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Analysis of Daily Energy Expenditure of Elite Athletes in Relation to Their Sport, the Measurement Method and Energy Requirement Norms

by

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The purpose of this study was to estimate the daily energy expenditure (DEE) of 30 Polish elite athletes (15 women and 15 men aged 20 to 34 years) representing aerobic-endurance sports and speed-strength sports and to compare the obtained values with energy requirement norms recommended for athletes. Participants' DEE was measured for seven days using a chronometric-tabular method and a kinematic method. The kinematic method provided significantly lower values of DEE, by 25%. Mean DEEs obtained for female aerobic-endurance and speed-strength athletes were 3042.6 ± 389 and 3255.7 ± 359 kcal/24h (a chronometric-tabular method) and 2230.9 ± 209 and 2346.3 ± 355 (the kinematic method), respectively. The differences between the two groups were not statistically significant ($p > 0.05$). Male athletes' mean DEEs were significantly higher ($p < 0.05$): 3778.0 ± 657 and 4036.7 ± 532 kcal/24h (a chronometric-tabular method) for aerobic-endurance athletes and 2983.3 ± 545 and 2970.4 ± 345 (the kinematic analysis) for speed-strength athletes. As in the case of female athletes, the differences were not significant ($p > 0.05$). While no evidence was found that the type of sport alone could cause significant differences in the overall mean DEE between aerobic endurance athletes and speed-strength athletes, athletes' sex significantly differentiated women from men in that respect (the latter's DEE was significantly greater). Such differences were not noted, though, when athletes' relative DEE (adjusted for body mass and body composition) were compared. The study revealed that the actual energy requirements of individual athletes can vary in a wide range and that they can be different from recommended energy intake.

Key words: *daily energy expenditure, athletes, accelerometer, questionnaire.*

Introduction

An appropriate dietary regime meeting athletes' individual requirements is a prerequisite of their health, optimal function and physical fitness. Together with genetic advantages and efficient training, a well-designed diet frequently determines their performance and ultimately decides about their success or failure in sport (IOC, 2010; Kreider et al., 2010). A daily food energy intake that is insufficient or exceeds energy expenditure may adversely affect the athlete's body mass, composition and function, and impair performance.

When more energy is consumed than expanded causing the energy balance to be positive, the surplus energy turns into fat tissue that increases body mass which may impair the athlete's motor skills and performance. However, excessive energy intake does not mean that the demand for nutritional substances is met. When a diet is rich in energy yet poor in certain minerals, vitamins or protein, qualitative undernourishment may develop.

On the other hand, a negative energy balance caused by less energy being taken in than is expended over a period of time can lead to energetic undernourishment that is frequently

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accompanied by macro and micronutrient deficiency, particularly when such periods are prolonged. Energetic undernourishment may hinder the growth of the athlete's body, disturb its function and cause weight loss and general debilitation, thus increasing the athlete's ability to exercise and increasing the risk of injuries (Arieli and Constantini, 2012; Burke, 2001; Loucks, 2004). It is relevant to note that the natural regulatory mechanism based on appetite and satiety is not a reliable indicator of a person's nutritional status and of whether or not their nutritional requirements are met (Carlsohn et al., 2011; Loucks, 2004). This implies a need to monitor the athletes' energy balance to ensure that they are adequately nourished.

