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Establishing cut-points for physical activity classification using triaxial accelerometer in middle-aged recreational marathoners

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Abstract

The purpose of this study was to establish GENEA (Gravity Estimator of Normal Everyday Activity) cut-points for discriminating between six relative-intensity activity levels in middle-aged recreational marathoners. Nighty-eight (83 males and 15 females) recreational marathoners, aged 30–45 years, completed a cardiopulmonary exercise test running on a treadmill while wearing a GENEA accelerometer on their non-dominant wrist. The breath-by-breath $\dot{V}O_2$ data was also collected for criterion measure of physical activity categories (sedentary, light, moderate, vigorous, very vigorous and extremely vigorous). GENEA cut-points for physical activity classification was performed via Receiver Operating Characteristic (ROC) analysis. Spearman's correlation test was applied to determine the relationship between estimated and measured intensity classifications. Statistical analysis were done for all individuals, and separating samples by sex. The GENEA cut-points established were able to distinguish between all six-relative intensity levels with an excellent classification accuracy (area under the ROC curve (AUC) values between 0.886 and 0.973) for all samples. When samples were separated by sex, AUC values were 0.881–0.973 and 0.924–0.968 for males and females, respectively. The total variance in energy expenditure explained by GENEA accelerometer data was 78.50% for all samples, 78.14% for males, and 83.17% for females. In conclusion, the wrist-worn GENEA accelerometer presents a high capacity of classifying the intensity of physical activity in middle-aged recreational marathoners when examining all samples together, as well as when sample set was separated by sex. This study suggests that the triaxial GENEA accelerometers (worn on the non-dominant wrist) can be used to predict energy expenditure for running activities.

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Introduction

Long-distance races have substantially increased in popularity over recent years by means of both the number of international marathon races, as shown in IAAF calendar (https://www.iaaf.org/competition/calendar), and the number of marathon/ultramarathon finishers constantly raised in the last few decades [1–6]. For example, in 2016, up to fifty marathon races were organized in Spain (http://www.carreraspopulares.com/solomaraton). Since the marathon is one of the most challenging endurance competitions [7,8], runners' interest for the improvement of training programs and for nutrition advice has been significantly increased in order to improve their marathon time without soreness and preventing energy deficit [9,10]. Elite athletes work closely with multidisciplinary teams (comprising coaches, nutritionists and medical specialists) to prepare training programs in order to achieve their goal [11–13]. Nowadays, recreational athletes are also advised by a wide range of professional experts who analyze training indicators after training sessions, since they are not usually present in each one of them [14,15]. The development of monitoring devices that provide valuable information (i.e. strength parameters, heart rate, movement acceleration, running pace, ground contact time measures, energy consumption, etc.) to athletes, coaches and healthcare experts has been recently targeted in an attempt to improve training session evaluation and design, as well as running performance [16,17].

The use of accelerometers in physical activity evaluation (in terms of intensity, frequency and duration) has exponentially increased since its creation in 1983 [18], being a potential tool to accurately estimate physical activity energy expenditure from accelerometer output data [17,19–21]. Research studies have been focused on the standardization of data collection, wear site, measurement period and data reduction methods, in order to uniformly measure the physical activity across studies [17,21–23]. Additionally, multiple validation researches attempt to distinguish different physical activity categories by cut-point approach [24–27], and to indirectly measure energy cost of physical activity–expressed as Metabolic Equivalent of Task (MET) [17,23,25,28–30]. Therefore, accelerometry may be a useful tool for monitoring athletes.

Among all the accelerometer-based physical activity monitors, the most recent developed triaxial wrist-worn accelerometer, the Gravity Estimator of Normal Everyday Activity (GENEA), has been found to present a high instrument reliability and criterion validity as well as to accurately classify different intensities of physical activity (sedentary, light, moderate and vigorous) [25]. Furthermore, due to its characteristics (watch-like design, small size, light weight and waterproof), the GENEA seems to be one of the most comfortable accelerometer device to wear during free-living condition assessment [24,31]. Previous validation studies of wrist-worn GENEA accelerometer have been performed in different specific populations (adults, children, wheelchair users, pregnant females, etc.) in order to analyze and quantify physical activity in normal daily activities for improvement of lifestyle conditions [22,26,27,29,32–35]. However, this study goes toward the use of accelerometer-based devices to track adult recreational marathoners, a population subset with higher physical and metabolic fitness than standard adult population. The reason of creating cut-points specific to a particular population is because the individualized energy expenditure may fluctuate according to the body weight and composition, sex, age, physical fitness, mechanical efficiency and the environmental conditions under which the activity is performed [16,17,20,36].

Therefore, the main purpose of this study was to establish wrist-worn GENEA cut-points for discriminating between sedentary, light, moderate, vigorous, very vigorous and extremely vigorous activity when assessing the physical activity intensity in adult recreational marathoners aged 30–45 years. Our secondary aim was to determine these cut-points taking into account the marathoners' sex, since females display lower record values in marathon compared to males.

We hypothesized that wrist-worn GENEA accelerometer may present high capacity of classifying the intensity of physical activity in middle-aged recreational marathoners, independently of sex.

Material and methods

Sample set

All participants of the Valencia Fundación Trinidad Alfonso EDP 2016 Marathon received an invitation email to participate in the current study. Two informative seminars were organized in order to fully explain the study design (aims, protocol, hypothesis, etc.) to those individuals who accepted the invitation (N = 456). A total of 98 recreational marathon runners (83 males and 15 females) were selected to participate in this study, according to the following inclusion criteria: (1) age between 30 and 45 years; (2) body mass index (BMI) between 16 and 24.99 $kg{\cdot}m^{-2}$; (3) previous marathon experience, having a performance best time in marathon between 3 and 4 hours for males and 3:30 and 4:30 hours for females; and (4) healthy individuals who were free from cardiac or renal disease and from consuming drugs.

Ethics statement

All individuals included in the current study were fully informed and gave their written consent to participate. The research was conducted according to the Declaration of Helsinki, and it was approved by the Research Ethics Committee of the Jaume I University of Castellon. This study is enrolled in the ClinicalTrails.gov database, with the code number NCT03155633 (www.clinicaltrials.gov).

