateau was met by 38% of the participants and 23% met both an $\text{HR} > 95\% \text{HR}_{\text{max}}$ and an $\text{RER} > 1.0$. According to the criteria for verifying $\text{VO}_{2\text{max}}$ used in children with obesity, 54% of the participants would have reached $\text{VO}_{2\text{max}}$ during the test. An $\text{RPE} > 5/10$ was reached by 92% of the participants. According to the Chi-square tests, youths with grade II obesity tended to be less likely to display an $\text{HR} > 95\% \text{HR}_{\text{max}}$ ($\text{OR} = 0.33$; $P = 0.06$) and more likely to indicate an $\text{RPE} > 5/10$ ($\text{OR} = 4.5$; $P = 0.07$) than grade I. However, no significant differences were found regarding the achievement of a VO_2 plateau ($P = 0.33$), $\text{RER} > 1.0$ ($P = 0.27$), or $\text{VO}_{2\text{max}}$ ($P = 0.44$).

*** Table 2 here ***

Discussion

The main purpose of this study was to study the influence of the grade of obesity on the probability to meet the primary and secondary threshold criteria for verifying $\text{VO}_{2\text{max}}$ during a treadmill test. The secondary purpose was to measure the cardiorespiratory and perceptual responses to this test in the youth with obesity, which is an under-evaluated population. The main findings of this study are that 1) youths with grade II obesity were less likely to display an $\text{HR} > 95\% \text{HR}_{\text{max}}$ and 2) youths with grade II obesity were more likely to indicate an RPE reflecting a “hard” level of effort than grade I. Furthermore,

youth with grade II obesity displayed lower peaks in minute ventilation normalized by the fat-free mass than grade I.

Adults suffering from chronic diseases have a lower ability to achieve $\text{VO}_{2\text{max}}$ during a progressive test conducted until exhaustion²⁰. However, in youths with obesity, current studies provide little data regarding the achievement of criteria for verifying $\text{VO}_{2\text{max}}$ ⁴⁻⁶. Therefore, knowledge about the individual's factors associated with the probability of achieving $\text{VO}_{2\text{max}}$ remains limited. Although no statistically significant, the present results in a relatively large sample of youth with obesity (n=72) suggest that the grade of obesity may be associated with a lower probability of meet an $\text{HR} > 95\% \text{HR}_{\text{max}}$ and a higher probability of meet a “hard” level of RPE. Thus, youths with higher grades of obesity might perceive the test as more difficult. This result may be of significance since perceptual responses play a major role during a progressive test conducted until exhaustion²⁰. The present data would be supporting those of our predecessors⁵ who found that RPE was higher in grade II than grade I obesity at the end of a treadmill test. They hypothesized that these differences could be due to an increased aerobic energy cost, a greater CO_2 turnover, and a lower anaerobic threshold in grade II obesity. In the present study, the peak in minute ventilation normalized by body mass was significantly lower in youths with grade II than grade I obesity, and this differences persisted even after removing differences in body composition. This could mean that ventilatory adaptations to exercise were lower in grade II vs. grade I. Interestingly, it has been previously suggested that lower cardiorespiratory fitness in youths with obesity could be partly explained by ventilatory factors²¹. The excess adipose tissue at the thoracic level would constrain them to breathe at low lung volumes, increasing the work of respiratory

muscles to the detriment of locomotor muscles²¹. Nevertheless, ventilatory factors would have a little impact on cardiorespiratory fitness in youths²¹. Accordingly, no differences were found between grade I and grade II regarding $\text{VO}_{2\text{peak}}$ after removing differences in body mass and composition. Therefore, the present data would be in accordance with the previous hypothesis⁵ that ventilatory factors are involved in the higher feeling of difficulty of youths with grade II obesity, but has limited influence on $\text{VO}_{2\text{peak}}$ ²¹. Otherwise, breathing difficulties could also explain that youths with grade II obesity were less likely to met an $\text{HR} > 95\% \text{HR}_{\text{max}}$. It should be noted however that the relative HR at which the RPE was 5/10 ("hard") was higher than what could be expected, supporting previous data showing that RPE is underestimated in youths with obesity^{5,22,23}.