To make a dietary plan effective, the athlete's energy expenditure must be estimated to determine how much energy they actually need. While the number of international studies on the energy expenditure of athletes in different sports and events is increasing (Clemente-Suárez, 2015; Coelho et al., 2010; Milia, 2014; Praz et al., 2014) few research reports on the training energy expenditure and daily energy expenditure of Polish elite athletes are available. To make up for the lack of necessary data, the generally available energy requirement norms are used as a basis for planning athletes' dietary intakes. The Academy of Nutrition and Dietetics, Dietitians of Canada (2016) and the American College of Sports Medicine (ACSM) (2016) recommend using norms developed for people who are physically very active, i.e. whose physical activity level (PAL) is 1.8-2.3; according to the WHO, the norms for PAL of 2.0-2.4 are appropriate (Carlsohn et al., 2011; FAO/WHO/UNU, 2005). Another option includes nutritional guidelines, recommendations and standards specifically addressing athletes' needs, many of which take into account the demands of their sport discipline (Celejowa, 2012). However, as all these values, norms and recommendations are relatively broad, calculating precisely the diet's energy value becomes problematic. For instance, a difference between dietary reference intake for an athlete aged 23 years with body mass of 70 kg may exceed 2000 kcal a day. One reason for undertaking this study was therefore a need to estimate the actual energy expenditure of Polish elite athletes representing various speed-strength sports and to compare these values with energy requirement norms recommended for athletes.

There are several methods for measuring energy expenditure, such as direct calorimetry, indirect calorimetry, the doubly labelled water (DLW) method, heart rate monitoring, a kinematic method and a chronometric-tabular method utilizing physical activity questionnaires, diaries and tables (Ainslie et al., 2003; Lipert and Jegier, 2009; Strath et al., 2013). The methods differ in convenience as well as in the reliability and accuracy of measurements. It is thought that the most reliable of them are indirect calorimetry, DLW and indirect calorimetry (Ainslie, 2003). Even so, inherent weaknesses and high costs of the methods prevent them from being widely used in studies on athletes' training energy expenditure or daily energy expenditure. For instance, the direct calorimetry method is not feasible outside a laboratory setting, the indirect calorimetry method requires the subject to wear a mask connected with a respiratory gas analyser, and the DLW is unsuitable for measurements that have to be made during short training units. Therefore, this study was also undertaken to estimate and compare energy expenditure values yielded by a kinematic method and a chronometric-tabular method which are considered to be the most convenient for athletes.

Methods

Participants

The study was carried out on 30 Polish athletes (15 women and 15 men aged 20 to 34 years) representing aerobic-endurance sports (7 women and 7 men) and speed-strength sports (8 women and 8 men). Based on athletes' sex and sport, four study groups were formed: WAE (n = 7) – female aerobic-endurance athletes (speed skating, cross-country-skiing, steeplechase, mountain biking); WSS (n = 8) – female speed-strength athletes (volleyball, downhill skiing, middle-distance running, sport climbing, lawn tennis, kayaking); MAE (n = 7) – male aerobic-endurance athletes (rowing, walking, cross-country skiing, biathlon, mountain biking); and MSS (men, speed-strength, n = 8) – male speed-strength athletes (kayaking, middle-distance running, fencing, speed skating, handball, volleyball, ice hockey).

The inclusion criterion for the study was athletes representing the national performance level in their respective disciplines. All participants were elite athletes, e.g. multiple champions of Poland and members of the national team. Some of them were among the top performers in international competitions. All measurements were performed during the preparatory period of the annual training cycle.

Design and Procedures

The baseline measurements of the participants' anthropometric variables included: body height (BH), body mass (BM), body fat mass (%BF), fat-free mass (FFM), and muscle mass (MM). The body composition variables were determined with a body composition analyser BodyComp MF+ made by Akern, Italy. Participants' body mass was measured using a Tanita TBF-300 digital scale.

The measurements of participants' daily energy expenditure were made over a period of 7 days under natural conditions. A chronometric-tabular method and a kinematic method were used for this purpose.

Participants were instructed to record all daily activities and their duration on the energy expenditure forms over a seven-day period. Then, using the available energy-cost tables for activities typical of daily living, work and sport, the energy expenditure of each activity was established. The numbers thus obtained were added up to estimate the DEE of individual participants (Celejowa, 2012).

The second method involved the use of triaxial accelerometers (ActiTrainer by ActiGraph, USA) that participants wore on the belts in the hip area (as required by the device's manual) for the seven days of the study. To make sure that readings were reliable, data concerning participants' sex, age, body height and body mass were entered into the devices before they were used for the first time.

