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Concurrent Validation of T-REX Accelerometer

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Abstract

Purpose: To examine the concurrent validity of the T-REX accelerometer assessing physical activity against indirect calorimetry (oxygen uptake) and two different accelerometers (Actical and ActiGraph).
Methods: Fifty healthy volunteers (25 men, age 23.5 ± 1.7 years; 25 women, age 22.4 ± 2.0 years) participated in tests using treadmill protocol. They walked or ran on a treadmill at four different speeds (4, 6, 8, and 10 $km \cdot h^{-1}$ for men and 4, 6, 7.5, and 9 $km \cdot h^{-1}$ for women) for 5 min at each speed. During the test, the T-REX (Taewoong Medical Co., Ltd., Korea) was attached at five locations on the body (ankle, arm, chest, waist, and wrist), the Actical was attached at two locations (waist and chest), and the ActiGraph was worn at the waist. Oxygen uptake (VO_2) was measured using a portable device during exercise, and metabolic equivalents (METs) were calculated. The validity of the T-REX was assessed using Pearson correlations and Bland–Altman plots.
Results: There were strong associations between T-REX and VO_2 in men (r = 0.92–0.95) and women (r = 0.83–0.91) on the treadmill test ($p<0.001$). Associations between the T-REX and two different accelerometers (Actical and ActiGraph) were also strong (r = 0.89–0.98). Similar associations were also observed between VO_2 and Actical (r = 0.87–0.95) and between VO_2 and ActiGraph (r = 0.85–0.87). In the Bland–Altman plots, there were no statistical differences between VO_2 and five T-REX sensor locations in both men and women (all $p>0.05$).
Conclusion: The T-REX has a high concurrent validity with VO_2 in assessing energy expenditure in men and women. This device might be an alternative to conventional accelerometers.

Key words: activity monitor, oxygen uptake, physical activity

Introduction

The benefit of physical activity (PA) in promoting public health and preventing disease has been well documented. Over the last few decades, researchers have been considering ways to quantify PA levels. Although a variety of PA measuring tools have already been developed, such as the self-report questionnaire, indirect calorimetry, heart rate monitoring, and the pedometer, they are limited in accuracy, cost, and comfort among other factors. The accelerometer has been receiving renewed attention as a relatively sound tool that overcomes these limitations (Atienza et al., 2011; Bassett, 2000; Lyden,

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Kozey, Staudenmeyer, & Freedson, 2011; Westerterp, 2009). The interest in accelerometers is expected to continue in the coming years because it is a leading product in the growing industry of wearable computing (Hekler et al., 2015; Mannini, Sabatini, & Intille, 2015). However, some improvements are still needed. Most accelerometers currently used are known for low accuracy in non-locomotion and very high- and low-intensity locomotion activities (Bassett, 2000; Johnson et al., 2015; Lyden et al., 2011). Furthermore, studies consistently report difficulties with interpreting data because of the absence of standardization (Freedson, Lyden, Kozey- Keadle, & Staudenmayer, 2011; Lyden et al., 2011; Staudenmayer, Pober, Crouter, Bassett, & Freedson, 2009). For example, each accelerometer yields different data, including counts, cutoff points to assess PA levels, and equations to predict energy expenditure. Many investigators have suggested alternatives to compensate for this limitation: optimal sensor positions (Atallah, Leong, Lo, & Yang, 2011; Ellis et al., 2014; Mannini et al., 2015; Pavey, Gomersall, Clark, & Brown, 2015; Zhu & Lee, 2010); combined sensors (Bassett, 2000; Swartz et al., 2000); modified cutoff points or equations (Crouter & Bassett, 2008; Esliger et al., 2011; Hanggi, Phillips, & Rowlands, 2013); and innovative data processing methodologies (Freedson et al., 2011; Hagenbuchner, Cliff, Trost, Van Tuc, & Peoples, 2015; Staudenmayer et al., 2009).

