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Using accelerometer to estimate energy expenditures with four equations in four training sessions

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Abstract

This study compares estimated energy expenditure (EE) from four equations using accelerometer counts in Zumba, interval 4x4 spinning, interval 4x4 running and pyramid running. The study also characterizes differences in EE and accelerometer counts during activity and recovery periods for these activities. Twenty six men and women (21.8±2.4 years) completed four training sessions. Vector magnitude counts along three axes were measured using ActiGraph GT3X accelerometers. EE was estimated using four equations. Results show that EE varied by 34.2%, 19.7%, 18.0% and 20.0% depending on which equation was used in Zumba, 4x4 running, 4x4 spinning and pyramid running, respectively ($p<0.001$). Compared with 4x4 running, Zumba had 22.0% lower EE and 4x4 spinning had 47.8% lower EE in kcal/min ($p<0.0001$). There was no significant difference in EE between 4x4 running and pyramid running. The mean VM/min (vector magnitude counts per min) for Zumba was 22.1% and 20.4% lower than for 4x4 running and pyramid running, respectively ($p<0.0001$). An 85.3% higher VM/min was found in 4x4 running compared to 4x4 spinning ($p<0.0001$). The various equations caused substantial differences in the estimation of EE, particularly in Zumba, which is explained. Interval running provided the highest EE and counts/min. When 4x4 spinning was carried out both in sitting and standing positions, the underestimation in EE from accelerometer was about 50% compared with 4x4 running.

Key words: Accelerometer counts, Zumba, running, spinning, interval, energy expenditure

Introduction

As accelerometers have become cheaper and more accurate, accelerometer measurements have become one of the most common objective methods to measure physical activity (Crouter et al., 2006; Härtel, 2011; Lyden et al., 2011). Until the early 2000s, accelerometers measured movement in the vertical (up and down) and anterior‐posterior (forward-backward) planes. The more recent accelerometers are triaxial and also measure movement in the medial‐lateral plane (sideways movement). Some studies reveal differences below 3% applying uniaxial (measurement of vertical plane only) or triaxial accelerometers for estimating energy expenditure (EE) (Howe et al., 2009; Vanhelst et al., 2012). One explanation for the low 3% value is the low impact of anterior-posterior and medial-lateral axis in the vector magnitude (VM) calculation using the triaxial accelerometer (Vanhelst et al., 2012). Greater differences between uniaxial - and triaxial equations probably occur in more dance-related activities with

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considerable activity in the anterior-posterior and medial–lateral planes.

The few accelerometer studies of vigorous physical activity that exist consider treadmill running, but also other activities have been assessed such as basketball, ascending stairs and housework (Lyden et al., 2011). No studies have used accelerometers to analyze movement pattern and energy expenditure in interval exercises such as 4x4 running, 4x4 spinning, and pyramid running, and no studies have analyzed Zumba. This paper conducts such a study. Analyzing interval exercises allows gaining insight into EE changes over time between vigorous and non-vigorous activities. Zumba is a Latin dance-inspired fitness program involving dance and aerobic elements, designed by Alberto "Beto" Perez during the 1990s (Lloyd, 2012). The EE during Zumba, which is continuous over 60 minutes without so-called activity and recovery periods (i.e. no intervals), is currently highly uncertain. Zumba is chosen due to its increasing popularity over the last decade and since it has received virtually no scientific scrutiny. As of August 1, 2013 Luettgen et al. (2012) and Sanders and Prouty (2012) are the only hits under topic "Zumba" in the ISI Web of Science database.

Rothney et al. (2008) studied the capabilities of eight previously published regression equations for three commercially available accelerometers to predict daily EE. They concluded that specific strengths and weaknesses exist for all equations and accelerometer types, and suggested that no one equation or monitor was superior in all circumstances. Aside from treadmill running, we are not aware of studies using accelerometers to evaluate high intensity activities.

Most papers in the literature analyze pure training forms such as running, weight lifting, step aerobics, etc., where time is not essential aside from the fact that longer duration causes higher exhaustion. In contrast, this paper focuses on how different activities are sequestered through time, i.e. we categorize differences in EE during both high intensity training and recovery periods. We are aware of two studies focusing on the time dimension. First, Hausken and Tomasgaard (2010) analyzed the time dimension providing insight into multiple training forms such as step aerobics, weight lifting, and aerobics joined sequentially into one training class. Second, Helgerud et al. (2007) analyzed the effect of four different training methods on VO2max and stroke volume. None of these studies used accelerometers.