Statistical Analysis

The statistical significance of differences between values obtained for male and female athletes was tested using the *t*-Student test, and whenever the data failed to meet its assumptions, the Mann-Whitney U-test was applied (a non-parametric equivalent of the *t*-Student test). ANOVA was performed on more than two groups of means to find significant differences between them. In the next step, significant differences were subjected to a more detailed analysis using the Tukey's test. If ANOVA assumptions were not met, a Kruskal-Wallis test and multiple-comparison post-hoc tests being a non-parametric equivalent of ANOVA were used.

All test values and coefficients were assumed to be statistically significant at $p < 0.05$.

Results

Tables 1 and 2 present participants' anthropometric characteristics and DEE values, respectively.

DEE values yielded by the kinematic method were significantly lower than those obtained with the chronometric-tabular method. The difference amounted to around 25%, i.e. 903.9 kcal/24h or 13 kcal/24 per kg of body mass. The kinematic method's tendency to produce lower values of energy expenditure (by around 20-30%) was observed in all between-group comparisons.

In all cases, the overall values of DEE were significantly higher in men. Depending on the measurement method the difference was 687 kcal/24h (accelerometers) or 759 kcal/24h (questionnaires). The relative values of DEE (adjusted for body mass) were also higher in men, but the difference between mean DEEs obtained with the questionnaire method was not statistically significant. The mean DEE of aerobic-endurance athletes and speed-strength athletes of the same sex was not significantly different, but significant differences were found between the mean DEE of male and female athletes.

Significant differences were also found between the minimum and maximum DEE of athletes in particular groups, which were unrelated to their sex and sport. Depending on the measurement method, the difference between the lowest and the highest DEE of female and male athletes was 612-1111 kcal and 1025-1976 kcal, respectively.

In the next stage of analysis, athletes' DEE was estimated taking into account body composition to obtain energy expenditure per 1 kilogram of fat-free body mass (DEE/kg FFM) and 1 kg of muscle mass (DEE/kg MM) (Table 3).

Neither athletes' sex nor sport caused significant differences between their mean relative DEE. However, while in the previous comparisons all DEE values (overall and per kilogram of body mass) were higher for men, their counterparts adjusted for FFM and MM were higher for women.

This regularity was observed in all comparisons of the questionnaire data and in most comparisons of results yielded by the kinematic method.

Table 1

Anthropometric characteristics of the studied athletes and differences between the groups' means

Group	Variable	Age [years]	BH [cm]	BM [kg]	BMI [kg/m²]	BF [%]	FFM [kg]
WAE	Mean	23.1	172.4	62.9	21.1	22.2	49.2
	SD	4.98	4.20	4.88	1.51	*4.84*	*4.97*
	Min	20.0	166.0	56.0	18.8	*14.6*	*44.2*
	Max	34.0	177.0	70.0	22.9	*26.5*	*57.4*
WSS	Mean	25.4	172.5	64.5	21.7	20.3	51.7
	SD	3.81	7.89	5.66	1.42	*5.61*	*3.73*
	Min	20.0	159.0	57.0	18.8	*12.9*	*45.9*
	Max	32.0	184.0	73.0	23.6	*29.1*	*56.8*
W	Mean	24.3	172.5	63.7	21.4	21.2	50.5
	SD	4.39	6.22	5.19	1.43	*5.17*	*4.38*
	Min	20.0	159.0	56.0	18.8	*12.9*	*44.2*
	Max	34.0	184.0	73.0	23.6	*29.1*	*57.4*
MAE	Mean	24.3	181.9	71.4	21.6	13.3	61.9
	SD	4.92	4.30	4.89	1.09	*4.22*	*5.54*
	Min	21.0	174.0	62.0	20.2	*8.1*	*53.8*
	Max	34.0	186.0	76.0	23.5	*20.2*	*70.0*
MSS	Mean	22.0	182.1	78.5	23.6	12.0	69.6
	SD	1.07	5.28	7.62	1.55	*3.37*	*5.27*
	Min	20.0	177.0	69.0	21.3	*7.0*	*64.3*
	Max	23.0	190.0	94.0	26.6	*15.3*	*80.3*
M	Mean	23.1	182.0	75.2	22.7	12.6	66.0
	SD	3.51	4.68	7.25	1.67	*3.71*	*6.53*
	Min	20.0	174.0	62.0	20.2	*7.0*	*53.8*
	Max	34.0	190.0	94.0	26.6	*20.2*	*80.3*
DIFFERENCES BETWEEN MEAN VALUES							
WAE – WSS		-2.3 (-10%)	-0.1 (-0.1%)	-1.6 (-2.5%)	-0.6 (-2.8%)	1.9	-2.5 (-4.9%)
MAE – MSS		2.3 (9.5%)	-0.2 (-0.1%)	-7.1 (-9.9%)	-2.0 (-9.3%)*	1.3	-7.6 (-11.0%)*
M – W		-1.2 (-5.2%)	9.5 (5.2%)*	11.5 (15.3%)*	1.3 (5.7%)*	-8.6*	15.5 (23.5%)*