Despite the work on accurately assessing PA, challenges remain in verifying PA measurement. Taewoong recently developed a new, small and lightweight accelerometer called the T-REX. In this paper, we examined the concurrent validity of the T-REX accelerometer assessing physical activity against indirect calorimetry (oxygen uptake) and two different accelerometers (Actical and ActiGraph).

Methods

Participants

The participants included 25 men (mean ± SD: age 23.5 ± 1.7 years, height 175.2 ± 5.4 cm, weight 69.8 ± 7.0 kg, BMI 22.7 ± 2.2 $kg{\cdot}m^{-2}$, leg length 101.5 ± 4.7 cm) and 25 women (age mean 22.4 ± 2.0 years, height 161.4 ± 4.5 cm, weight 55.9 ± 5.1 kg, BMI 21.4 ± 1.6 $kg{\cdot}m^{-2}$, leg length 94.8 ± 3.5 cm) from Kookmin University in Seoul, South Korea. No participants had any problems with PA and or any cardiovascular, respiratory, or metabolic disease. Before attending the experimental session, all participants refrained from vigorous PA and alcohol intake on the day before taking part in the experiment. The purpose and objectives of our study were clearly explained to each participant and written informed consent was obtained.

Measures

To verify the validity of T-REX during exercise, we simultaneously measured oxygen consumption and compared the T-REX output with two different types of commercial accelerometers: Actical and ActiGraph. The T-REX (Taewoong Medical Co., Ltd., Seoul, South Korea) is a small (3.8 × 3.8 × 0.7 cm) and lightweight (10.2 g) triaxial accelerometer. The activity signal, which is produced by measured force changes at the unit's movement sensor, is continuously recorded. The T-REX accelerometer reacts to triaxial changes in acceleration based on microelectromechanical systems. The signal is digitized and stored in memory. The dynamic range of the accelerometer is ±8g. The sample rate for body motion is 50 samples per second with 16-bit resolution. Data were downloaded from the T-REX to a computer after gathering all of the accelerometer data. The data were calculated as a vector magnitude with the gravitational acceleration component removed through a high-pass filter.

To measure oxygen consumption, we used the Cosmed K4b² (Cosmed, Rome, Italy) metabolic system, which has been shown to be a valid instrument for measuring oxygen uptake (VO_2) and carbon dioxide production (VCO_2). The system is easy to monitor in real time because it is light (925 g) and wireless, and all of the data were measured through a breath-by-breath analysis: VO_2 and VCO_2 were collected breath-by-breath every 10 s for each activity, and energy expenditure was calculated from the prediction equations. Before each test, the system was calibrated according to the manufacturer's instructions. All data from the Cosmed $K4b^2$ were stored on a Windows-based personal computer.

The Actical and ActiGraph have commonly used accelerometers. The Actical (model IPX7, Mini Mitter Co., Inc., Bend. OR, USA) is an omnidirectional accelerometer that is a small (2.7 x 2.8 x 1.0 cm), lightweight (17 g), wireless, and noninvasive PA monitoring system. The Actical is a dual-mode accelerometer that uses a piezoelectric mechanism. The ActiGraph (model GT3X, LLC, FL, USA) is also a lightweight, portable device (3.8 x 3.7 x 1.8 cm, 27 g). The ActiGraph is a triaxial monitor that provides activity count and inclinometer information on the vertical, horizontal, and lateral axis. This monitor can detect acceleration and provides the activity data in the raw mode. In our study, the Actical and ActiGraph data were collected in 1-s epochs and downloaded directly to a compatible computer.

Procedure

All experimental sessions were performed in an exercise physiology laboratory at Kookmin University. Before starting, the weight, height, and blood pressure of each participant were measured, and BMI was calculated. After anthropometry measurements, the T-REX, Actical, ActiGraph and $K4b^2$ were attached to the participants. The T-REX accelerometers were positioned at five locations (ankle, upper arm, chest, waist, and wrist). The Actical accelerometers were worn on the waist and chest, and ActiGraph accelerometers were worn on the waist using an elastic belt. The $K4b^2$ was worn as a vest. All instruments were synchronized before the experiments.