Data collection and analysis

A standardized questionnaire was used to collect demographic information as well as medical information, training plan and competition history (see S1 File for details).

Before performing the cardiopulmonary tests, anthropometric data of all the individuals were evaluated. Height was measured using a SECA 213 portable stadiometer (Seca GmbH & Co. Kg, Hamburg, Germany). Body mass was assessed with light sport clothing and barefoot using a Tanita MC-780 U (Tanita Corporation, Arlington Heights, IL). BMI was then calculated ($height{\cdot}mass^{-2}$). Bioelectrical impedance analyses (Tanita MC-780 U) was also used to determine body composition for all individuals, according to manufacturer's protocol.

Each participant was then asked to complete a cardiopulmonary exercise test, which was done on a treadmill (pulsar® 3p, h/p/cosmos sports & medical gmbh, Nussdorf-Traunstein, Germany) until exhaustion. Breath-by-breath gas exchange was measured by the Jaeger MasterScreen® CPX gas analyzer. Gas analysis system was calibrated before each testing session. The run exercise test performed was an adaptation of the incremental ramp exercise protocol [37,38]. Initially, participants were standing on the treadmill for one minute. Then, speed was progressively increasing until reaching 6 $km{\cdot}h^{-1}$, where participants warmed-up for three minutes. After the warming-up period, speed was growing by 1 $km{\cdot}h^{-1}$ per minute from 8 $km{\cdot}h^{-1}$ to 11 or 12 $km{\cdot}h^{-1}$ when examining females or males, respectively. This speed was maintained during three minutes. Finally, speed was again increasing by 1 $km{\cdot}h^{-1}$ per minute until participant exhaustion. The breath-by-breath $\dot{V}O_2$ data collected by the gas analysis system was averaged per minute for further analysis. Arterial tension was measured each 3 min of the exercise test by using a Tango M2 Blood Pressure Monitor (GE Healthcare, Finland). Additionally, heart activity was evaluated throughout exercise test by using an electrocardiograph 1200W Digital RF Wireless System (Norav Medical, Germany).

During the course of the cardiopulmonary exercise test, participants wore a GENEActiv accelerometer (Activinsights Ltd., Kimbolton, Cambridgeshire, United Kingdom). The accelerometer was worn on the non-dominant wrist as a watch. Accelerometers were adjusted to record acceleration data at a rate of 85.7 Hz. Accelerometry data was collected at this frequency because of two different reasons: 1) to follow the same methodology than Esliger *et al*. (2011), and 2) to be able to collect information during 10 days (allowing us to monitor runners from 24h before to 9 days after the marathon).

Devices were calibrated by the manufacturer prior to use. Accelerometer devices were time synchronized with the gases analysis software. Acceleration data of each individual was downloaded using the GENEActiv software (Version 2.9). The BIN file created by the device was firstly converted to a CSV file. Then, the data was exported to a standard Excel file (Microsoft Excel 2013, Microsoft Corporation, Redmond, WA). We used the acceleration data to provide a Signal Magnitude Vector gravity-subtracted (SVMgs) per minute [25].

Statistical analysis

To establish cut-points for the GENEA accelerometers, each minute of the run exercise test was then classified into one of the six relative-intensity categories: sedentary (<10% of $\dot{V}O_{2max}$), light ($10 \leq X < 25\%$ of $\dot{V}O_{2max}$), moderate ($25 \leq X < 45\%$ of $\dot{V}O_{2max}$), vigorous ($45 \leq X < 65\%$ of $\dot{V}O_{2max}$), very vigorous ($65 \leq X < 85\%$ of $\dot{V}O_{2max}$), and extremely vigorous ($\geq$85% of $\dot{V}O_{2max}$) (Table 1). This classification was based on previous studies [16,17,23]. Then, the $\dot{V}O_2$ data per minute was converted to METs according to the standard conversion (1 MET = 3.5 ml·kg^{-1}·min^{-1}), with the aim to transform the breath-to-breath $\dot{V}O_2$ values to the energy consumption rate of physical activities [17,28]. Next, the METs per minute was recoded into binary indicator variables (0 or 1). Binary codification was based on the relative-intensity categories: sedentary (non-sedentary *versus* sedentary), light (less than light *versus* light to

Table 1. Relative-intensity categories of physical activity according to individualized $\dot{V}O_{2max}$ measured in 98 adult marathon runners.

Relative-intensity levels of physical activity #	All samples (N = 98)		Males (N = 83)		Females (N = 15)	
	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	METs *	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	METs *	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	METs *
Sedentary $X < 10\%$	$\dot{V}O_2 < 5.45$	METs < 1.56	$\dot{V}O_2 < 5.57$	METs < 1.59	$\dot{V}O_2 < 4.82$	METs < 1.38
Ligth $10\% \leq X < 25\%$	$5.45 \leq \dot{V}O_2 < 13.63$	$1.56 \leq$ METs < 3.90	$5.57 \leq \dot{V}O_2 < 13.94$	$1.59 \leq$ METs < 3.97	$4.82 \leq \dot{V}O_2 < 12.07$	$1.38 \leq$ METs < 3.45
Moderate $25\% \leq X < 45\%$	$13.63 \leq \dot{V}O_2 < 24.54$	$3.9 \leq$ METs < 7.01	$13.94 \leq \dot{V}O_2 < 25.08$	$3.97 \leq$ METs < 7.15	$12.07 \leq \dot{V}O_2 < 21.72$	$3.45 \leq$ METs < 6.21
Vigorous $45\% \leq X < 65\%$	$24.54 \leq \dot{V}O_2 < 35.44$	$7.01 \leq$ METs < 10.13	$25.08 \leq \dot{V}O_2 < 36.23$	$7.15 \leq$ METs < 10.33	$21.72 \leq \dot{V}O_2 < 31.38$	$6.21 \leq$ METs < 8.97
Very Vigorous $65\% \leq X < 85\%$	$35.44 \leq \dot{V}O_2 < 46.35$	$10.13 \leq$ METs < 13.24	$36.23 \leq \dot{V}O_2 < 47.38$	$10.33 \leq$ METs < 13.50	$31.38 \leq \dot{V}O_2 < 41.03$	$8.97 \leq$ METs < 11.72
Extremely Vigorous $X \geq 85\%$	$\dot{V}O_2 \geq 46.35$	METs $\geq$ 13.24	$\dot{V}O_2 \geq 47.38$	METs $\geq$ 13.50	$\dot{V}O_2 \geq 41.03$	METs $\geq$ 11.72

Abbreviations: N, number of individuals; $\dot{V}O_{2max}$, maximum oxygen consumption; MET, metabolic equivalent task

Each minute of the cardiopulmonary test was classified into one of the six intensity categories of physical activity relative to an individual's level of cardiorespiratory ($\dot{V}O_{2max}$).