BH – body height, BM – body mass, BMI – body mass index, BF – body fat, FFM – fat free mass)

*M – men, W – women, * - significant differences (p < 0.05)*

WAE – women, aerobic endurance; WSS – women, speed strength; MAE – men, aerobic endurance; MSS – men, speed strength; M – men; W – women.

Table 2

Overall and relative (adjusted for athletes' body mass) values of DEE by group and measurement method

Measurement method		Questionnaire		Accelerometer	
Group		DEE	DEE/kg BM	DEE	DEE/kg BM
		[kcal/24h]			
All	Mean	3536.1	50.8	2632.2	37.8
	SD	*619.9*	*5.26*	*497.93*	*4.93*
	Min	*2342*	*41.8*	*1719*	*27.3*
	Max	*5107*	*67.2*	*3659*	*48.2*
W	Mean	3156.3	49.5	2288.6	35.9
	SD	*376.23*	*3.86*	*286.32*	*3.61*
	Min	*2342*	*41.8*	*1719*	*27.3*
	Max	*3634*	*56.5*	*2795*	*42.7*
M	Mean	3916.0	52.1	2975.9	39.6
	SD	587.57	6.22	422.57	5.46
	Min	3020	43.8	2217	28.0
	Max	5107	67.2	3659	48.2
WAE	Mean	3042.6	48.3	2230.9	35.5
	SD	*389.17*	*3.63*	*209.06*	*2.46*
	Min	*2342*	*41.8*	*1833*	*32.7*
	Max	*3453*	*52.6*	*2445*	*39.0*
WSS	Mean	3255.7	50.5	2346.3	36.3
	SD	*359.22*	*3.98*	*355.17*	*4.67*
	Min	*2799*	*45.9*	*1719*	*27.3*
	Max	*3634*	*56.5*	*2795*	*42.7*
MAE	Mean	3778.0	52.7	2983.3	41.5
	SD	657.69	6.83	545.1	4.92
	Min	3131	45.4	2217	35.8
	Max	5107	67.2	3659	48.2
MSS	Mean	4036.7	51.5	2970.4	38.2
	SD	532.93	6.07	345.41	4.48
	Min	3020	43.8	2322	28.0
	Max	4669	61.0	3347	44.6

DIFFERENCES BETWEEN MEAN VALUES

Measurement method	Questionnaire		Accelerometer	
Groups	DEE	DEE/kg BM	DEE	DEE/kg BM
	[kcal/24h]			
M – W	759.7 (19.4%)*	2.6 (5.0%)	687.3 (23.1%)*	3.7 (9.3%)*
WAE – WSS	-213.1 (-7.0%)	-2.2 (-4.6%)	-115.4 (-5.2%)	-0.8 (-2.3%)
MAE - MSS	-258.7 (-6.8%)	1.2 (2.3%)	12.9 (0.4%)	3.3 (8.0%)
MAE – WAE	735.4 (19.5%)*	4.4 (8.3%)	752.4 (25.2%)*	6.0 (14.5%)
MSS – WSS	781.0 (19.3%)*	1.0 (1.9%)	624.1 (21.0%)*	1.9 (5.0%)
MAE – WSS	522.3 (13.8%)	2.2 (4.2%)	637.0 (21.4%)*	5.2 (12.5%)
MSS - WAE	994.1 (24.6%)*	3.2 (6.2%)	739.5 (24.9%)*	2.7 (7.1%)

