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Comparison of Two Questionnaires with a Tri-Axial Accelerometer to Assess Physical Activity Patterns

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Two physical activity questionnaires were evaluated against cardiorespiratory fitness ($\dot{V}O_2$ peak), and a tri-axial accelerometer for movement registration (Tracmor) in 166 men, aged 40 years, within the framework of the Leuven Longitudinal Study on Lifestyle, Fitness, and Health. Tracmor data were obtained during four successive days. Besides the work index, the sport index, and the total activity index from the Baecke questionnaire, the subjective activity score, calculated energy expenditure during work, work index, and the total activity index from the Tecumseh Community questionnaire showed significant correlation coefficients with the mean Tracmor output ($r = 0.26–0.47$, $p < 0.01$). The questionnaire submeasures and the Tracmor output as generated in the same physical activity dimension showed the same relationships ($r = 0.22–0.50$, $p < 0.01$). Multiple stepwise regression and stepwise discriminant analyses showed the Baecke questionnaire as the best indicator of the subject's physical activity level. Extra information about the physical activity level was given by two Tecumseh submeasures, e.g. energy expenditure during work and sleeping time. The results indicated that the Baecke questionnaire is superior in large-scale studies because of simplicity. However, the Tecumseh questionnaire can give detailed information about physical activity patterns and energy expenditure.

Key words: Physical activity, validity, accelerometry, questionnaires, energy expenditure.

Introduction

Assessment of physical activity can be carried out with a wide range of methods including indirect calorimetry, behavioural observation, questionnaires, and accelerometers. Registration of energy expenditure by means of doubly labelled water (DLW), as a method of indirect calorimetry, is nowadays considered as the gold standard in the field of physical activity assessment [2, 20]. The selection of the measurement technique is mostly based on the purpose of the study, the sample size, the time frame and costs, the compatibility with physical activity, and its reliability and validity. Registration of physical activity or energy expenditure by means of DLW is not opportune in large scale studies because of the costs. Besides the costs DLW can only provide average values of energy expenditure over a 1–3 week period. However, because of accuracy DLW is used for validation of other physical activity measurements in smaller sample sizes. The questionnaire method can potentially provide detailed information about physical activity and physical activity patterns relative to the costs and the administration time. Therefore the questionnaire method is the most popular technique in physical activity research [21]. Registration of body movements by means of accelerometers, as a rather new technique, has already shown the ability to provide valid data about physical activity and can be considered as an objective criterion to which questionnaires can be compared [11, 14, 27, 29]. During the last 10 years tri-axial accelerometers were developed for one major reason: three-dimensional registration may provide more accurate estimation of physical activity than single-plane accelerometers [10, 17, 18]. Most of the validation studies using motion sensors as a criterion are based on sample sizes between 10 and 50 subjects. Only one study investigated the validity of physical activity questionnaires compared with different validation measures including the Caltrac in 78 men and women [13]. Additionally the relationship between a pedometer and a physical activity questionnaire was studied in 493 subjects of a large population survey in order to see whether the pedometer could provide additional information about physical activity [31]. During a follow up of the Leuven Longitudinal Study on Lifestyle, Fitness, and Health (LLSLFH) in 1996 a 4-day movement registration from a tri-axial accelerometer (Tracmor) was used as a more objective (DLW validated) measure of daily physical activity and its patterns. Previous studies have already demonstrated good validity of the Tracmor against DLW and its acceptability in daily life situations [7, 8]. Recently we showed a moderate to high association of three physical activity questionnaires with energy expenditure as measured by DLW in 19 male adults during a 2-week period [23]. However, no detailed information was available about the ability of questionnaires to detect activity patterns compared to simul-

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taneous registration of body movements. Therefore it was interesting to investigate the degree of matching concerning physical activity patterns between the questionnaires and the Tracmor, using data from the LLSLFH.