* 1 MET = 3.5 ml·kg^{-1}·min^{-1}

X denotes the percentage of a person's aerobic capacity ($\dot{V}O_{2max}$) used to classify each one of the six relative-intensity categories

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extremely vigorous), moderate (less than moderate *versus* moderate to extremely vigorous), vigorous (less than vigorous *versus* vigorous to extremely vigorous), very vigorous (less than very vigorous *versus* very to extremely vigorous), and extremely vigorous (less than extremely vigorous *versus* extremely vigorous).

The binary-coded MET data and SVM_{gs} per minute were exported to R software in order to accomplish a receiver operating characteristic (ROC) curve analysis. ROC analysis was adopted to evaluate the potential of using accelerometer data to distinguish between the different relative-intensity categories. The Youden Index method was used to set the optimal cut-point–the point on the curve at which (sensitivity + specificity − 1) is maximised. Therefore, the cut-point that optimizes the classification ability of accelerometry data, when equal weight is given to sensitivity and specificity, is established as the optimal cut-point [25,39]. Basic prediction accuracy parameters–including the area under the ROC curve (AUC), sensitivity and specificity–were calculated. ROC AUC values varies between 0 and 1, where 0.5 denotes a bad diagnostic test and 1 denotes an excellent diagnostic test. The ability of accelerometry data to distinguish between the different relative-intensity categories was inferred as follow: excellent (AUC = 0.90–1.00); good (AUC = 0.80–0.90); fair (AUC = 0.70–0.80); poor (AUC = 0.60–0.70); and fail (AUC = 0.50–0.60).

This analysis was carried out for each one of the six relative-intensity categories. Indeed, ROC analysis was done for all individuals, as well as for males and females separately. Note that ROC analysis were performed including data from 0 to 16 min for males, excluding data from 17 and 18 min since only 17 individuals were able to continue running after 16 min of the exercise test. For females, data from 0 to 15 min was used.

Finally, Spearman's correlation test was used to known whether there was a linear correlation between SVMgs and METs. This test was used due to a non-normal distribution of the accelerometer data, according to Kolgomorov-Smirnov test. Statistical analysis was done using R software, and p-values lower than 0.05 were considered as statistically significant.

Results

Detailed description of individuals regarding anthropometric data evaluated, as well as demographic information, medical information, training plan and competition history, is summarized in Table 2.

A total of 98 participants (83 males and 15 females) completed a cardiopulmonary exercise test until exhaustion. Table 3 recapitulates the results of the cardiopulmonary exercise tests per minute for all individuals, as well as for males and females separately. Exercise time length was higher in males than in females. All males completed 12 min running on the treadmill, and progressively interrupted their exercise test due to fatigue after that minute. The best four males completed a total of 18 min, being the treadmill velocity of 19 $km \cdot h^{-1}$. Among female participants, exercise test duration was not less than 12 min. Two out of 15 females were able to complete a total of 15 min running, being the treadmill velocity of 16 $km \cdot h^{-1}$. Each minute of the run exercise test was then classified into one of the six relative-intensity categories by taking into account a person's aerobic capacity ($\dot{V}O_{2max}$). The intensity of each relative-physical activity in METs and $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) is summarized in the Table 1.

Table 4 summarizes the results of the ROC curve analyses performed to establish cut-points for the GENEA devices. Cut-points in SVM_{gs}, sensitivity and specificity values, and the area under the curve (AUC) were estimated for all six relative-intensity categories of physical activity. ROC analyses revealed that GENEA devices were able to distinguish between all relative-intensity levels, presenting AUC values ranging from 0.881 to 0.995. Indeed, sensitivity and specificity values were reasonably high, confirming the great overall capability to discriminate

Table 2. Population description.

Variable		All sample (N = 98)	Males (N = 83)	Females (N = 15)
Physiological characteristics *	**age**	38.72 ± 3.63	38.76 ± 3.65	38.50 ± 3.63
	BMI	22.87 ± 1.71	23.18 ± 1.48	21.32 ± 2.01
	% body fat	14.74 ± 3.25	13.81 ± 3.67	19.54 ± 4.16
	right-handed	91	76	15
	left-handed	7	7	0
	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	54.53 ± 5.63	55.74 ± 5.14	48.27 ± 3.60
	maximum METs	15.54 ± 1.62	15.92 ± 1.46	13.72 ± 1.02
Training indicators*	**years of running**	6.49 ± 2.81	6.58 ± 2.91	5.38 ± 1.80
	sessions per week	4.81 ± 0.86	4.90 ± 0.85	4.33 ± 0.81
	kilometers per week	63.16 ± 13.42	64.45 ± 13.21	55.66 ± 12.79
	hours per week	7.30 ± 2.67	7.46 ± 2.69	6.21 ± 2.27
History as marathoner *	**marathons finished**	3.28 ± 3.00	3.56 ± 3.09	1.92 ± 2.08
	marathon per year	1.09 ± 0.61	1.21 ± 0.61	0.93 ± 0.59
Work intensity #	**high intensity**	7.07%	8.43%	0%
	medium intensity	31.31%	31.32%	31.25%
	low intensity	61.61%	60.24%	68.75%
Levels of study #	**school graduate**	5.10%	4.87%	6.25%
	high school graduate	6.12%	6.09%	6.25%
	professional certificate	16.32%	18.29%	6.25%
	undergraduate degree	72.4%	70.73%	81.25%

Abbreviations: N, number of samples; BMI, body mass index; SD, standard deviation

* Values are presented as mean ± SD

\# Values are presented as percentage of all individuals, males and females

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between sedentary, light, moderate, vigorous, very vigorous and extremely vigorous intensity levels of the wrist-worn GENEA devises. Regarding all different intensities, extremely vigorous category showed the lower AUC values (0.886 for all individuals, 0.881 for males and 0.924 for females), being the hardest intensity level to discriminate. Note that the reduced specificity and sensitivity for extremely vigorous intensity influenced the accurate classification of this relative-intensity category (Table 4).