The purposes of this study were to compare EE estimated from accelerometer using four published equations, in Zumba, interval 4x4 spinning, interval 4x4 running and pyramid running, and provide specific results for which equations are suitable for which training intensities. To highlight characteristic differences in these four training sessions, a secondary aim was to examine EE and accelerometer counts during activity and recovery periods.

METHODS

Participants

The participants were (with one exception) recruited among university students in athletic programs. Thirty five participants (22 females) were included. Some participants dropped out from one or several sessions. Twenty six participants (15 females), with a mean age of 21.8±2.4 years and a mean BMI of 22.1±2.1, completed all training sessions with valid data. The study information was explained orally and in writing and the volunteers gave their written informed consent. The study was submitted for Institutional Review Board (IRB) approval by the Norwegian Ethics Committee which concluded that the study does "not require formal IRB approval according to Norwegian laws and regulations in force." The study was approved by the Norwegian Social Science Data Services AS.

Design

The participants carried out four different training sessions, described below, at SIS Sports Center at the University of Stavanger, Norway during two weeks. The participants followed the instructions through the training sessions. EE was estimated from accelerometer counts and results from four different equations were compared. Accelerometer counts and EE estimated from equation (4) during activity and recovery periods were also compared to characterize differences between the training sessions.

Monday: Zumba 60 min: First 5 min warm-up, thereafter 50 min of Zumba with four short breaks for drinking, and 5 min cool-down at the end.

Thursday: 4x4 running 45 min: First 12 min warm-up, then 4 min running at 90-95% of max heart rate and 3 min jogging at 70% of max heart rate, four times, for a total of 28 min, and finally 5 min cool-down.

Monday: 4x4 spinning 45 min: Same structure as 4x4 running, replacing running/jogging with spinning.

Thursday: Pyramid running 45 min: First 12 min warmup, then 6 min running 90-95% of max heart rate and 1 min jogging ca 70% of max heart rate, then 5 min running and 1 min jogging, 4 min running and 1 min jogging, 3 min running and 1 min jogging, 2 min running and 1 min jogging, 1 min running and 1 min jogging, and finally 1 min running and 5 min cooldown.

Accelerometer measurements

The ActiGraph GT3X (ActiGraph, LLC, Pensacola, FL, USA) was used to measure the participants' accelerometer counts, and physical activity intensities were defined as light 0-2690 vector magnitude counts per minute (VM/min) or <3 METs, moderate 2691- 6166 VM/min or 3 - 5.99 METs, vigorous 6167-9642 VM/min or > 6 METs, and very vigorous > 9642 VM/min (Sasaki et al., 2011). The accelerometers were initialized (initial conditions and participants' characteristics were inserted) and data were downloaded using the ActiLife 6 software provided by the manufacturer (ActiGraph LLC). The data were collected in 60-second epochs with normal frequency filter. Depending on the equation used to estimate EE, both activity counts measured in the vertical plane only and tri-axial VM was used.

Estimating energy expenditure

The EE in kcal min^{-1} is determined by four methods, referred to as equations (1)-(4).

The first is Crouter et al.'s (2006) equation:

$$EE_C = \begin{cases} \dfrac{weight}{60} \text{ if } \dfrac{cnts}{min} \le 50 \\ \dfrac{weight}{60} \times 2.379833 \times e^{0.00013529\,\text{cnts min}^{-1}} \text{ if } \dfrac{cnts}{min} > 50 \; and \; CV \le 10 \\ \dfrac{weight}{60}\left[2.330519 + 0.001646 \times \dfrac{cnts}{min} - 1.2017 \times 10^{-7} \times \left(\dfrac{cnts}{min}\right)^2 + 3.3779 \times 10^{-12} \times \left(\dfrac{cnts}{min}\right)^3\right] \\ \text{if } \dfrac{cnts}{min} > 50 \; and \; \{CV = 0 \; or \; CV > 10\} \end{cases} \tag{1}$$

where CV is the coefficient of variation (100× SD/mean) for six consecutive 10-second epochs, SD means standard deviation, mean is the mean cnts/min, and e = 2.718. Cnts/min refers to counts measured in the vertical plane only. In equation (1) CV determines the intervals and is not present in the equations. The nature of the four sessions is such that we mostly have 0<CV≤10. Thus the first two intervals are most common. CV=0 is uncommon since participants only exceptionally cease moving. CV>10 is uncommon since participants seldom switch very abruptly in their movements. This enables us as an approximation to ignore the third interval, acknowledging that measuring every 60- second means that CV is undetermined. We multiply with weight/60 in equation (1) to convert from MET (kcal $kg^{-1} \cdot h^{-1}$) to kcal $\cdot$ min^{-1}. See Crouter et al. (2010) for an alternative to equation (1), which we have not used since it uses CV more extensively.