The main purpose of this study was to compare the activity scores from two questionnaires with the output of a tri-axial accelerometer in order to look for the ability of the questionnaires in describing and detecting physical activity patterns. As frequently used, maximal oxygen uptake ($\dot{V}O_2$ peak) was added as an additional indirect measure of physical activity.

Material and Methods

Subjects

The data are from the LLSLFH, a longitudinal study started in 1969 as the Leuven Growth Study of Belgian Boys [5]. In total 588 boys were followed longitudinally over six years (1969–1974). In 1986 and 1991, respectively 173 and 149 of these boys were measured again at the age of 30 and 35. In 1996 130 subjects participated in the next phase of the study. Additionally 36 drop-outs from 1986 and 1991 could be recruited as well, resulting in a total sample of 166 subjects aged 40 years. The subjects visited the Faculty of Physical Education and Physiotherapy in Leuven for a one-day investigation (on a Friday) including physical activity, physical fitness, and health outcome measurements. At the end of the day the subjects were asked to wear the Tracmor on the four following days (Saturday, Sunday, Monday, and Tuesday).

Questionnaires

Two physical activity questionnaires are being administered in the LLSLFH. The first questionnaire (TCQ) is an adapted version of the questionnaire used for the Tecumseh Community Health Study [24]. The adaptation was made in the leisure time supplement and changed into a simple and brief scheme [25]. During a personal interview a detailed inventory of an average week based on the last year was made about occupation, sport participation, other active leisure time activities, quiet leisure time activities, and eating and sleeping time. Metabolic rates (expressed as a ratio of work metabolism to basal metabolism) as described in the compendium of physical activities by Ainsworth and colleagues [1] were used to calculate energy expenditure (during work and active leisure time), the different activity indices, and a total activity index. Using the subject's weight, daily energy expenditure (kcal/day) could be calculated. Each subject was also asked to rate his physical activity on a 7-point scale (1 is not active and 7 is very active). The second questionnaire (BAQ) was described by Baecke et al. [4]. The subject's responses on 5-point scales (never, seldom, sometimes, often, very often or always) permit calculation of a work index (8 questions about sedentary and walking activities, lifting loads, and sweating), a sport index (4 questions including information about the 2 most frequently played sports), a leisure time index excluding sports activities (4 questions about watching television, walking, and cycling), and the total activity index as the sum of the three. All questionnaires were translated into Dutch. A more comprehensive description of the questionnaires and the data about reliability and validity in Flemish males were documented before [22,23].

Movement registration

Besides the questionnaires, physical activity was also measured with the Tracmor. The subjects were asked to wear the Tracmor during four subsequent days immediately after the visit at the Faculty. The Tracmor was not worn during the sleeping hours, bathing, and other water activities. In order to interpret the Tracmor data, the subjects kept an activity log. In this way it was possible to relate Tracmor output to occupational activities, sports activities or other leisure time activities etc. to validate the submeasures of the questionnaires by the Tracmor output generated in the same dimensions of physical activity. The Tracmor integrated data at 1-min intervals and output was expressed as counts per minute. More detailed information about the Tracmor has been described before [6,8,9].

Statistical analysis

Data were analysed using SAS procedures [30]. Means, standard deviations, minima and maxima of the physical activity variables from the different measures were computed as descriptive statistics. The relationship between the different measures was analysed using Pearson correlation coefficients. Paired t-tests were used to compare the differences between reported hours (work, active leisure time, etc.) from the activity log (Tracmor registration) and the TCQ. In order to indicate which physical activity variable from the two questionnaires delivered the best discrimination of the physical activity level based on the Tracmor output, first a multiple stepwise regression analysis and afterwards a stepwise discriminant analysis were conducted, with $p \leq 0.15$ as the inclusion criterium for the model. For the stepwise discriminant analysis the distribution of the total mean Tracmor output was divided into tertiles (low active, moderate active, high active).