Fig 1 illustrates the relationship between METs and SVM_{gs} for all individuals. Vertical lines delimited the different relative-intensity levels according to cut-points in SVM_{gs} estimated, and horizontal lines delimited the different relative-intensity levels according to cut-points in METs measured (equivalent to $\dot{V}O_{2max}$ classification). Therefore, grey regions delimit the consensus outcome between the measured and predicted intensity categories, and all observations inside these regions are correct classifications for each intensity level. The Spearman's correlation test showed a high linear relationship between METs and SVM_{gs} when all individuals were analyzed together (rs = 0.886, p-value = 2.20×10^{-16}), as well as when sample set was separated by sex (rs = 0.884 and p-value = 2.20×10^{-16} for males, rs = 0.912 and p-value = 2.20×10^{-16} for females).

Discussion

The delineation and validation of intensity levels of physical activity from accelerometer data has been deeply studied in the last few years [17,20,21,40]. The GENEA accelerometer has

Table 3. Mean values of energy expenditure (METs) and accelerometer output (SVM_{gs}) for each minute of the 98 cardiopulmonary exercise tests.

Time (min)	Speed ($km \cdot h^{-1}$)	All individuals (N = 98)			Males (N = 83)			Females (N = 15)		
		N	METs *	SVM_{gs} (g·min)	N	METs *	SVM_{gs} (g·min)	N	METs *	SVM_{gs} (g·min)
0	0	98	1.46 ± 0.57	93.47 ± 65.82	83	1.46 ± 0.55	87.05 ± 57.75	15	1.49 ± 0.70	129.02 ± 94.28
1	0.5	98	1.44 ± 0.49	187.54 ± 155.86	83	1.48 ± 0.49	190.41 ± 164.10	15	1.21 ± 0.43	171.67 ± 101.39
2	6	98	2.73 ± 0.72	857.32 ± 462.82	83	2.76 ± 0.76	870.25 ± 483.22	15	2.54 ± 0.38	785.79 ± 331.65
3	6	98	4.70 ± 0.67	1405.01 ± 424.64	83	4.68 ± 0.70	1381.87 ± 387.93	15	4.82 ± 0.46	1533.02 ± 589.21
4	6	98	5.30 ± 0.61	1624.80 ± 584.02	83	5.29 ± 0.64	1595.57 ± 608.89	15	5.36 ± 0.41	1786.54 ± 398.27
5	8	98	6.40 ± 0.89	3269.14 ± 1009.90	83	6.39 ± 0.95	3281.01 ± 1028.88	15	6.48 ± 0.42	3203.45 ± 927.77
6	9	98	8.66 ± 0.73	4455.89 ± 862.04	83	8.67 ± 0.76	4511.70 ± 816.02	15	8.61 ± 0.55	4147.08 ± 1061.97
7	10	98	9.58 ± 0.74	4837.47 ± 986.13	83	9.60 ± 0.76	4846.79 ± 972.38	15	9.46 ± 0.61	4785.89 ± 1093.78
8	11	98	10.32 ± 0.75	5145.54 ± 1101.79	83	10.34 ± 0.78	5132.55 ± 1086.95	15	10.23 ± 0.62	5217.48 ± 1218.38
9	12 / 11 #	98	11.05 ± 0.99	5497.10 ± 1192.59	83	11.08 ± 1.04	5489.30 ± 1197.44	15	10.93 ± 0.65	5540.25 ± 1205.68
10	12 / 11 #	98	11.68 ± 0.82	5716.85 ± 1260.17	83	11.81 ± 0.77	5725.23 ± 1275.23	15	10.96 ± 0.78	5670.45 ± 1213.19
11	12	98	12.01 ± 0.82	5826.97 ± 1289.95	83	12.13 ± 0.80	5776.95 ± 1291.03	15	11.36 ± 0.66	6103.74 ± 1292.11
12	13	98	12.29 ± 0.85	6144.29 ± 1410.26	83	12.37 ± 0.82	6048.91 ± 1393.39	15	11.80 ± 0.84	6672.02 ± 1433.74
13	14	96	12.90 ± 0.88	6746.56 ± 1661.72	83	12.97 ± 0.87	6617.35 ± 1577.41	13	12.47 ± 0.86	7571.53 ± 2001.21
14	15	90	13.64 ± 0.89	7337.31 ± 1714.91	81	13.67 ± 0.90	7228.05 ± 1648.30	9	13.36 ± 0.74	8320.66 ± 2083.25
15	16	76	14.36 ± 0.94	8027.57 ± 2046.65	74	14.38 ± 0.95	8056.41 ± 1799.32	2	13.58 ± 0.12	10974.31 ± 370.23
16	17	52	15.13 ± 1.02	9101.20 ± 2038.07	52	15.13 ± 1.02	9101.20 ± 2038.07	-	-	-
17	18	17	16.29 ± 1.02	9780.52 ± 2683.43	17	16.29 ± 1.02	9780.52 ± 2683.43	-	-	-
18	19	4	16.72 ± 0.97	11745.28 ± 3470.36	4	16.72 ± 0.97	11745.28 ± 3470.36	-	-	-

Abbreviations: N, number of samples; MET, metabolic equivalent task; SVM_{gs}, signal magnitude vector gravity-subtracted; SD, standard deviation

Values are presented as mean ± SD

* 1 MET = 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$

Treadmill speed at 12 or 11 $km \cdot h^{-1}$ when examining males or females, respectively

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been proposed as one of the most accurate tools to assess physical activity (in terms of intensity, frequency and duration) during free-living conditions. However, to our knowledge, this is the first time that researching have been focused on distinguish each relative-intensity activity level in adult recreational marathoners from accelerometer data. It is note that relative-intensity activities, rather than standard-intensity activities established for adult population [25], were used in this study since marathon runners present previous exercise experience and therefore higher relative level of fitness than standard adult population. Processing original accelerometer data to distinguish relative-intensity activity levels might provide valuable information for athletes, coaches and healthcare specialists, such us energy expenditures during daily activities, training sessions or over the course of a long-distance race.