Second we use Williams' (1998) equation:

$$EE_W = 0.0000191 \times \frac{cnts}{min} \times \ weight \qquad (2)$$

Third we combine Freedson et al. (1998) and Williams (1998):

$$EE_{FW} = \begin{cases} 0.0000191 \times \frac{cnts}{min} \times weight \text{ if } \frac{cnts}{min} \le 1951 \\ 0.00094 \times \frac{cnts}{min} + 0.1346 \times weight - 7.37418 \text{ if } \frac{cnts}{min} > 1951 \end{cases} \qquad (3)$$

where × means multiplication, and weight is in kg, and cnts/min means counts per minute. Freedson et al.'s (1998) equation is known to underestimate activities of daily living and vigorous treadmill activities. See Lyden et al. (2011) for an evaluation of the equations of Crouter et al. (2006), Freedson et al. (1998) and other equations.

Fourth we combine Sasaki et al. (2011) and Williams (1998) equations:

$$EE_{SW} = \begin{cases} 0.0000191 \times \frac{cnts}{min} \times \text{weight if } \frac{VMC}{min} \le 2453 \\ 0.001064 \times \frac{VM}{min} + 0.087512 \times weight - 5.500229 \text{ if } \frac{VMC}{min} > 2453 \end{cases} \qquad (4)$$

where VMC is the Vector Magnitude Counts. $VM = \sqrt{(Axis\ 1)^2 + (Axis\ 2)^2 + (Axis\ 3)^2}$ is the Vector Magnitude combination of the three axes. Axis 1, Axis 2 and Axis 3 are counts measured in the vertical, horizontal and lateral axis, respectively.

The negative constants −7.37418 and −5.500229 in equations (3) and (4) are such that when participants don't exercise (cnts=VM=0), EE is negative in the equation from Freedson et al. (1998) when weight <54.79kg, and EE is negative in Williams (1998) equation when weight<62.85kg. EE cannot be negative, and the presence of the equation from Williams (1998) in equations (3) and (4) prevents negative EE and ensures that EE increases gradually from 0 as participants start to exercise (ActiGraph, 2011). EE estimated from these four equations were compared. The equation from Sasaki et al. (2011) is the newest developed equation and is the only tri-axis model. Thus, this equation is set as the reference equation in Tables 1 and 2, and used to characterize differences in EE and accelerometer counts during activity and recovery periods in the four training sessions. However, since this is a comparison study and not a validation study, the terms overestimation/ underestimation according to energy estimation from the different equations are not used.

Statistical analyses

To measure differences between the mean accelerometer counts and EE measured by equation (4) in the four training sessions, we used a paired sample t-test. To test if counts per minute significantly exceeded specific values, we used mean values and 95% confidence interval (CI) to determine the lower and upper bound.

To study how quickly and to which level the accelerometer counts and EEs decreased at the onset of

Table 1. Energy expenditure (EE) in kcal/min ± standard deviation for the four equations (1)-(4) during the four training sessions, and the mean % differences with equation (4). The percentages under EE±SD in the first three rows express the EE difference in percent between this row and equation (4) in the fourth row.

Equation	Zumba	4x4 running	4x4 spinning	Pyramid running	Mean for the four sessions
(1)	4.75± 0.9	7.94± 2.18	4.56±.0.92	7.60± 2.26	6.21± 1.40
	-34.2%	-14.2%	-5.6%	-15.6%	-18.1%
(2)	5.25± 1.34	9.89± 2.59	4.19± 1.26	9.50± 2.71	7.21± 1.66
	-27.3%	6.7%	-13.2%	5.5%	-4.9%
(3)	5.18±1.45	8.72± 2.12	3.96± 1.18	8.43± 2.40	6.58± 1.56
	-28.2%	-5.8%	-18.0%	-6.7%	-13.2%
(4)	7.22±1.73	9.26± 1.86	4.83± 1.25	9.00± 2.01	7.58± 1.34

All mean % differences are different with significance $p<0.01$.