** - significant differences ($p < 0.05$)*
Group symbols as in Table 1.

Table 3

DEE values adjusted for athletes' body composition by group and measurement method

Measure method		Questionnaire		Accelerometer	
		DEE/kg FFM	DEE/kg MM	DEE/kg FFM	DEE/kg MM
Group		[kcal/24h]			
All	Mean	61.0	107.2	45.1	79.5
	SD	7.2	12.2	6.1	11.6
	Min	44.2	82.3	31.4	53.4
	Max	76.0	132.2	53.8	102.0
W	Mean	62.6	110.5	45.2	80.0
	SD	7.0	12.3	5.9	11.4
	Min	52.6	90.8	31.4	53.4
	Max	76.0	132.2	53.8	94.7
M	Mean	59.4	103.9	45.0	79.0
	SD	7.2	11.5	6.6	12.2
	Min	44.2	82.3	31.4	55.3
	Max	73.0	127.4	53.7	102.0
WAE	Mean	62.0	110.7	45,6	81.6
	SD	6.98	12.30	5.16	9.88
	Min	52.6	96.8	38.6	67.0
	Max	71.5	128.4	52.9	94.4
WSS	Mean	63.1	110.3	44.8	78.4
	SD	7.50	13.22	7.01	13.32
	Min	53.4	90.8	31.4	53.4
	Max	76.0	132.2	53.8	94.7
MAE	Mean	60.9	107.5	47.7	84.6
	SD	7.41	12.84	5.78	12.20
	Min	49.8	87.5	40.5	71.2
	Max	73.0	127.4	53.7	102.0
MSS	Mean	58.1	100.8	43.0	74.8
	SD	7.34	9.97	6.74	11.00
	Min	44.2	82.3	31.4	55.3
	Max	65.7	112.5	52.1	88.1

DIFFERENCES BETWEEN MEAN VALUES

Measure method	Questionnaire		Accelerometer	
	DEE/kg FFM	DEE/kg MM	DEE/kg FFM	DEE/kg MM
Groups	[kcal/24h]			
M – W	-3.2 (-5.1%)	-6.6 (-6.3%)	-0.2 (-0.3%)	-1.0 (-1.2%)
WAE – WSS	-1.2 (-1.8%)	0.4 (0.4%)	0.8 (1.9%)	3.1 (3.9%)
MAE – MSS	2.8 (4.5%)	6.6 (6.2%)	4.7 (9.9%)	9.9 (11.7%)
MAE – WAE	-1.1 (-1.8%)	-3.2 (-2.9%)	2.1 (4.5%)	3.1 (3.6%)
MSS – WSS	-5.0 (-8.0%)	-9.5 (-8.6%)	-1.8 (-4.0%)	-3.7 (-4.7%)
MAE – WSS	-2.3 (-3.6%)	-2.8 (-2.6%)	3.0 (6.2%)	6.2 (7.4%)
MSS – WAE	-3.9 (-6.2%)	-9.9 (-9.0%)	-2.6 (-5.8%)	-6.8 (-8.7%)

** - significant differences (p<0.05)*
Group symbols as in Table 1.

Table 4

Discrepancies between energy requirement norms and athletes' DEE obtained with 2 measurement methods (means for all athletes)