Previous studies recommend being cautious using the GENEA cut-points when testing different populations and/or activities other than those on which the cut-points were specifically established [24,26,32]. For that reason, the main aim of the current study was to determine relative-intensity activity cut-points in middle-aged recreational marathoners using the GENEA accelerometer. This was done for six relative-intensity activity levels (sedentary, light, moderate, vigorous, very vigorous and extremely vigorous), which were established based on individualized $\dot{V}O_{2max}$. A total of 98 participants were collected for this primary purpose, being a significantly larger sample set compared to previous studies [22,24,25,29].

In this study, cardiopulmonary exercise test approach was performed with the individual running on a treadmill, rather than riding on a stationary bicycle, since individuals were

Table 4. Performance analysis of wrist-worn GENEA cut-points for each intensity level in adult marathon runners.

Intensity level of physical activity	Sensitivity (%)	Specificity (%)	Area under the ROC curve (95% CI)	Youden Index	GENEA cut-points in SVM_{gs} (g·min) *
All samples (N = 98)					
Sedentary	99.2	93.6	0.973 (0.966–0.980)	0.928	$SVM_{gs} < 528.31$
Light	93.6	99.2	0.973 (0.966–0.980)	0.928	$528.31 \leq SVM_{gs} < 1166.28$
Moderate	97.2	93.5	0.993 (0.990–0.996)	0.907	$1166.28 \leq SVM_{gs} < 3679.91$
Vigorous	96.5	93.9	0.988 (0.984–0.993)	0.904	$3679.91 \leq SVM_{gs} < 4155.94$
Very Vigorous	95.1	78.0	0.943 (0.933–0.954)	0.731	$4155.94 \leq SVM_{gs} < 5250.68$
Extremely Vigorous	88.9	71.0	0.886 (0.867–0.905)	0.599	$SVM_{gs} \geq 5250.68$
Males (N = 83)					
Sedentary	99.1	94.0	0.973 (0.966–0.981)	0.931	$SVM_{gs} < 528.31$
Light	94.0	99.1	0.973 (0.966–0.981)	0.931	$528.31 \leq SVM_{gs} < 1166.28$
Moderate	97.0	93.2	0.992 (0.989–0.996)	0.902	$1166.28 \leq SVM_{gs} < 3679.91$
Vigorous	97.6	93.8	0.99 (0.985–0.995)	0.914	$3679.91 \leq SVM_{gs} < 4364.64$
Very Vigorous	91.7	80.9	0.94 (0.929–0.952)	0.726	$4364.64 \leq SVM_{gs} < 5264.37$
Extremely Vigorous	89.9	70.3	0.881 (0.859–0.903)	0.602	$SVM_{gs} \geq 5264.37$
Females (N = 15)					
Sedentary	100	93.0	0.968 (0.946–0.990)	0.930	$SVM_{gs} < 326.08$
Light	93.0	100	0.968 (0.946–0.990)	0.930	$326.08 \leq SVM_{gs} < 1264.59$
Moderate	98.3	97.8	0.995 (0,989–1.000)	0.961	$1264.59 \leq SVM_{gs} < 2717.5$
Vigorous	97.8	93.8	0.988 (0.977–0.999)	0.916	$2717.5 \leq SVM_{gs} < 3355.56$
Very Vigorous	98.3	86.5	0.97 (0.951–0.989)	0.848	$3355.56 \leq SVM_{gs} < 5796.21$
Extremely Vigorous	86.1	82.5	0.924 (0.883–0.965)	0.686	$SVM_{gs} \geq 5796.21$

Abbreviations: N, number of samples; ROC, receiver operation curve; CI, coefficient interval; SVM_{gs}, signal magnitude vector gravity-subtracted

* Optimal cut-points maximising Youden Index

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marathon runners. The biomechanical differences between running and riding might influence the accelerometer data collection [26,40]. According to that, the accelerometer device was placed on the non-dominant wrist in order to record arm movement during running, as recommended by previous studies [17,21,26,36]. Body location of GENEA devices has been identified as an essential detail to take into account in physical activity monitoring studies [17,22,26,27,40].

Cut-points for the GENEA devices were established to optimize the balance between sensitivity and specificity (maximizing the Youden index), in order to guarantee the optimality of the cut-points. As expected, cut-points in SVM_{gs} were greater for sedentary, light, moderate and vigorous activity than these reported by Esligher *et al.* (2011). Besides marathon runners display greater level of fitness compared to normal population, these discrepancies might also be due to testing approach differences. In this study, we monitored runners during a continuous activity that progressively increases its intensity. However, Esligher *et al.* (2011) monitored adults performing a wide range of structured activities in a lab-based environment, classifying each activity as sedentary, light, moderate or vigorous activity. Indeed, Esligher *et al.* (2011) had a relatively small sample size (18 individuals for slow treadmill run, 14 for medium treadmill run, and 5 for fast treadmill run), which may limit their results for classifying vigorous activity.