Participants walked or ran on a treadmill at four different speeds (4, 6, 8, and 10 $km \cdot h^{-1}$ for men and 4, 6, 7.5, and 9 $km \cdot h^{-1}$ for women). The treadmill speeds used in this study were based on a those used in previous studies (Eston, Rowlands, & Ingledew, 1998; Stone, Rowlands, & Eston, 2009). However, in our pilot experiment, we found that the 10 $km \cdot h^{-1}$ treadmill walking speed was too difficult for women. Therefore, we amended the treadmill walking speeds to 4, 6, 7.5, and 9 $km \cdot h^{-1}$ for women. Each 5-min stage of treadmill exercise was separated by a 1-min rest period.

Data Processing

After each experimental session, all data were downloaded and stored on a Windows-based personal computer for further analysis. The VO_2 data were filtered with 1-min averaging using the $K4b^2$ software. T-REX, Actical, and ActiGraph data were also integrated into 1-min epochs for further analysis. The three types of accelerometers' data were synchronized with the minute- by-minute data from the $K4b^2$. Some data were missing during the experimental session and data downloading.

Statistical Analysis

Descriptive statistics (mean and SD) were calculated for each device. All variables were tested for normality assumptions using the Shapiro-Wilk test. The concurrent validity of T-REX, measured at five different locations (ankle, upper arm, chest, waist, and wrist), was assessed with VO_2 using Pearson correlations. Standard errors of estimate (SEE) were also estimated to quantify the prediction accuracy of VO_2 by T-REX, Actical, and ActiGraph, respectively, using a simple regression analysis. One-way repeated measures ANOVAs were used to test mean differences for VO_2, T-REX, and Actical and ActiGraph values across treadmill speeds. We corrected critical F value multiplying ϵ by the degrees of freedom when the sphericity assumption was unjustified (Greenhouse- Geisser ϵ<0.75). We standardized all variables to z-scores and performed Bland–Altman plots, testing mean differences between VO_2 and T-REX using one-sample t-tests. All statistical procedures were performed using the SPSS Statistics version 23 (SPSS Inc., Chicago, IL, USA).