Results

Descriptive statistics

Means, standard deviations, minimal and maximal values for height, weight, body mass index, $\dot{V}O_2$ peak, and all physical activity measures are presented in Table **1**. These values represent the entire study population (N = 166) of the LLSLFH, examined in 1996. After medical screening, 10 subjects were excluded for the maximal performance test on the bicycle ergometer due to cardiac risk indication, and abnormal data from four subjects were excluded from the analysis. From 134 subjects correct Tracmor output was received. Four subjects refused to wear the Tracmor for professional reasons while Tracmor registration could not be fitted in the time schedule of four subjects. From 24 subjects registrations were lost due to Tracmor battery malfunction. Physical activity questionnaires were derived from the total sample. All but one subject were employed.

Questionnaires versus Tracmor registration

The Pearson correlation coefficients between the physical activity variables from the questionnaires and the validity measures are shown in Table **2**.

According to the activity log for each subject Tracmor output was divided into the same dimensions of daily physical activity: occupational activities, active leisure time, and quiet lei-

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Table 1 Characteristics (means, standard deviations, minimal and maximal values) of the study population (male adults aged 40 years)

	Variable	N	Mean	SD	MIN	MAX
	weight (kg)	166	78.7	10.0	57.1	110.9
	height (m)	166	1.77	0.06	1.60	1.91
	body mass index (kg/m^2)	166	25.0	2.8	18.0	32.6
	$\dot{V}O_2$ peak (ml/min/kg)	152	39.3	7.3	24.8	63.4
	Tracmor total mean output (counts/min)	134	1328	441	538	3206
TCQ†	subjective activity score	166	4.2	1.4	1	7
	time work (hrs/wk)	165	49.5	12.0	22.9	85.6
	EE work (kcal/kg/wk)	165	112.4	48.0	49.0	390.0
	work index (MET)	165	2.3	0.7	1.5	6.5
	time active leisure time (hrs/wk)	166	9.0	7.0	0.1	40.2
	EE active leisure time (kcal/kg/wk)	166	42.1	30.1	0.3	189.9
	active leisure time index (MET)	166	5.1	1.4	2.0	9.5
	time quiet leisure time (hrs/wk)	166	51.5	14.1	8.6	92.2
	time sleep (hrs/wk)	166	49.3	6.0	28.0	70.0
	time eat (hrs/wk)	166	9.1	3.0	3.5	17.5
	total activity index (MET)	165	1.6	0.3	1.2	3.0
	daily energy expenditure (kcal/day)	165	2949	598	1740	5634
BAQ†	work index	165	2.3	0.6	1.25	4.4
	sport index	166	2.7	0.8	1.0	4.5
	leisure time index	166	2.7	0.6	1.5	4.5
	total activity index	165	7.7	1.2	5.0	12.0

Table 2 Pearson correlation coefficients between the physical activity variables from TCQ, and BAQ and the two validity measures

			Tracmor (counts)						
		$\dot{V}O_2$ peak	total	work		active leisure time		quiet leisure time	
	Variable	(ml/min/kg) N = 152	mean N = 134	sum N = 133	mean N = 133	sum N = 134	mean N = 134	sum N = 134	mean N = 134
TCQ†	subjective activity score	0.28**	0.31**	0.22*	0.21	0.13	0.21	0.13	0.14
	EE work (kcal/kg/wk	0.00	0.28*	0.50**	0.26*	0.02	0.15	– 0.23*	– 0.04
	work index (MET)	0.14	0.27*	0.39**	0.34**	0.02	0.00	– 0.03	– 0.04
	EE active leisure time (kcal/kg/wk)	0.33**	0.11	– 0.02	0.09	0.16	– 0.00	0.03	– 0.04
	active leisure time index (MET)	0.17	0.16	0.07	0.10	0.13	0.25*	– 0.09	– 0.03
	total activity index (MET)	0.20	0.32**	0.45**	0.31**	0.08	0.12	– 0.17	– 0.07
	daily energy expenditure (kcal/day)	– 0.00	0.22	0.34**	0.23*	0.02	– 0.00	– 0.15	– 0.03
BAQ†	work index	0.11	0.26*	0.42**	0.33**	– 0.06	0.04	0.02	0.03
	sport index	0.47**	0.37**	0.12	0.17	0.34**	0.34**	0.13	0.21
	leisure time index	0.28**	0.19	0.13	0.17	0.06	– 0.01	0.20	0.28**
	total activity index	0.49**	0.47**	0.38**	0.37**	0.21	0.24*	0.19	0.30**