Overall, the SVM_{gs} cut-points established in this study were able to efficiently classify different activities with a good to excellent accuracy. Since no previous studies have used a similar methodology as well as equivalent sample population, we are not able to perform a comprehensive comparison of our classification accuracy values. Our results revealed a classification

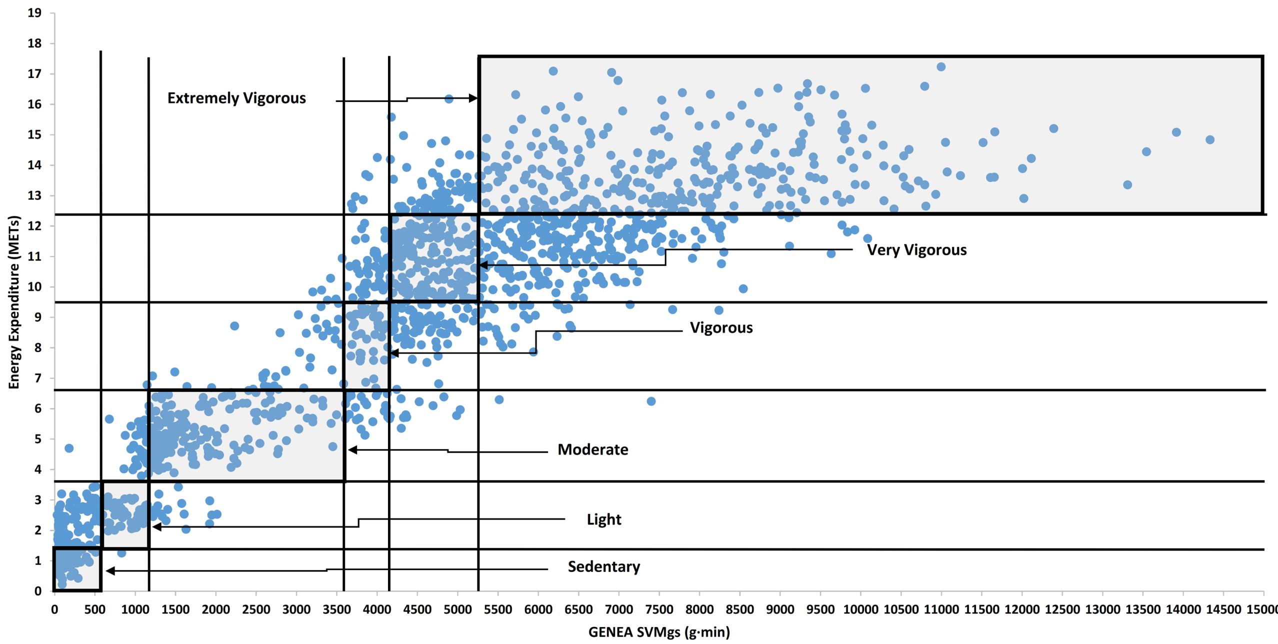

Fig 1. Correlation between the wrist-worn GENEA SVM$_{gs}$ (g·min) and the energy expenditure (METs) along the 98 cardiopulmonary exercise tests. Vertical lines delimited the different relative-intensity levels according to SVM$_{gs}$ cut-points estimated, and horizontal lines delimited the different relative-intensity levels according to METs cut-points measured (equivalent to $\dot{V}O_{2max}$ classification). Grey regions delimit the consensus outcome between the measured and predicted intensity categories, and all observations inside these regions are correct classifications for each intensity level. SVMgs, signal magnitude vector gravity-subtracted. MET, metabolic equivalent task.

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accuracy of 94.08% for sedentary, 94.08% for light, 96.54% for moderate, 95.53% for vigorous, 86.27% for very vigorous, and 73.61% for extremely vigorous activity. An important advance of the current study is the ability to split vigorous activities into three different intensity categories: vigorous, very vigorous and extremely vigorous. Enlarging the range of physical activity intensities covered by adding new activity categories allow to accurately calculate energy expenditure for activities with higher than 7 METs values (i.e. running values commonly range from 8 to 18 METs [28,41]).

In this regard, our correlation analyses reported that the GENEA devices explained 78.50% of the total variance in energy expenditure ($rs^2 = 0.785$), suggesting that the triaxial accelerometers (worn on the non-dominant wrist) can be used to predict energy expenditure for running activities with high metabolic cost (≥7 METs). However, the estimation accuracy of energy expenditure in METs from accelerometer data was slightly reduced at extremely vigorous activity because fatigue has been revealed to interfere in running biomechanics, as shown by natural arm and legs movement alteration [42], increasing therefore the standard deviation of SVM$_{gs}$ collected by the accelerometer device. Besides, the number of data points collected at extremely vigorous activity was reduced–runners were progressively stopped because of exhaustion.

Linear correlation between SVM$_{gs}$ and METs reported by previous studies for wrist-worn accelerometers was slightly lower than our correlation values [25,26]. Reasonably, the homogeneity of the sample set (adult recreational marathoners with similar age, body mass index, and level of fitness) is the reason of having a remarkably correlation between SVM$_{gs}$ and METs. Because of the main purpose of this study was to establish cut-points in adult recreational marathoners, we carefully selected individuals that represents this specific population subset. For example, individuals aged between 30 and 45 years were selected because it is the age group with higher number of marathon participants [1,2,43]. Indeed, their performance in terms of running speed appeared to be unaffected by their age [1–3,43]. Consequently, our relative-intensity activity cut-points are not applicable for adult marathon runners older than 45 years, being necessary to estimate specific cut-points in SVM_{gs} for other age groups. Therefore, it is recommended to establish specific cut-points for a specific population subset in order to accurately predict energy expenditure by using accelerometer devices.

It is well-known that there are essential physical differences between males and females with regard to sport performance [2,5,16,44]. Accordingly, we performed all cut-point analysis separating the sample set by sex. Males showed higher $\dot{V}O_{2max}$, and therefore higher MET cut-points for each relative-intensity activities, compared to females (see Table 1). In general, the ability of GENEA devices for classifying activity intensities was relatively greater in females than in males. However, given the small number of female participants (N = 15), results obtained should be cross-validated in a largest population. The reason for having small number of females is that only a 14.20% of finishers in the Valencia Fundación Trinidad Alfonso EDP 2016 Marathon were females. In this study, the percentage of females was 15.15%. To confirm our results, future research determining the SVM_{gs} cut-points should be achieved in a larger population of female marathon runners aged from 30 to 45 years.

Several strengths and limitations are noteworthy in the present study. To our knowledge, this is the first study focused on distinguish between different intensities of physical activity levels in middle-aged recreational marathoners from accelerometer data. The well-controlled experimental design allowed us to delineate specific GENEA cut-points for a robust assessment of physical activity intensity level. Finally, the homogeny and large population used was essential for ensuring the optimality of the cut-points. The main limitation of this study was that measures were not performed in free-living conditions.