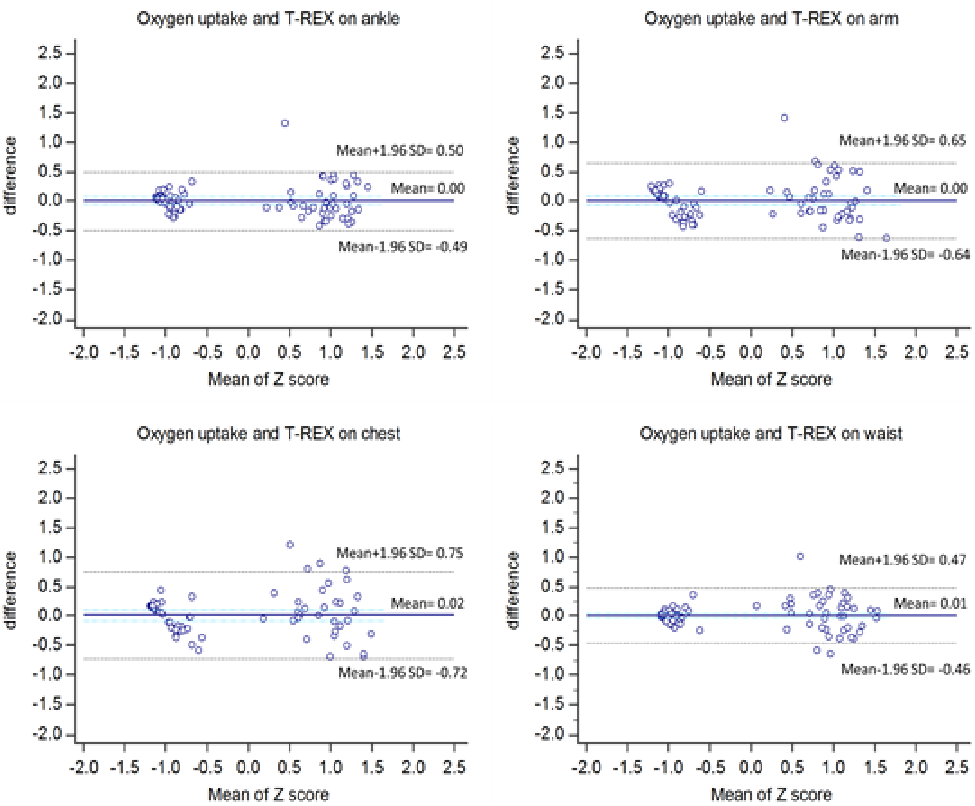
Results

Means and SDs for VO_2, T-REX, Actical, and AtiGraph values and manual step counts for locomotion on the treadmill are shown in Table 1. The accelerometer values and METs predicted by the accelerometer were subdivided according to sensor location from each device and sex, respectively. The mean scores for VO_2, T-REX, and Actical and ActiGraph values were progressively higher across treadmill speed levels (all $p<0.001$). As shown in Table 2, there were strong associations between T-REX and VO_2 (r = 0.83–0.95). The associations between the T-REX and two different accelerometers (Actical and ActiGraph) were also strong (r = 0.89–0.98). Similar associations were also observed between VO_2 and Actical (r = 0.87–0.95) and between VO_2 and ActiGraph (r = 0.85–0.87). In general, these associations were higher in men (T-REX, r = 0.92–0.95; Actical, r = 0.94–0.95; ActiGraph, r = 0.87) than in women (T-REX, r = 0.83–0.91; Actical, r = 0.87–0.88; ActiGraph, r = 0.85) across all locations for three different devices. The standard errors of estimate provided by regression analysis for T-REX (men, 3.14 to 3.73 ml kg^{-1} min^{-1}; women 3.83 to 4.58 ml kg^{-1} min^{-1}), Actical (men, 3.02 to 3.54 ml kg^{-1} min^{-1}; women 3.84 to 3.92 ml kg^{-1} min^{-1}) and ActiGraph (men, 3.45 ml kg^{-1} min^{-1}; women 4.33 ml kg^{-1} min^{-1}) were relatively small to moderate ranges (Table 2).

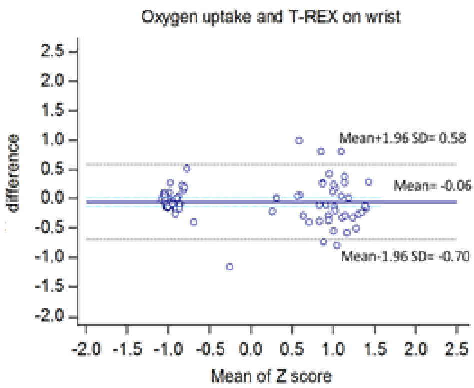
As shown in Figure 1, Bland–Altman plots showed high agreement between VO_2 and T-REX at all sensor locations for the treadmill exercises. There were no significant mean differences between VO_2 and five T-REX sensor locations in men and women (all $p>0.05$), respectively. The range of mean difference for five locations of T-REX (95% CI) was -0.72 to 0.75 in men and -1.14 to 1.16 in women.