*$p < 0.01$; **$p < 0.001$
†TCQ, Tecumseh Community Questionnaire, BAQ, Baecke Questionnaire

sure time. Both questionnaires showed a moderate relationship with the total Tracmor output, 0.47 and respectively 0.32 for the total activity indices from BAQ and TCQ. When the relationships were studied between the submeasures of the questionnaires and the output from the subdivisions of the Tracmor, the correlations became higher compared to the correlations with the total Tracmor output. Regarding the measures of the occupational activities from the TCQ (energy expenditure during work and work index), correlations ranged between 0.26 ($p < 0.01$) and 0.50 ($p < 0.001$) with Tracmor output during work. The same pattern was observed for the BAQ. Correlations of 0.42 and 0.33 ($p < 0.001$) were found with the occupational measures from the Tracmor. The same procedure was followed for the active leisure time activities and the quiet leisure time. The active leisure time index from the TCQ correlated with the mean Tracmor output during active leisure time ($r = 0.25$, $p < 0.01$). Energy expenditure during active leisure time showed no significant relation with the sum of the counts or

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with the mean of the Tracmor output during active leisure time. The Baecke sport index correlated significantly with the Tracmor active leisure time measures (both $r = 0.34$, $p < 0.001$). Only the Baecke leisure time index showed a significant correlation with the quiet leisure time component (mean counts) from the Tracmor registration: 0.28 ($p < 0.001$).

Underreporting

Associations between the reported hours from the activity log (Tracmor registration) and the TCQ were studied by means of correlations and paired t-tests and are presented in Table **3**. After correction of the Tracmor data into a one-week registration, all time variables of the TCQ, except eating time, correlated significantly with the time reported in the activity log. The highest correlation was found for working time ($r = 0.58$, $p < 0.001$). The paired t-test indicated that for working time, and for the time spent on active leisure time activities no significant differences were found between the questionnaire method and the activity log. However, subjects reported less eating and sleeping time compared to the indications on the activity log. This underreporting in the TCQ resulted in an overestimation of the quiet leisure time of about 10 hours. In the TCQ the quiet leisure time was estimated from the remaining time after working time and active leisure time, and eating and sleeping time had been subtracted from 168 (total hours in a week).

Table 3 Comparison of the different time variables (hrs/wk) from the Tecumseh Community Questionnaire and the activity log from the Tracmor registration

	Activity log		TCQ†			
Variables (n = 134)‡	Mean	SD	Mean	SD	r	t-test
time work	50.4	13.4	50.2	12.4	0.58**	ns
time active leisure time	9.9	8.2	8.7	6.7	0.25*	ns
time quiet leisure time	40.2	14.1	50.4	14.5	0.44**	**
time eat	11.1	4.2	9.3	3.0	0.16	**
time sleep	56.4	6.5	49.4	5.8	0.42**	**

* $p < 0.01$; ** $p < 0.001$; ns, no significant difference between the means
† TCQ, Tecumseh Community Questionnaire
‡ Subjects with missing data for the Tracmor output are not included in the analysis

Classification of the activity level

Fig. **1** shows the Tracmor output, averaged over 5-minutes intervals, for a low active subject (Fig. **1 a**) and a high active subject (Fig. **1 b**). The low active subject had a sedentary job and was not engaged in sports activities. The high active subject was a physiotherapist with mostly standing and walking activities. A brisk walk and inline skating generated the peak Tracmor output on Sunday morning.