Since the present study was lab-based, future validation of the SVM_{gs} cut-points in an independent sample set of adult recreational marathoners running in free-living conditions for optimal practical applications. Cross-validation would be assist in quantifying energy expenditure during the course of a marathon race. Besides, monitoring runners during non-training activities would allow comparing sedentary and light cut-points in this specific population with these previously established for standard population.

In conclusion, the GENEA accelerometer have been able to efficiently classify between all six-relative intensity levels of physical activity in adult recreational marathoners aged between 30 and 45 years. The GENEA accelerometer presents an excellent intensity classification accuracy when applying GENEA cut-points established for all samples, males and females. Remarkably, correlation tests showed a high linear relationship between energy expenditure (expressed as METs) and GENEA estimated SVM_{gs} when all individuals were analyzed together, as well as when sample set was separated by sex. Therefore, the GENEA accelerometer could be a useful tool for athletes, coaches and healthcare specialists to measure energy expenditure during races and training sessions, but also to monitor daily routine activities and rest time.

Supporting information

S1 File. Standardized questionnaire from data collection. Questionnaire used to collect information from participants in Spanish and English.
(PDF)

S2 File. Raw data of the study.
(XLSX)

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References

1. El Helou N, Tafflet M, Berthelot G, Tolaini J, Marc A, Guillaume M, et al. Impact of environmental parameters on marathon running performance. PLOS ONE 2012; 7:e37407. https://doi.org/10.1371/journal.pone.0037407 PMID: 22649525
2. Zavorsky GS, Tomko KA, Smoliga JM. Declines in marathon performance: Sex differences in elite and recreational athletes. PLOS ONE 2017; 12:e0172121. https://doi.org/10.1371/journal.pone.0172121 PMID: 28187185
3. Ahmadyar B, Rüst CA, Rosemann T, Knechtle B. Participation and performance trends in elderly marathoners in four of the world's largest marathons during 2004–2011. SpringerPlus 2015; 4:465. https://doi.org/10.1186/s40064-015-1254-6 PMID: 26339566
4. Hoffman MD, Ong JC, Wang G. Historical analysis of participation in 161 km ultramarathons in North America. Int J Hist Sport 2010; 27:1877–91. https://doi.org/10.1080/09523367.2010.494385 PMID: 20684085
5. Hoffman MD, Krishnan E. Health and exercise-related medical issues among 1,212 ultramarathon runners: baseline findings from the Ultrarunners Longitudinal TRAcking (ULTRA) Study. PLOS ONE 2014; 9:e83867. https://doi.org/10.1371/journal.pone.0083867 PMID: 24416176
6. Knechtle B, Nikolaidis PT, Zingg MA, Rosemann T, Rüst CA. Differences in age of peak marathon performance between mountain and city marathon running—The 'Jungfrau Marathon' in Switzerland. Chin J Physiol 2017; 60.
7. Esteve-Lanao J, Moreno-Pérez D, Cardona CA, Larumbe-Zabala E, Muñoz I, Sellés S, et al. Is Marathon Training Harder than the Ironman Training? An ECO-method Comparison. Front Physiol 2017; 8:298. https://doi.org/10.3389/fphys.2017.00298 PMID: 28611674
8. Mansour SG, Verma G, Pata RW, Martin TG, Perazella MA, Parikh CR. Kidney Injury and Repair Biomarkers in Marathon Runners. Am J Kidney Dis Off J Natl Kidney Found 2017. https://doi.org/10.1053/j.ajkd.2017.01.045 PMID: 28363731
9. Vickers AJ, Vertosick EA. An empirical study of race times in recreational endurance runners. BMC Sports Sci Med Rehabil 2016; 8:26. https://doi.org/10.1186/s13102-016-0052-y PMID: 27570626

10. Hoffman MD, Goulet EDB, Maughan RJ. Considerations in the Use of Body Mass Change to Estimate Change in Hydration Status During a 161-Kilometer Ultramarathon Running Competition. Sports Med 2017:1–8.
11. Dijkstra HP, Pollock N, Chakraverty R, Alonso JM. Managing the health of the elite athlete: a new integrated performance health management and coaching model. Br J Sports Med 2014; 48:523–31. https://doi.org/10.1136/bjsports-2013-093222 PMID: 24620040
12. Angus SD. Did recent world record marathon runners employ optimal pacing strategies? J Sports Sci 2014; 32:31–45. https://doi.org/10.1080/02640414.2013.803592 PMID: 23879745
13. Burrows M, Bird S. The physiology of the highly trained female endurance runner. Sports Med Auckl NZ 2000; 30:281–300.
14. Gabbett TJ, Nassis GP, Oetter E, Pretorius J, Johnston N, Medina D, et al. The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. Br J Sports Med 2017; 51:1451–2. https://doi.org/10.1136/bjsports-2016-097298 PMID: 28646100
15. Szabo A, Vega RDL, Ruiz-BarquÍn R, Rivera O. Exercise addiction in Spanish athletes: Investigation of the roles of gender, social context and level of involvement. J Behav Addict 2013; 2:249–52. https://doi.org/10.1556/JBA.2.2013.4.9 PMID: 25215208
16. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report, 2008. Washintong DC: U.S. Department of Health and Human Services 2008.
17. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, et al. Guide to the Assessment of Physical Activity: Clinical and Research Applications A Scientific Statement From the American Heart Association. Circulation 2013:01.cir.0000435708.67487.da. https://doi.org/10.1161/01.cir.0000435708.67487.da PMID: 24126387
18. Montoye HJ, Washburn R, Servais S, Ertl A, Webster JG, Nagle FJ. Estimation of energy expenditure by a portable accelerometer. Med Sci Sports Exerc 1983; 15:403–7. PMID: 6645869
19. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. J Appl Physiol 2008; 105:977–87. https://doi.org/10.1152/japplphysiol.00094.2008 PMID: 18635884
20. Cordero MJA, López AMS, Barrilao RG, Blanque RR, Segovia JN, Cano MDP. Accelerometer description as a method to assess physical activity in diferent periods of life; review. Nutr Hosp 2014; 29:1250–61. https://doi.org/10.3305/nh.2014.29.6.7410 PMID: 24972461
21. Bassett DR, Troiano RP, McClain JJ, Wolff DL. Accelerometer-based physical activity: total volume per day and standardized measures. Med Sci Sports Exerc 2015; 47:833–8. https://doi.org/10.1249/MSS.0000000000000468 PMID: 25102292
22. Montoye AHK, Mudd LM, Biswas S, Pfeiffer KA. Energy Expenditure Prediction Using Raw Accelerometer Data in Simulated Free Living. Med Sci Sports Exerc 2015; 47:1735–46. https://doi.org/10.1249/MSS.0000000000000597 PMID: 25494392
23. Shephard RJ. Absolute versus relative intensity of physical activity in a dose-response context. Med Sci Sports Exerc 2001; 33:S400–418; discussion S419-420. PMID: 11427764
24. Phillips LRS, Parfitt G, Rowlands AV. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. J Sci Med Sport Sports Med Aust 2013; 16:124–8. https://doi.org/10.1016/j.jsams.2012.05.013 PMID: 22770768
25. Esliger DW, Rowlands AV, Hurst TL, Catt M, Murray P, Eston RG. Validation of the GENEA Accelerometer. Med Sci Sports Exerc 2011; 43:1085–93. https://doi.org/10.1249/MSS.0b013e31820513be PMID: 21088628
26. Welch WA, Bassett DR, Thompson DL, Freedson PS, Staudenmayer JW, John D, et al. Classification accuracy of the wrist-worn gravity estimator of normal everyday activity accelerometer. Med Sci Sports Exerc 2013; 45:2012–9. https://doi.org/10.1249/MSS.0b013e3182965249 PMID: 23584403
27. Welch WA, Bassett DR, Freedson PS, John D, Steeves JA, Conger SA, et al. Cross-validation of waist-worn GENEA accelerometer cut-points. Med Sci Sports Exerc 2014; 46:1825–30. https://doi.org/10.1249/MSS.0000000000000283 PMID: 24496118
28. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Tudor-Locke C, et al. 2011 Compendium of Physical Activities: a second update of codes and MET values. Med Sci Sports Exerc 2011; 43:1575–81. https://doi.org/10.1249/MSS.0b013e31821ece12 PMID: 21681120
29. Schaefer CA, Nigg CR, Hill JO, Brink LA, Browning RC. Establishing and evaluating wrist cutpoints for the GENEActiv accelerometer in youth. Med Sci Sports Exerc 2014; 46:826–33. https://doi.org/10.1249/MSS.0000000000000150 PMID: 24121241
30. Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. J Appl Physiol Bethesda Md 1985 2005; 99:1112–9. https://doi.org/10.1152/japplphysiol.00023.2004 PMID: 15831804