Table 2. Energy expenditure (EE) in kcal/min ± standard deviation for the four equations (1)-(4) during the recovery and activity periods, and the mean % differences with equation (4). For the recovery periods we specify the mean minimum. For the activity periods we specify the mean max. The percentages under EE±SD in the first three rows express the EE difference in percent between this row and equation (4) in the fourth row.

	Energy expenditure (kcal/min)					
	4x4 running		4x4 spinning		Pyramid running	
Equation	Recovery	Activity	Recovery	Activity	Recovery	Activity
(1)	6.09± 1.96	9.00± 2.84	2.49± 0.87	7.69±.2.27	5.89± 2.27	8.11± 2.82
	-14.6%	-15.2%	383.3%	-29.6%	-13.9%	-17.2%
(2)	7.65± 2.75	11.29± 3.16	0.69± 0.76	9.61± 3.03	7.24± 3.24	10.19± 3.39
	7.3%	6.4%	-4.2%	-12.0%	5.8%	4.1%
(3)	7.05± 2.43	9.78± 2.39	0.70± 0.81	8.69± 2.31	6.67± 2.78	8.96± 2.70
	-1.1%	-7.8%	-2.8%	-20.4%	-2.5%	-8.5%
(4)	7.13± 2.29	10.61± 2.13	0.72± 0.83	10.92± 2.78	6.84± 2.75	9.79± 2.57

each recovery period and increased at the onset of each activity period, we extracted the single maximum (max) VM count and kcal per minute each participant reached during all the activity periods in 4x4 running, spinning and pyramid running and determined the mean of this max for the 26 participants with a 95% CI. This is referred to as max VM/min or max EE kcal/min. These data are not the same as the activity mean max data in Tables 2 and 3. Mean max and mean minimum VM counts or EE are the mean of the max and minimum values extracted from each activity or recovery period. Data are presented as means ± standard deviation (SD) or 95% CI. Statistical significance was set at $p<0.05$. All statistical analyses were performed using PASW Statistics 18 for Windows (IBM Corporation, Route, Somers, NY, USA).

RESULTS

Energy expenditure from different equations

The time dimension is essential in this study. Figure 1 shows the time development of the mean and standard deviation of the EE using the four equations for the four sessions, expressed statically in the tables. For 4x4 running and 4x4 spinning the four activity periods and four recovery periods are clearly distinguishable in Figure 1 with high and low values, respectively. For pyramid running the seven successively shorter activity periods and the six one min recovery periods are also distinguishable. Warm-up show increasing values and cool-down show decreasing values for all sessions. Mean EE estimated from equations (1)-(4) in the four