Figure 1. *Bland–Altman plots between oxygen uptake and T-REX across five different body locations in men (a) and women (b).*

(a)



(a)


Oxygen uptake and T-REX on wrist
difference
Mean of Z score
Mean+1.96 SD= 0.58
Mean= -0.06
Mean-1.96 SD= -0.70

(b)

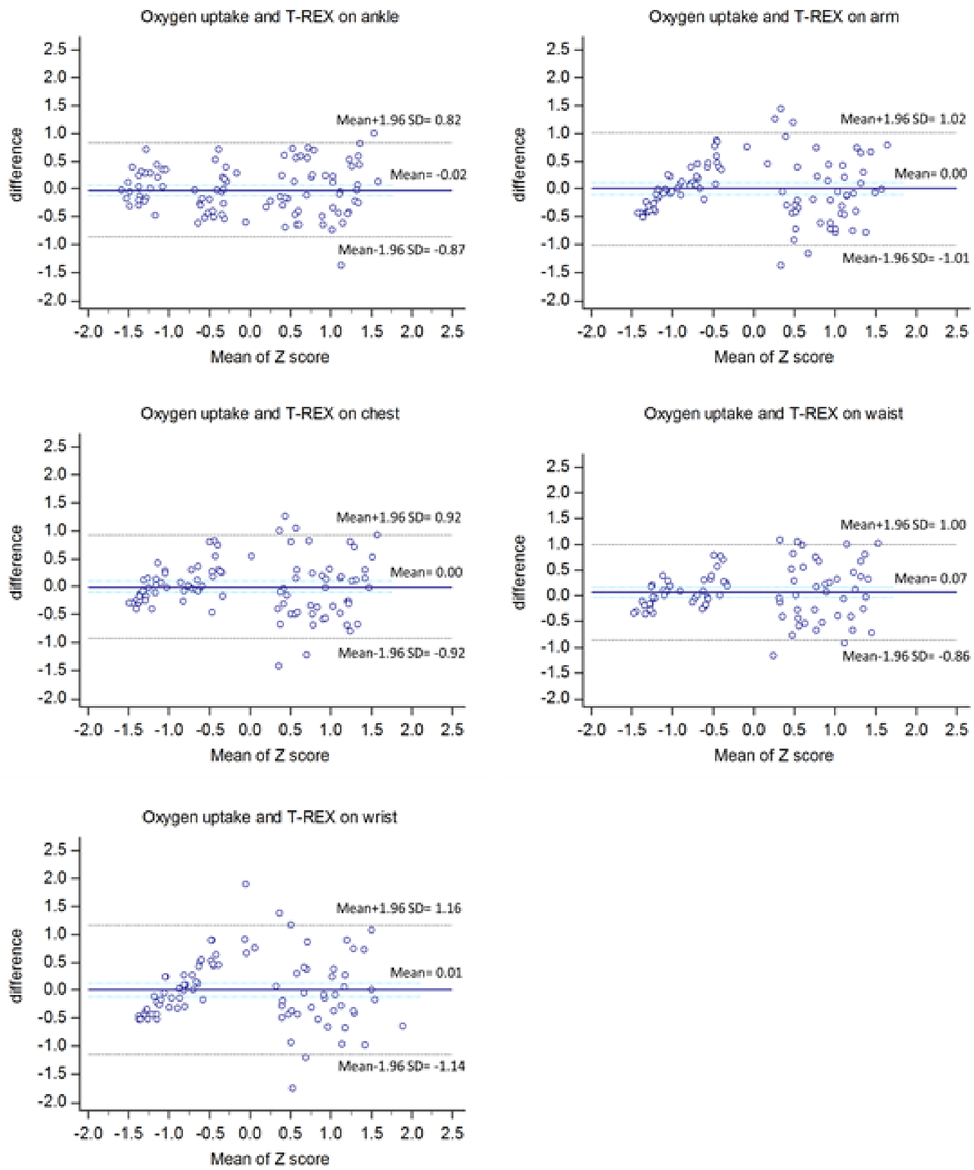

Oxygen uptake and T-REX on ankle
difference
Mean of Z score
Mean+1.96 SD= 0.82
Mean= -0.02
Mean-1.96 SD= -0.87
Oxygen uptake and T-REX on arm
difference
Mean of Z score
Mean+1.96 SD= 1.02
Mean= 0.00
Mean-1.96 SD= -1.01
Oxygen uptake and T-REX on chest
difference
Mean of Z score
Mean+1.96 SD= 0.92
Mean= 0.00
Mean-1.96 SD= -0.92
Oxygen uptake and T-REX on waist
difference
Mean of Z score
Mean+1.96 SD= 1.00
Mean= 0.07
Mean-1.96 SD= -0.86
Oxygen uptake and T-REX on wrist
difference
Mean of Z score
Mean+1.96 SD= 1.16
Mean= 0.01
Mean-1.96 SD= -1.14