Other factors may explain that youths with higher grades of obesity perceive their effort as more difficult. Firstly, obesity has many deleterious consequences on the musculoskeletal function of the lower limbs in youths²⁴. Thus, lower limb pain sensations may contribute to the higher RPE in those who have obesity. Considering the low RPE scores found at the end of an incremental running or walking fitness test^{5,21,22}, it could be relevant to use an RPE scale based on muscular sensations. Indeed, current RPE scales are based on cardiorespiratory sensations²⁵, assuming that cardiorespiratory function is the limiting factor during an aerobic fitness test. Conversely, the combination of both a "local" and "overall" RPE scale would make it possible to dissociate the chest sensations from the lower limb sensations, which could help clinicians to better identify the reason for stopping the test. This approach has already been used in healthy children using an incremental cycling test and showed that "leg RPE" was significantly higher than "overall RPE" and "chest RPE".²⁶ Secondly, the lack of experience in vigorous-intensity exercises (due to poor engagement in physical

activities) is known to negatively affect RPE measurements²⁷. However, physical activity levels were not measured in this study, limiting further interpretation of current data.

The probability of achieving $\text{VO}_{2\text{max}}$ using a treadmill protocol according to the grade of obesity has previously been studied in women¹⁹. In accordance with the present results in youths, the authors found no differences between grade I and grade II obesity women regarding the achievement of a VO_2 plateau. However, they also reported no differences regarding the achievement of secondary threshold criteria (i.e., $\text{HR} > 95\% \text{HR}_{\text{max}}$, $\text{RER} > 1.15$, $\text{RPE} > 18/20$, and blood lactate $> 8 \text{ mmol.L}^{-1}$), contrary to the present study. Therefore, the lower ability of grade II obesity individuals to meet an $\text{HR} > 95\% \text{HR}_{\text{max}}$ during a treadmill test could only concern youths. According to a recent study²⁸, treadmill tests would elicit ~4% lower HR_{peak} than active games in children with obesity. This study reinforces the idea that a high proportion of youths with obesity is not achieving a maximal effort during a treadmill test.

The VO_2 plateau used to be the primary criteria for verifying $\text{VO}_{2\text{max}}$, but it is still debated whether the occurrence of VO_2 plateau is only influenced by the sampling intervals, or if physiological factors could be involved²⁹⁻³¹. In adults with obesity¹⁹, the VO_2 plateau was reached by 46% of the participants, which is higher than the 37% found in our study using the same definition of a VO_2 plateau, but close to previous studies in youths with⁶ or without³² obesity. Since the range of VO_2 plateau can vary from 30 to 50% between the studies^{6,32-33}, the present differences are probably not meaningful. Furthermore, comparisons between studies might be not available since a different sampling interval²⁹ can significantly affect the results regarding the VO_2 plateau.

271

272 ***Limitations and perspectives***

273 This study has limitations. Although the methodology was based on the most recent
 274 recommendations^{18,34}, the criteria that should be used to verify $\text{VO}_{2\text{max}}$ are still debated.
 275 However, the use of supramaximal tests to verify the achievement of $\text{VO}_{2\text{max}}$ is not
 276 clinically appropriate in youths with obesity. Furthermore, the present results could
 277 have been strengthened by physical activity data and the use of an RPE scale based on
 278 the muscular feeling of pain. These data could have strengthened the interpretation of
 279 the results regarding the mechanisms associated with the achievement of a VO_2 plateau
 280 or secondary threshold criteria for verifying $\text{VO}_{2\text{max}}$. Despite these limitations, the
 281 present findings are of clinical importance since performing a maximal
 282 cardiorespiratory effort is the gold standard for measuring $\text{VO}_{2\text{max}}$ ³. According to the
 283 criteria used in this study and those of predecessors⁴⁻⁶, a high proportion of youths with
 284 different grades of obesity (approximating 50% in our study) would not $\text{VO}_{2\text{max}}$ using a
 285 treadmill walking test. Thus, clinicians should be aware that $\text{VO}_{2\text{max}}$ may be
 286 underestimated in this population when it is measured using these protocols.