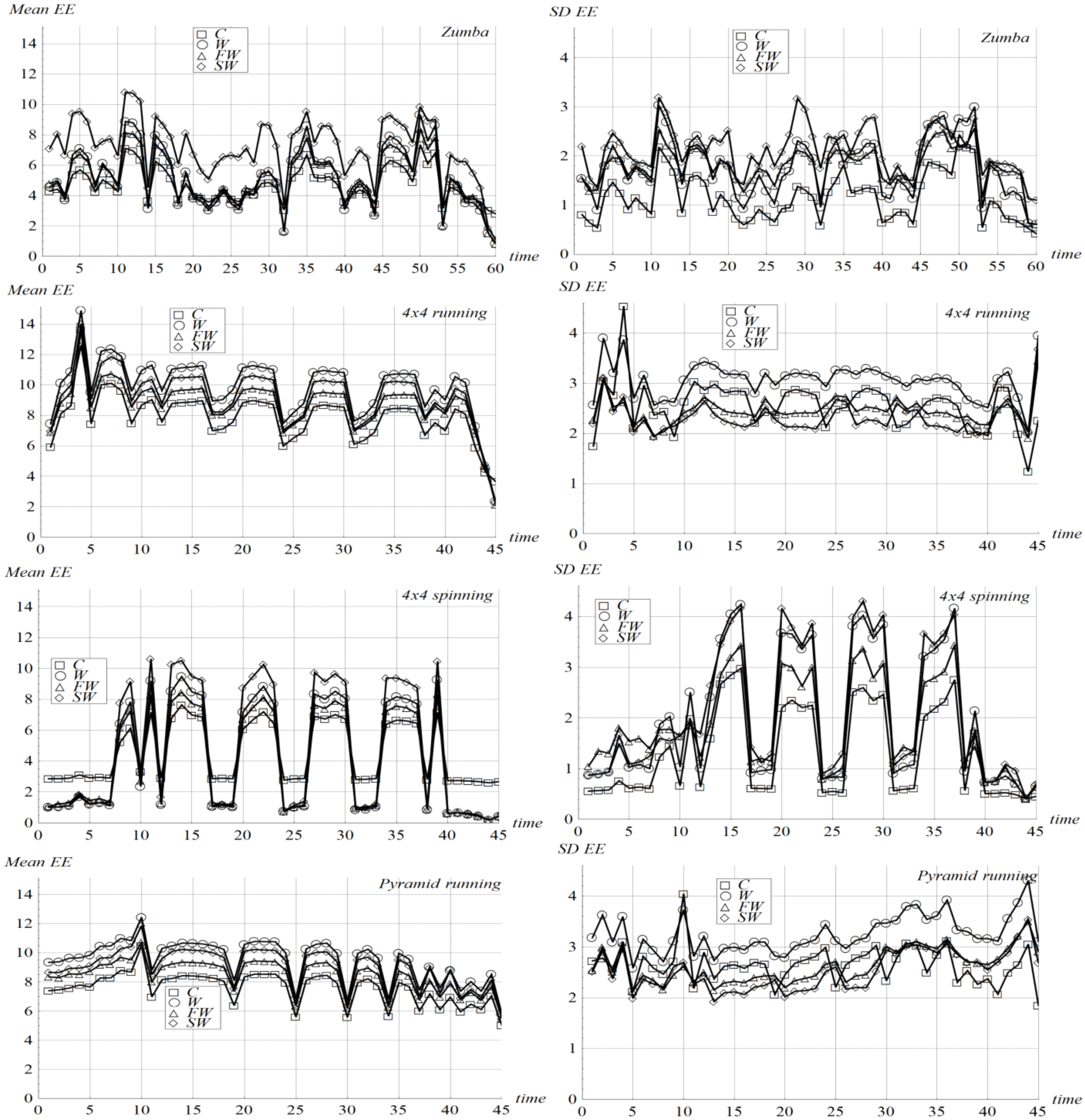

Figure 1. *Mean (four left panels) and standard deviation SD (four right panels) for energy expenditure EE (kcal/min) during time (minutes) for the four sessions where C,W,FW,SW refer to equations (1),(2),(3),(4), respectively.*

training sessions are presented in Table 1. The greatest difference in EE was found in Zumba. All four equations estimate significantly different energy expenditure ($p<0.01$) between all four sessions with two exceptions out of 16. First, for Zumba the t-test on equations (2) and (3) caused significance $p=0.48$. Second, for 4x4 spinning the t-test on equations (2) and (3) caused significance $p=0.063$.

To compare EE using the various equations in both high and low intensities in different training sessions, data from both recovery and activity periods were extracted (Table 2). Using mean minimum (see statistical analyses) EE during the recovery periods, Table 2 shows 9.0%=(0.69/7.65)100%, 9.9%= (0.70/7.05)100%, 10.1%=(0.72/7.13)100% EE in 4x4 spinning compared with 4x4 running for equations (2),(3),(4), and 40.9%=(2.49/6.09)100% for equation (1) (due to the large constant 2.330519). Using mean max (see statistical analyses) EE during the activity periods, Table 2 shows 85.4%, 85.1%, 88.9% EE in 4x4 spinning compared with 4x4 running for equations (1),(2),(3), and 102.9% for equation (4).

Accelerometer counts and energy expenditure during the four training sessions

Table 3 shows the mean EE for the various training periods using equation (4) (Sasaki et al., 2011) and the vector magnitude counts per minute (VM/min) for the different training sessions. Zumba has no intervals, and data from the 50 min duration (aside from warm-up and cool-down) is reported under Activity periods, and thus the six cells for Recovery periods, Recovery mean minimum, and Activity mean max, in Table 3 are empty. The mean VM/min for Zumba was 22.1% and 20.4% lower than for 4x4 running and pyramid running, respectively ($p<0.0001$). The measured VM/min for Zumba was 44.3% higher than for spinning ($p<0.0001$; Table 3). The EE in Zumba was 49.4% higher than in 4x4 spinning, while it was 22.1% and 19.8% lower than in 4x4 running and pyramid running, respectively ($p<0.0001$).