Table 1. Descriptive statistics for locomotion on the treadmill using indirect calorimetry (oxygen uptake), T-REX, Actical, and ActiGraph

Measure	Male, M Female, F	4(km·h⁻¹) 4(km·h⁻¹)	6(km·h⁻¹) 6(km·h⁻¹)	8(km·h⁻¹) 7.5(km·h⁻¹)	10(km·h⁻¹) 9(km·h⁻¹)	*p* value*
K4b²						
VO_2(ml·kg⁻¹·min⁻¹)	M(n=25)	13.01±1.51	18.90±1.97	31.06±2.29	36.63±3.25	<0.001
	F(n=25)	12.45±1.94	18.93±2.17	27.60±2.88	32.16±3.32	<0.001
METs	M(n=25)	3.72±0.43	5.40±0.56	8.87±0.65	10.47±0.93	<0.001
	F(n=25)	3.56±0.55	5.41±0.62	7.89±0.82	9.19±0.95	<0.001
T-REX(waist)						
Value	M(n=19)	2.92±0.45	4.60±0.55	9.01±0.98	11.32±1.16	<0.001
	F(n=22)	3.11±0.35	5.31±1.15	9.23±1.30	11.24±1.73	<0.001
METs	M(n=19)	3.74±0.48	5.98±0.53	8.15±0.57	10.56±0.78	<0.001
	F(n=22)	4.10±0.22	5.42±0.72	7.92±0.81	9.17±1.08	<0.001
T-REX(chest)						
Value	M(n=25)	2.20±0.26	4.00±0.46	9.00±1.21	10.90±1.19	<0.001
	F(n=25)	2.52±0.44	4.65±1.32	8.77±1.05	10.60±1.10	<0.001
METs	M(n=25)	4.04±0.18	5.28±0.31	8.87±0.86	10.23±0.84	<0.001
	F(n=25)	4.03±0.27	5.27±0.80	7.79±0.91	8.89±0.66	<0.001
T-REX(ankle)						
Value	M(n=25)	5.96±0.63	8.99±0.70	11.82±0.76	15.01±1.03	<0.001
	F(n=25)	6.31±0.60	9.40±0.73	12.19±0.85	14.33±0.81	<0.001
METs	M(n=25)	3.73±0.48	5.98±0.53	8.15±0.57	10.56±0.78	<0.001
	F(n=25)	3.60±0.40	5.63±0.48	7.57±0.58	9.01±0.55	<0.001
T-REX(arm)						
Value	M(n=25)	1.97±0.22	3.18±0.34	10.90±1.46	13.00±0.86	<0.001
	F(n=25)	2.06V0.32	3.75±1.64	9.47±2.22	11.73±1.79	<0.001
METs	M(n=25)	4.20±0.13	4.87±0.19	9.08±0.79	10.21±0.46	<0.001
	F(n=25)	4.30±0.15	5.06±0.76	7.77±1.03	8.82±0.83	<0.001
T-REX(wrist)						
Count	M(n=25)	2.00±0.41	2.96±0.66	13.28±2.29	15.89±1.83	<0.001
	F(n=23)	2.36±0.70	4.24±2.75	11.91±3.49	14.51±3.79	<0.001
METs	M(n=25)	4.47±0.16	4.82±0.27	9.04±0.93	10.10±0.74	<0.001
	F(n=23)	4.06±0.23	5.17±0.90	7.71±1.14	8.57±1.24	<0.001
Actical(waist)						
Count	M(n=25)	509±391	1350±901	12466±2123	14305±1682	<0.001
	F(n=25)	1243±926	2727±1248	10418±2776	12478±3702	<0.001
METs	M(n=25)	2.17±0.57	3.20±0.89	11.54±1.56	12.89±1.23	<0.001
	F(n=25)	3.12±0.88	4.37±0.99	10.01±2.04	11.50±2.75	<0.001
Actical(chest)						
Count	M(n=25)	1330±342	3430±732	10377±1303	12389±1320	<0.001
	F(n=25)	1363±543	5327±805	9098±2370	11520±1422	<0.001
METs	M(n=25)	3.68±0.23	5.06±0.48	9.60±0.83	10.92±0.84	<0.001
	F(n=25)	3.63±0.61	5.13±0.53	8.76±1.55	10.34±0.93	<0.001
ActiGraph(waist)						
Count	M(n=19)	105±5.11	123±3.77	162±8.66	166±9.02	<0.001
	F(n=21)	107±11.3	129±4.42	160±8.56	167±11.28	<0.001
Manual count step						
	M(n=25)	530±27	615±24	799±50	825±54	<0.001
	F(n=25)	560±24	644±24	799±40	834±56	<0.001