The results of the multiple regression analysis and the stepwise discriminant analysis in classifying the activity level are presented in Table **4**. The Baecke total activity index, energy expenditure during work (TCQ), and sleeping time (TCQ) appeared as the most important variables with significant power in both analyses, with $r^2 = 0.29$. Fifty-four percent of the subjects could be classified correctly in the three physical activity levels (low active, moderate active, and high active) as tertiles in the distribution of the total mean Tracmor output.

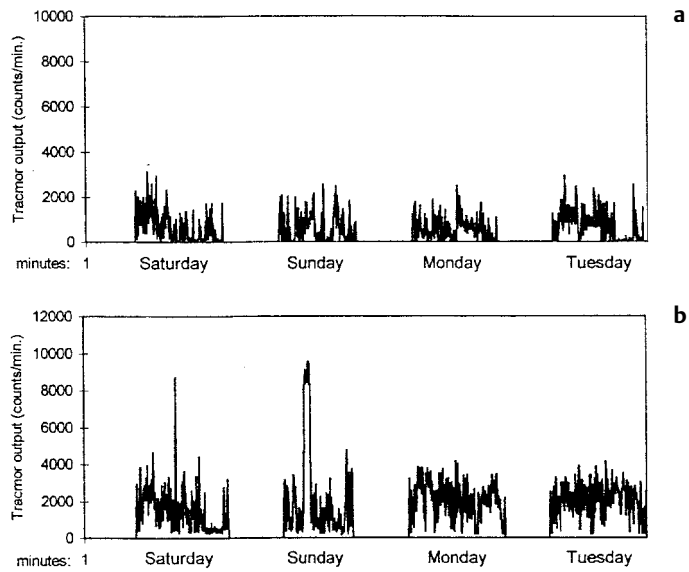

Fig. 1 Mean Tracmor output from four successive days in a low active subject (**a**) and a high active subject (**b**).

Table 4 Multiple stepwise regression and stepwise discriminant analysis in discriminating the activity level (from the mean Tracmor output) with the variables from the two questionnaires as the potential variates in the model

Step	Variable to add	Stepwise regression r^2	Stepwise discriminant % agreement three activity levels
1	total activity index (BAQ)†	0.22	49% (66/134)
2	energy expenditure work (TCQ)	0.26	51% (68/134)
3	time sleep (TCQ)	0.29	54% (72/134)

† BAQ, Baecke Questionnaire, TCQ, Tecumseh Community Questionnaire

Discussion

This study investigated the relationship between two physical activity questionnaires and a tri-axial accelerometer for movement registration in the total sample of the Leuven Longitudinal Study on Lifestyle, Fitness, and Health. This study had some major advantages. Firstly, the study was performed on a large sample of over 133 subjects. Secondly, two physical activity questionnaires with different approaches were evaluated simultaneously, and the information was obtained in an interviewer-assisted way. The TCQ is a comprehensive questionnaire about physical activity from the previous year and describes physical activity in detail. The BAQ is easy to administer and contains information about daily physical activity in a more general way though it doesn't reflect energy expenditure. Thirdly, the questionnaires were evaluated against the Tracmor, a tri-axial accelerometer as a more objective measure of physical activity. Finally, the present study involved subjects with a wide range of physical activity levels from sedentary lifestyle to high active sport participation. However, a possible confounder has to be considered. The subjects had been participating in the LLSLFH since 1969. Their high degree of motivation to participate in this study may possibly have a confounding effect on the results.