The 4x4 spinning session resulted in 46.0% and 47.8% lower VM/min and EE kcal · min^{-1}, respectively, than for 4x4 running ($p<0.0001$; Table 3). During the recovery periods in 4x4 spinning and running, the mean minimum VM/min and EE were only 15.6% and 10.1%, respectively, in 4x4 spinning compared to 4x4 running ($p<0.0001$; Table 3). No significant difference emerged in mean max VM/min ($p=0.65$) and EE ($p=0.64$) in the activity periods in 4x4 spinning and 4x4 running. The max VM/min during the activity periods in 4x4 spinning was 11076 (95% CI: 10261-11891, n=26). The participants' mean VM/min during the activity and recovery periods in 4x4 spinning was 79.6% and 18.4%, respectively, of max VM/min during the activity periods. The max EE during spinning was 11.91 kcal/min (95% CI: 11.04-12.77). The mean EE during the spinning activity and recovery periods is shown in Table 3. The participants' mean EE during the activity and recovery periods in spinning was 79.5% and 15.6%, respectively, of max EE during the activity periods.

The max VM/min during the activity periods in 4x4 running was 10207 (95% CI: 9643-10772, n=26). The participants' mean VM/min during the activity and recovery periods in 4x4 running was 94.1% and 72.2, respectively, of max VM/min during the activity periods. The max EE during the activity periods in 4x4 running was 10.98 kcal/min (95% CI: 10.11- 11.86). The mean EE during the 4x4 activity and recovery periods is shown in Table 3. The participants' mean EE during

Table 3. Mean vector magnitude counts per minute with standard deviation and mean energy expenditure (EE) in kcal/min with standard deviation in four different training sessions lasting 60 min (Zumba) or 45 min (other sessions). Equation (4) is used for estimating EE.

	Zumba		4x4 running		4x4 spinning		Pyramid running	
Part	Counts/min ± SD	EE ± SD (kcal/min)	Counts/min ± SD	EE ± SD (kcal/min)	Counts/min ± SD	EE ± SD (kcal/min)	Counts/min ± SD	EE ± SD (kcal/min)
Warm-up	7745 ± 1549	8.36 ± 2.13	9474 ± 1162	10.20 ± 2.36	3320 ± 670	3.45 ± 1.35	8887 ± 1271	9.50 ± 2.47
Recovery periods			7366 ± 1530	7.96 ± 2.37	2033 ± 610	1.86 ± 1.17	6307 ± 1795	6.84 ± 2.60
Recovery mean minimum			6578 ± 1536	7.13 ± 2.13	1025 ± 594	0.72 ± 0.78	6307 ± 1795	6.84 ± 2.60
Activity periods	6755 ± 1505	7.29 ± 2.18	9611 ± 1353	10.35 ± 2.17	8816 ± 2949	9.46 ± 3.77	9208 ± 1421	9.76 ± 2.40
Activity mean max			9859 ± 1364	10.61 ± 2.13	10142 ± 2328	10.92 ± 2.43	9290 ± 1414	9.79 ± 2.26
5 min cool-down	3768 ± 942	3.85 ± 1.51	6338 ± 1745	6.66 ± 2.66	763 ± 597	0.49 ± 0.78	6340 ± 2086	6.99 ± 3.01
Entire training session	6704 ± 1424	7.22 ± 1.73	8612 ± 1101	9.26 ± 1.86	4647 ± 1110	4.83 ± 1.25	8417 ± 1251	9.00 ± 2.01

the activity and recovery periods in 4x4 running was 94.2% and 72.5%, respectively, of max EE during the activity periods.

The max VM/min during the pyramid running was 9887 (95% CI: 9294-10480, n=26). The participants' VM/min during the activity periods in pyramid running was 93.1% of max VM/min with a 95% CI from 87.3-98.9% of max VM/min. The participants' mean max EE during the activity periods in pyramid running was 8.3% lower than during the activity periods in 4x4 running (p=0.004). The participants' mean minimum EE during the recovery periods in pyramid running was not significantly different from the recovery periods in 4x4 running. No significant difference in VM/min and EE kcal · min^{-1} occurred between pyramid running and 4x4 running (Table 3).

Comparing 4x4 running and pyramid running

Illustrative for increases in accelerometer counts after recovery periods, and decreases after activity periods, in the two running sessions, is the following results. The mean increase in accelerometer counts after the 3 min recovery periods in 4x4 running was 1865±1659 VM/min, which was 50.3% lower than the increase after the 1 min recovery period in pyramid running (p=0.02). The mean decrease in accelerometer counts after the 4 min activity periods in 4x4 running was 2595±1583 VM/min, which was not significantly different from the decrease after the activity periods in pyramid running (p=0.71, 2398±2215).