Data presented as mean ± SD. METs, metalbolic equivalents. *P-value based on F-test using one-way repeated measures ANOVAs.

Table 2. *Correlations (R) and standard errors of estimate (SEE) of oxygen uptake with T-REX, Actical, and ActiGraph and correlations between T-REX and Actical and ActiGraph during treadmill exercises**

		Oxygen uptake(VO_2)				Actical (waist)		Actical (chest)		ActiGraph (waist)	
		Male R	SEE	Female R	SEE	Male R	Female R	Male R	Female R	Male R	Female R
T-REX	waist	0.94**	3.41	0.88**	3.83	0.93**	0.89**			0.92**	0.89**
	chest	0.94**	3.34	0.89**	3.72			0.98**	0.97**		
	ankle	0.94**	.38	0.91**	3.43						
	arm	0.95**	3.14	0.87**	4.07						
	wrist	0.92**	3.73	0.83**	4.58						
Actical	waist	0.94**	3.54	0.87**	3.92						
	chest	0.95**	3.02	0.88**	3.84						
ActiGraph	waist	0.87**	3.45	0.85**	4.33						

* indicates Pearson correlations;SEE(ml kg^{-1} min^{-1}) was estimated by a simple regression.**$p<0.001$.

Discussion

This study investigated the concurrent validity of T-REX, a newly developed triaxial accelerometer, to measure PA. Our major finding is that the T-REX has a strong correlation with VO_2, a gold standard for measuring PA. The Bland–Altman plots showed high agreement between T-REX and VO_2 with nonsignificant mean differences. We also found strong associations of T-REX with Actical and ActiGraph, two widely used accelerometers.

In general, there are high correlations between widely used accelerometers and energy expenditure estimated by indirect calorimetry of treadmill exercise (r = 0.80–0.90) (Bassett, 2000). Our findings are consistent with other studies, which showed a strong association between VO_2 and accelerometer while walking or running on a treadmill (Eston et al., 1998; Sieverdes et al., 2013). Sieverdes et al. (2013) showed a high correlation between VO_2 and the My Wellness Key in the hip and knee (r = 0.90, $p<0.001$), and Eston et al. (1998) found a good correlation between VO_2 and Tritrac in the hip (r= 0.83, $p<0.01$). Our results document the high concurrent validity of T-REX to measure energy expenditure in all five sensor locations in both men (r>0.92) and women (r>0.83).