	Athletes' DEE according to 2 measurement methods	Energy requirement norms[1]					
		very active persons (from PAL 1.75 to PAL 2.4)				Athletes	
		PAL 1.75	PAL 2.0	PAL 2.2	PAL 2.4	Period I[2]	Period II[3]
	Mean [kcal/24h]	2816.7	3223.3	3555.0	3873.3	4667.1	5067.2
Measurement method		Differences between norms and DEE (kcal/24h)					
Accelerometer	2632.2	184.5 (7.0%)	591.1 (22.5%)*	922.8 (35.1%)*	1241.1 (47.2%)*	2034.9 (77.3%)*	2435.0 (92.5%)*
Questionnaire	3536.1	-719.4 (-20.3%)*	-312.8 (-8.8%)*	18.9 (0.5%)	337.2 (9.5%)*	1131.0 (32.0%)*	1531.1 (43.3%)*

[1] – taking account of athletes' age, sex and body mass; general population norms and norms for athletes
[2] – period of smaller training workloads
[3] – period of larger training workloads
** - significant differences (p<0.05)*

Table 5

Number and percentage of athletes in the sample whose DEE obtained with the two measurement methods was the most compatible with particular energy requirement norms

Norms Measure method	< PAL 1.75	PAL 1.75	PAL 2.0	PAL 2.2	PAL 2.4	SPORT I
Accelerometer	14 (46.7%)	12 (40 %)	4 (13.3%)	--	--	--
Questionnaire	--	3 (10%)	8 (26.7%)	12 (40%)	6 (20%)	1 (3.3%)

Table 6

Mean differences between minimum and maximum values of DEE on training days (TD max-min) and training and non-training days (TD-NTD) by measurement method

Group		Measurement method			
		Questionnaire		Accelerometer	
		TD max - min	TD - NTD	TD max - min	TD - NTD
W	Mean	835.2	1257.7	746.8	1009.4
	SD	363.01	456.48	331.57	315.57
	Max	1623.0	1931.0	1350.0	1473.0
	Min	363.0	456.5	331.0	315.6
M	Mean	1492.1	2067.7	913.4	1318.1
	SD	626.8	1053.2	345.1	530.5
	Max	2819.0	3183.0	1654.0	1996.0
	Min	522.0	619.0	491.0	616.0

TD – training days; NTD – non-training days

The mean values of athletes' DEE were subsequently compared with energy requirement norms developed for the Polish population, taking PAL of 1.75-2.4 (Table 4) (Jarosz, 2012), and with norms created specifically for athletes (taking into account participants' respective sports) (Celejowa, 2012). As can be seen, mean DEE derived for all athletes from the questionnaire data matched energy requirement norms for PAL 2.2 and mean DEE calculated from accelerator readings corresponded to norms for PAL 1.75.

In most cases (14 athletes), DEE values obtained for individual participants with the kinematic method were below energy requirement norms for PAL 1.75; for 12 athletes (7 women and 5 men) the norms for PAL 1.75 were appropriate, and for 4 athletes the norms for PAL 2.0 were appropriate (Table 5). As far as the questionnaire method is concerned, the individual DEE of most athletes matched the norms for PAL 2.2, in the case of 8 and 6 athletes the norms for PAL 2.0 and PAL 2.4 were the most appropriate, and the DEE of 3 athletes corresponded to norms for PAL 1.75. Only one athlete's mean DEE matched the norms for athletes.

The weekly differences between athletes' minimum and maximum DEE on training and non-training days were also compared (Table 6). In some athletes, the difference between the highest and lowest values of DEE exceeded 2500 kcal on training days (TD max–min) and 3000 kcal when the maximum DEE on a training day and the minimum DEE on a non-training day (TD–NTD) were compared. Therefore, particular athletes' DEE can vary significantly over a week.

Discussion

In this study, energy expenditure of the study participants was evaluated using a kinematic method utilising accelerometer readings and a chronometric-tabular method requiring athletes to self-complete daily physical activity questionnaires. Both methods are considered to be the most convenient in studies with athletes. DEE values obtained with the first method proved to be lower by 20-30% (an equivalent of around 900 kcal/24h) compared with those yielded by the questionnaire method. A similar difference was reported by Rafamantanantso et al. (2002), Koehler et al. (2011), and Brage et al. (2015), in whose studies daily energy expenditure derived from accelerometers readings was lower by around 20%.