31. Zhang S, Murray P, Zillmer R, Eston RG, Catt M, Rowlands AV. Activity classification using the GENEA: optimum sampling frequency and number of axes. Med Sci Sports Exerc 2012; 44:2228–34. https://doi.org/10.1249/MSS.0b013e31825e19fd PMID: 22617400
32. Nightingale TE, Walhin J-P, Thompson D, Bilzon JLJ. Influence of accelerometer type and placement on physical activity energy expenditure prediction in manual wheelchair users. PLOS ONE 2015; 10: e0126086. https://doi.org/10.1371/journal.pone.0126086 PMID: 25955304
33. Pentecost C, Farrand P, Greaves CJ, Taylor RS, Warren FC, Hillsdon M, et al. Combining behavioural activation with physical activity promotion for adults with depression: findings of a parallel-group pilot randomised controlled trial (BAcPAc). Trials 2015; 16:367. https://doi.org/10.1186/s13063-015-0881-0 PMID: 26289425
34. Hamlyn-Williams CC, Freeman P, Parfitt G. Acute affective responses to prescribed and self-selected exercise sessions in adolescent girls: an observational study. BMC Sports Sci Med Rehabil 2014; 6:35. https://doi.org/10.1186/2052-1847-6-35 PMID: 25285215
35. Morgan KL, Rahman MA, Hill RA, Zhou S-M, Bijlsma G, Khanom A, et al. Physical Activity and Excess Weight in Pregnancy Have Independent and Unique Effects on Delivery and Perinatal Outcomes. PLOS ONE 2014; 9:e94532. https://doi.org/10.1371/journal.pone.0094532 PMID: 24722411
36. Wijndaele K, Westgate K, Stephens SK, Blair SN, Bull FC, Chastin SFM, et al. Utilization and Harmonization of Adult Accelerometry Data: Review and Expert Consensus. Med Sci Sports Exerc 2015; 47:2129–39. https://doi.org/10.1249/MSS.0000000000000661 PMID: 25785929
37. Myers J, Bellin D. Ramp exercise protocols for clinical and cardiopulmonary exercise testing. Sports Med Auckl NZ 2000; 30:23–9.
38. Boone J, Bourgois J. The oxygen uptake response to incremental ramp exercise: methodogical and physiological issues. Sports Med Auckl NZ 2012; 42:511–26. https://doi.org/10.2165/11599690-000000000-00000 PMID: 22571502
39. Ruopp MD, Perkins NJ, Whitcomb BW, Schisterman EF. Youden Index and optimal cut-point estimated from observations affected by a lower limit of detection. Biom J Biom Z 2008; 50:419–30. https://doi.org/10.1002/bimj.200710415 PMID: 18435502
40. Zhang S, Rowlands AV, Murray P, Hurst TL. Physical activity classification using the GENEA wrist-worn accelerometer. Med Sci Sports Exerc 2012; 44:742–8. https://doi.org/10.1249/MSS.0b013e31823bf95c PMID: 21988935
41. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 2000; 32:S498–504. PMID: 10993420
42. Fudge BW, Wilson J, Easton C, Irwin L, Clark J, Haddow O, et al. Estimation of oxygen uptake during fast running using accelerometry and heart rate. Med Sci Sports Exerc 2007; 39:192–8. https://doi.org/10.1249/01.mss.0000235884.71487.21 PMID: 17218902
43. Trappe S. Marathon runners: how do they age? Sports Med Auckl NZ 2007; 37:302–5.
44. Hoffman MD, Parise CA. Longitudinal Assessment of Age and Experience on Performance in 161-km Ultramarathons. Int J Sports Physiol Perform 2014; 10:93–8.