DISCUSSION

One main finding of the study was the large variations in estimated EE using accelerometer across the four equations. The EE per min and VM in counts per min were lower in Zumba and 4x4 spinning compared to both interval running sessions. No significant difference in EE and VM was found between the two running sessions. For very vigorous intensity (> 9642 VM/min) no significant difference in EE and VM was found between 4x4 spinning and 4x4 running.

The significant differences between the four equations in EE estimation were particularly seen in Zumba where equations (1),(2),(3) estimated 34.2%, 27.3% and 28.2%, respectively, lower EE than equation (4). The main reason is that equation (4) also includes movement in the medio-lateral plane (sideways movement), which is substantial in Zumba, and not just the vertical plane (up and down) and the antero-posterior plane (forward- backward). Therefore, equation (4) is used as the reference against which equations (1), (2), (3) are compared (Table 1).

Four results are noteworthy about Table 1. First, all the 15 percentages with two exceptions are negative. This is mainly due to equation (4) accounting for all the three axes. The two exceptions are equation (2) for 4x4 running and pyramid running with positive percentages 6.7% and 5.5%, respectively. Two reasons for the higher EE estimation are that running is a vigorous activity, and that Williams' (1998) one-term equation is often used for non-vigorous activities, as shown with its presence in equations (3) and (4). Thus a linearly increasing curve through the origin, such as equation (2), can easily overestimate for vigorous activities.

Second, compared with equation (4), equations (1) and (3) give lower EE in all activities, while equation (2) gives a higher EE in both running sessions and gives a lower EE in Zumba and 4x4 spinning. Hence overall for all activities, equation (2) based on Williams (1998) seems as the best substitute for equation (4) if not all three axes can be measured. However, in both running sessions the mean EE from equations (2) and (3) are similar.

Third, as shown in Table 1, equation (1) for 4x4 running and pyramid running gives −14.2% and −15.6%, respectively, compared with equation (4). More accurately, equation (3) for 4x4 running and pyramid running gives -5.8% and -6.7%, respectively, compared with equation (4). Thus equation (3) is preferred to equation (1) in both running sessions where intensities were mostly vigorous, but extend into very vigorous for some participants (Table 3). During both running sessions the participants burned above 9 kcal/min (Table 3). Lyden et al. (2011) found that the bias for estimating EE in activities of daily living, which were light, moderate, or vigorous, was -0.2 METS for equation (1), and -2.0 METS for equation (3) compared with equation (4). However, the bias for estimating EE in moderate walking intensity, 1.34 m/s (5.9 kcal/min) or 1.56 m/s (6.7 kcal/min), and running 2.23 m/s (9.2 kcal/min, vigorous intensity) was -1.0 METS for equation (1) and -0.8 METS for equation (3), using Howley and Thompson (2012) conversion Table 6.5. Lyden et al.'s (2011) results for activities of daily living and running are therefore conflicting. Assuming that daily living involves light intensity, the implication is that equation (1) is best for light intensity and equation (3) is best for vigorous intensity. However, both give lower EE than equation (4). This implication is consistent with our results. Lyden et al. (2011) claim that equation (1) (Crouter et al., 2006), based on a two-regression model, may not extrapolate well to activities outside the intensity ranges within which it was developed. Running at 11 km/h was one of the activities included when developing equation (1). Using Howley and Thompson's (2012) conversion Table 6.5, a participant with weight 64.2 kg and running at 11 km/h burns around 12.2 kcal/min. This means that the running intensity used in the present study should be accounted for in equation (1). Even so, we conclude that equation (1) (Crouter et al., 2006) results in a much lower EE for vigorous and very vigorous intensities compared to equations (3) and (4). One reason for this could be that the impact of very vigorous intensities is not sufficiently well accounted for in equation (1). Table 2 shows that the recovery periods during 4x4 spinning yielded very low EE between 0.69 and 0.72 kcal/min for equations (2),(3),(4) due to limited hip movement. Equation (1) provides the larger EE=2.49 kcal/min due to the large constant 2.330519×weight/60 in line 3 which applies regardless of cnts when cnts/min>50, and which better reflects the basic metabolic rate at low intensities. The first line in equation (1) gives the lower value weight/60 when cnts/min≤50, which occurs only rarely. Hence equation (1) gives a more precise EE estimation than equation (3) in activities with low intensity. This finding is also reported by Crouter et al. (2006) and Lyden et al. (2011).