The dietary studies indicate that the daily energy requirements of athletes may range between 2500-2600 kcal/24h and 7000-8000 kcal/24h (Celejowa, 2012; Kreider et al., 2010; Schetty, 2005), but ultra-endurance athletes competing in events such as ultramarathons, multi-stage races, etc. may require more than 10000 kcal/24h (Barrero et al., 2014; Bescos et al., 2012).

The highest individual DEE obtained in this study was 5107 kcal (the chronometric-tabular method) and 3659 kcal (accelerometers). An interesting finding was that in both methods the lowest individual DEE was below 2500 kcal, the smallest one (1719 kcal) having been determined for a female athlete from accelerometer readings. These findings are in line with previous studies as athletes practising different sports, particularly women, had DEE below 2500 kcal (Eisenmann and Wickel, 2007; Frączek et al., 2018; Ismail et al., 1997).

One of the main factors determining athlete's energy expenditure is their sex. In female athletes, a higher percentage of fat tissue and lower oxygen uptake at rest and during exercise slow down their basal and post-exercise metabolism, thus reducing their daily energy expenditure. The results of this study also confirm that women have lower DEE values. All DEE values (both total and relative, i.e. adjusted for athletes' body mass) proved to be higher in men, although relative DEEs obtained for female and male athletes in aerobic-endurance and speed-strength sports did not significantly differentiate men from women.

DEE values were also calculated with respect to athletes' body composition to evaluate their energy expenditure per kilogram of fat-free body mass (DEE/kg FFM) and muscle mass (DEE/kg MM). The analysis of relative DEEs did not show male and female athletes to be significantly different from each other.

Another factor that determines athletes' energy expenditure includes demands of particular sports disciplines; however, in this study the mean DEE of male and female athletes was not found to be significantly different considering this factor alone.

An interesting observation that was made while analysing athletes' DEE was its different values between athletes of the same sex and of the same sports discipline and different DEEs in the same athletes depending on the day of the week. Depending on the measurement method, differences between the lowest and the highest values of DEE amounted to 612- 1111 kcal/24h (for female athletes) and to 1025-1976 kcal/24h (for male athletes). Differences between the relative DEE in the same groups ranged between 20 and 40%.

Similar differences between the DEE of athletes representing similar sport disciplines were found in a study of Japanese athletes (Motonaga et al., 2006), whose energy expenditure was estimated at an average of 4514 ± 739 kcal. The lowest and the highest DEE of two athletes calculated as four-day averages were 3993 ± 1052 kcal and 5960 ± 1496 kcal, respectively (a difference of 1967 kcal). Interestingly, the athlete with the smallest DEE ran longer training distances (ca. 758 km/month) than the other athlete (680 km/month). The athletes were comparable regarding their anthropometric characteristics.

In this study, participants' DEE changed between the days of the week depending on training intensity on a given day or a lack of training. The overall DEE of 10 players of the Canadian Interuniversity women's volleyball team studied by Woodruff and Meloche (2013) was estimated at an average of 3479 ± 603 kcal and their relative DEE at 46 ± 6 kcal/kg of body mass. The mean DEE of some players was different by more than 1000 kcal. In all cases the difference between the lowest and highest DEE exceeded 1000 kcal; in 4 athletes it was 1500 kcal and in 2 as much as 2000 kcal. In this study, the mean weekly DEE of 2 players of the first-league women's volleyball team was 2537 ± 530 kcal and 2280 ± 454 kcal (accelerometer readings) and 3634 ± 684 kcal and 3125 ± 541 kcal (questionnaires), respectively. The largest differences between their DEE noted on particular days of the study were 1931 and 1703 kcal. It was also interesting to find that athletes had significantly different DEE between training days; in some athletes the difference exceeded 2500 kcal.