Several investigators have reported the importance of optimal sensor position, which could influence accelerometer outputs (Bouten, Sauren, Verduin, & Janssen, 1997; Esliger et al., 2011; Lyden et al., 2011; Mannini et al., 2015; Pavey et al., 2015; Schall, Fethke, & Chen, 2016). According to Bouten et al. (1997), the place of attachment of accelerometers does not influence the assessment of energy expenditure during locomotion. Esliger et al. (2011) also showed high and similar criterion validity between VO_2 and the GENEA accelerometer, which measured three locations (left wrist, r = 0.86; right wrist, r = 0.83; waist, r = 0.87), and between VO_2 and the ActiGraph measured at the waist (r = 0.86) and RT3 (r = 0.88). Our study also shows no differences in all sensor positions to measure VO_2. Nonetheless, it is worth considering the different places of attachment of accelerometers in free-living settings and with specific exercise types (Pavey et al., 2015; Schall et al., 2016).

Our interesting finding was that men had higher associations between T-REX and VO_2 in comparison to women. Notably, the sex difference was observed across all sensor locations of T-REX, Actical, and ActiGraph. Several researchers have suggested sex-specific analysis in measuring energy expenditure of PA due to sex-specific variations of energy efficiency (Daniels & Daniels, 1992), body composition (Hall, Figueroa, Fernhall, & Kanaley, 2004), or mechanical movement (Saibene & Minetti, 2003). Although it is important to evaluate men and women separately, many investigators have failed the sex-specific analysis in measuring PA (Crouter & Bassett, 2008; Esliger et al., 2011; Hasson, Haller, Pober, Staudenmayer, & Freedson, 2009; Staudenmayer et al., 2009). For instance, some investigators have shown that the combined results without adjustment for sex (Atallah et al., 2011; Berendsen et al., 2014; Brown, Grimwade, Martinez-Bussion, Taylor, & Gladwell, 2013; Ellis et al., 2014; Hanggi et al., 2013; Hekler et al., 2015; Pavey et al., 2015; Sieverdes et al., 2013; Tully, McBride, Heron, & Hunter, 2014; Welch et al., 2014). To our knowledge, only one study explained a sex difference in triaxial accelerometer measurements during locomotion, which showed higher vertical axis accelerometer ($counts \cdot s^{-1}$) in males at the hip while walking using ActiGraph (Van Domelen et al., 2014). More research is necessary to determine the reasons for the sex differences.

Many investigators have indicated that choosing a suitable tool to measure PA is important because an accurate assessment of PA is critical in clinical and epidemiologic research (Atallah et al., 2011; Bassett, 2000; Lyden et al., 2011; Sieverdes et al., 2013; Staudenmayer et al., 2009). Thus, many factors including subject characteristics, PA type, sensor location, and data analysis should be considered when choosing an accelerometer for precise measurement.

The strength of our study is that our data represents sex-specific findings. Further research should consider the sex-specific study design and data analysis in developing tools to measure PA. Our study also simultaneously assessed the T-REX values attached at five different locations and compared with four additional values (indirect calorimetry, two locations of Actical, and one location of ActiGraph).

The limitation of our study is that the standard MET ($3.5\ mL \cdot kg^{-1} \cdot min^{-1}$) was used to determine the criterion MET values from indirect calorimetry data. The MET values of present results would have underestimated the resting metabolic rate (Hall, Howe, Rana, Martin, & Morey, 2013). Another limitation is that the T-Rex was attached at five sensor locations, while the Actical and ActiGraph were worn only at two and one locations, respectively. Small sample size is also a limitation of a validation study, and larger studies are needed to determine the accuracy of T-REX. Our findings are based on Korean young adults. Therefore, our findings may not be generalizable other groups. Further studies should investigate the validity of T-REX across different race and age groups.

Conclusion

The newly developed T-REX seems to be a valid device for assessing energy expenditure. There was a strong association between T-REX and VO_2 in laboratory settings. This device might be an alternative to conventional accelerometers.

Acknowledgment

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Conflict of Interest

All authors have no conflict of interest to disclose. The sponsor had no role in conducting this experiment, interpreting the data, and writing and submitting the manuscript for publications.

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