Fourth, for Zumba the absolute values of the negative percentages are so large that equations (1),(2),(3) in our view are useless to accurately predict EE. This is especially the case for equation (2) causing a severely lower EE also for non-vigorous activities. But, even equations (2) and (3) caused unacceptably large differences, -27.3% and -28.2%, compared to equation (4).

During Zumba the participants had around 20% lower VM/min and EE than during the two running sessions. This could be caused by Zumba lasting 15 min longer than the running sessions, and the fact that many participants tried Zumba for the first time. However, even though most of the participants were inexperienced in Zumba, the mean VM/min score during Zumba was 6704 VM/min, 8.7% above the lower threshold for vigorous intensity. This may be explained by the participants being relatively athletic, and Zumba enabling participants to exhaust themselves to some extent.

Large differences in VM/min and EE were found between 4x4 spinning and 4x4 running. The differences were far greater during recovery than activity. The participants during 4x4 running decreased their VM/min from 94% of max during the activity periods to 72% of max in the recovery periods. Surprisingly, the max VM/min during 4x4 spinning was 7.8% higher than during 4x4 running. However, the mean VM/min during 4x4 spinning was around 80% of max during activity, and only 18% of max during recovery. This could be explained by most participants choosing to spin in standing position during the activity periods of 4x4 spinning, and to sit during the recovery periods. If the participants had been spinning in standing position during the entire session, the VM/min in 4x4 spinning and 4x4 running would have been similar. The literature does not distinguish between sitting and standing in spinning, tests only at light intensity, and measures EE using a variety of different methods. Previous studies have found that EE in stationary cycling estimated by accelerometer was only between 33-62% of EE estimated by oxygen consumption (Campbell et al., 2002; Jakicic et al., 1999; Yokoyama et al., 2002). Table 3 illustrates that 4x4 spinning generated 52.2% (i.e. 4.83/9.26) of the EE generated by 4x4 running. These two activities are usually believed to be similarly exhaustive. Thus as a rough estimate if only accelerometer measurements are available, spinning EE measurements are doubled, and comparable to 4x4 running, if participants are spinning equally long in standing and sitting positions.

During pyramid running the participants' VM/min followed the same pattern as during 4x4 running, but the mean VM/min was lower during the recovery periods than in 4x4 running. The participants' VM/min decreases equivalently from activity to recovery in pyramid- and 4x4 running. However, the activity patterns are only similar during the first minute of recovery. During both running sessions the participants generated lowest EE during the first minute of each recovery period. Since the increase in VM/min after 3 min recovery in 4x4 running was around 50% lower than the increase in VM/min after the 1 min recovery period in pyramid running, it seems that the participants increased their activity levels gradually during the last 2 min of the recovery period in 4x4 running. This implies that the participants needed the first minute of recovery to recover during both running sessions, but were ready to increase their intensity after this first minute.

The finding in Table 3 that participants have 4.2% lower VM/min during the activity periods in pyramid running than in 4x4 running, could be a result of a longer total activity time in pyramid running compared to 4x4 running (22 min = 6+5+4+3+2+1+1 min vs. 16 min = 4x4 min). The difference in the length of the activity and recovery periods does not result in significant difference in VM/min and EE between the two running sessions. The participants may therefore choose their preferred running session knowing that their choice hardly influences EE.

CONCLUSIONS

Different equations for estimating energy expenditure from accelerometer counts have been published. This study examined the differences between four different equations in four different exercise settings, and found a variation in energy expenditure up to 34.2%. We compare the intensities and energy expenditure (EE) between the types of exercise, and compare the equations for EE estimation against each other. Based on findings from the present study it is recommended that in Zumba and other activities which involve acceleration in all three movement-planes, a triaxial accelerometer and equation (4) (Sasaki et al., 2011) should be used to estimate energy expenditure. If not all three axes are measured, Williams (1998) seems as the best substitute for equation (4) overall for all sessions tested in this paper. During vigorous activity (6167-9642 counts per minute) equation (3) (Freedson et al. (1998) and Williams (1998)) give results similar to Williams (1998) and equation (4).

No significant difference in energy expenditure was found between 4x4 running and pyramid running, which are two very different interval running sessions. The first minute of the recovery periods in interval running seems to be most important. During Zumba the energy expenditure per minute was around 20% lower than interval running, but 50% higher than for 4x4 spinning. Monitoring spinning with accelerometer placed at the hip could be useful when participants are cycling in standing position. When spinning roughly equally much in sitting and standing positions, the underestimation in energy expenditure from accelerometer is about 50% compared with 4x4 running.

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