It is not unusual for sport dieticians to use dietary norms created for the general population as a reference in calculating food energy intake for athletes. The Academy of Nutrition and Dietetics, Dietitians of Canada (2016) and the American College of Sports Medicine (2016) recommend using dietary norms for people who are physically very active, i.e. whose physical activity is best described by a PAL of 1.8-2.3. According to the WHO, dietary norms for PAL of 2.0-2.4 are appropriate (Carlsohn et al., 2011; FAO/WHO/UNU, 2005). Dietary guidelines, recommendations and norms for athletes proposed in the Polish and international literature, many of which were developed with the demands of particular sports in mind, can also be used for reference (Celejowa, 2012; Kreider et al., 2010; Potgieter et al., 2013). The International Society of Sports Nutrition (ISSN) recommends a daily energy intake of 50-80 kcal/kg of body mass, an equivalent of 2500-8000 kcal/24h for an athlete weighing between 50 and 100 kg (Kreider et al., 2010). This guideline is challenged by the results of this and other studies, according to which the daily energy requirement of athletes in various sports can be lower than the lowest values recommended by the ISSN, i.e. 2500 kcal/24h and/or less than 50 kcal/kg/24h. In this study, participants' mean DEEs were compared with the Polish energy requirement norms established for the general population (PAL of 1.75-2.4) (Jarosz, 2012) and with the norms recommended for athletes in different sports (Celejowa, 2012). According to the accelerometer readings, the DEE of 14 athletes was below the norms for PAL of 1.75, in 12 athletes it matched the norms for PAL of 1.75, and in the case of 4 athletes the norms for PAL 2.0 were appropriate. In all cases the dietary recommendations developed for athletes were rejected as inappropriate.

The authors of other studies also found athletes' actual DEE to be different from the established energy requirement norms. Having studied the energy expenditure of 29 young male adults aged 18-27 years, Rush et al. (2008) reported that their PAL varied from 1.7 to as much as 3.2 (2.2 on average). The PAL of basketball players examined by Silve et al. (2013) ranged from 2.2 to 3.7 (2.8 ± 0.4 on average). Ebine et al. (2002) reported that the PAL of professional soccer players in their study was in the range of 1.81 to 2.81 (2.19 ± 0.3 on average). Ismail et al. (1997) estimated the energy expenditure of 84 male athletes and 24 female athletes representing 9 and 4 sport disciplines, respectively, as corresponding to a PAL of 1.72-2.58 (men) and 1.65-2.34 (women). In the study by Carlson et al. (2011), the actual PAL of 40 young athletes (60%) aged 15 years was lower than 2.0 (1.9 on average), i.e. below that established by the WHO for adult athletes.

From the above it follows that using the energy requirement norms developed for athletes and/or individuals who are physically very active to develop dietary plans for athletes may disturb their energy balance. This may happen when the actual energy expenditure of an athlete is substantially at variance with the broadly defined dietary recommendations. The planning of dietary strategies for athletes must therefore be based on monitoring their energy expenditure to ensure that the proposed energy intake matches their real requirements for energy.

Conclusions

1. The kinematic method produced lower values of athletes' daily energy expenditure (DEE) compared with the questionnaire method, which imply the necessity to monitor them for actual energy expenditure.
2. Significantly different DEE of the same athlete depending on the day of the week is an argument for monitoring the energy balance of particular athletes.
3. The DEE of male and female athletes was not found to be influenced by their sport; this implies that the type of sport is not a strong determinant of energy expenditure.
4. Athletes' sex significantly differentiated between the mean energy expenditure of male and female athletes, which was higher in the former. However, the differences between the athletes' relative energy expenditure (adjusted for body mass and body composition) were either small or non-significant.
5. The actual energy requirement of an athlete can be significantly different from the energy intake norms recommended in the literature. Using the norms as the only reference for developing dietary plans for athletes may result in the miscalculation of calorie intake and energy balance disturbances.

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