287 **Conclusion**

288 The rate of achievement of an $\text{HR} > 95\% \text{HR}_{\text{max}}$ and $\text{RPE} > 5/10$ (“hard”) was respectively
 289 independent of the grade of obesity in a sample of 72 youths. These criteria were
 290 achieved by a minority of participants (15 to 64%), suggesting that a maximal
 291 cardiorespiratory effort was not achieved by the participants during the test. Youths
 292 with grade II obesity displayed a lower peak in minute ventilation normalized to fat-free
 293 mass and a premature feeling of difficulty than grade I during progressive walk tests,
 294 which may be attributable to higher ventilatory constraints and premature feeling of leg

muscular pain. Thus, our study supports the idea that a dose-response relationship exists between the grade of obesity and the psychophysiological responses to an incremental treadmill test in children.

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421 Table 1 : Participants' characteristics, cardiorespiratory and perceptual responses by
 422 grade of obesity subgroups.

	IOTF Grade I obesity (n=15)	IOTF Grade II obesity (n=57)
Age (years)	11.9 ± 1.8	11.6 ± 1.8
Age of PHV (years)	12.8 ± 1.2	12.0 ± 0.9 [*]
Maturity (years from PHV)	-0.9 ± 1.1	-0.4 ± 1.8
Height (cm)	152 ± 10	153 ± 11
Weight (kg)	56.0 ± 11.7	70 ± 18.8 ^{***}
Body Mass Index (kg.m ⁻²)	23.9 ± 2.2	29.8 ± 4.6 ^{***}
Fat mass (% body mass)	28.7 ± 4.4	39.1 ± 7.1 ^{***}
IOTF BMI z-score (SD)	1.8 ± 0.2	2.7 ± 0.5 ^{***}
VE _{peak} mL.kgFFM ⁻¹ .min ⁻¹	1.94 ± 0.33	1.71 ± 0.31 [*]
VE _{peak} mL.kgBM ⁻¹ .min ⁻¹	1.39 ± 0.26	1.04 ± 0.24 ^{***}
VO _{2peakBM} (mL.kgBM ⁻¹ .min ⁻¹)	34.5 ± 7.1	27.2 ± 5.1 ^{**}
VO _{2peakFFM} (mL.kgFFM ⁻¹ .min ⁻¹)	48.2 ± 8.7	44.8 ± 7.4
HR _{peak} (bpm)	192 ± 14	185 ± 13
HR _{peak} (% predicted HR _{max})	96.2 ± 7.1	92.5 ± 6.7
HR _{RPEhard} (%HR _{peak})	93.3 ± 6.2	94.1 ± 4.7
RER _{peak} (Arbitrary unit)	1.10 ± 0.17	1.08 ± 0.14

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Table 2 : Number and rate of participants having reached the criteria for varying VO_{2max} and achieved VO_{2max} according to these criteria, by grade of obesity and results of logistic regressions.

	VO _{2max}		VO ₂ plateau		HR>95%		RER>1.0		RPE>5/10	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Grade I	n=7 47%	n=8 53%	n=4 27%	n=11 73%	n=9 60%	n=6 40%	n=8 53%	n=7 47%	n=12 80%	n=3 20%
Grade II	n=33 58%	n=24 42%	n=23 40%	n=34 60%	n=19 33%	n=38 67%	n=39 68%	n=18 32%	n=54 95%	n=3 5%
X ² tests	<i>P</i> =0.44		<i>P</i> =0.33		<i>P</i> =0.06		<i>P</i> =0.27		<i>P</i> =0.07	
OR	NS		NS		0.33		NS		4.5	

Abbreviations : VO₂ = oxygen uptake ; HR = heart rate ; OR = odds-ratio; RER = respiratory exchange ratio ; RPE = rating of perceived exertion ; X² = chi-square tests