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Table 5 Overview of correlation coefficients between physical activity questionnaires and two validity measures (cardiorespiratory fitness and Caltrac measures) from literature

Questionnaire	Variable	N	$\dot{V}O_2$max	Caltrac Kcal/day	Met	Counts	Reference
Baecke	total index	30		0.53*	0.40*		Gretebeck and Montoye (1990) [12]
Minnesota and Tecumseh	work and leisure	30		0.86*	0.63*		
Baecke	work index	28				0.10	Mahoney and Freedson (1990) [16]
	sport index	28				0.46*	
	leisure index	28				0.56**	
	total index	28				0.53**	
Baecke	work index	73	0.23*	– 0.03	0.11		Jacobs et al. (1993) [13]
	sport index	73	0.52*	– 0.02	0.32*		
	leisure index	73	0.26*	– 0.11	0.01		
	total index	73	0.54*	– 0.08	0.19		
HIP New York	work index	73	0.07	0.07	0.14		
Minnesota Heart Health Program	work index	73	0.00	– 0.01	0.04		
	leisure index	73	0.56*	– 0.16	0.28*		
Baecke	total index	33		0.40			Miller et al. (1994) [19]
Minnesota Leisure Time	total leisure index	78	0.47**		0.21		Richardson et al. (1994) [28]
Tecumseh Occupational	light to moderate intensity	46	0.29*				Ainsworth et al. (1999) [3]
	moderate intensity	46		0.34*			

*$p < 0.05$; **$p < 0.01$ as indicated in literature

A key result in this investigation is the considerable relationship between the Baecke questionnaire and both $\dot{V}O_2$ peak and the Tracmor output. The same pattern, but in a weaker way, was observed for the TCQ. Our results are in accordance with most of the studies or show even higher correlation coefficients as reported in the literature [3,12,13,15,16,26,28], An overview of some of these important results is given in Table **5**.

However, in the present study validity was investigated in a more comprehensive way because the Tracmor output was also divided in similar physical activity dimensions. In this way it was possible to compare the activity variables from the questionnaires with an objective measure generated in the same dimension. This information clearly indicated that the questionnaires can be used to measure levels of physical activity and to detect physical activity patterns. When the relationships with Tracmor output are considered, measures between the same physical activity dimensions are significantly related to each other with the highest correlations for occupational physical activity. Jacobs et al. [13] found no considerable relationship between the occupational questionnaire measures and the Caltrac, suggesting the inadequacy of the used validation techniques as a possible reason. Previous studies [6–9] showed that the Tracmor is sensitive enough to detect interindividual differences, even in the more sedentary job activities. However, only a moderate relationship between the active leisure time Tracmor output and the active leisure time indices from the TCQ was found. A possible explanation is that active leisure time in the TCQ includes a wide range of activities including sport participation, house maintenance, and gardening and thus not only reflecting heavy intensity activities. Moreover the TCQ active leisure time measure is a larger mixture of activities with different intensities compared to the occupational activities. However, comparison between the activity log from the Tracmor registration and the TCQ of hours spent in specific activity categories suggests that the subjects are able to report strong arranged and planned activities (work) and moderate to high intensity activities (active leisure time) in an accurate way. Underreporting sedentary activities (combined eating and sleeping time) resulted in an overestimation of the quiet leisure time of about 10 hours/week.

Support for the correlation analysis also comes from the stepwise discriminant analysis. The Baecke total activity index appeared as the main variable in classifying the activity level. Miller et al. [19] found a higher degree of association (84 percent) between the Caltrac and the 7-day recall in the classification of a smaller sample of 33 subjects (males and females) into two activity groups. Matthews and Freedson [17] found the same high degree of association in 25 men and women between the Tritrac and a 3-day physical activity log. Despite the lower degree of association it seemed that the BAQ can provide a valid indication about the physical activity level.

In conclusion, the Baecke and the Tecumseh questionnaire, in a comprehensive comparison with a tri-axial accelerometer, can provide accurate data about physical activity and physical activity patterns in a large population of Flemish males. The Baecke questionnaire showed the strongest relationship with the Tracmor output. A major advantage in the use of the Tracmor is the possibility to analyse physical activity over time. In this way the validity of the questionnaires increased because information from the same physical activity category was used by the different methods. It is clear that this knowledge about physical activity and physical activity patterns should be applied in further research in order to describe the links with physical fitness and health.

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