ORIGINAL ARTICLE

Measuring Free-Living Physical Activity in Adults With and Without Neurologic Dysfunction With a Triaxial Accelerometer

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ABSTRACT. Hale LA, Pal J, Becker I. Measuring free-living physical activity in adults with and without neurologic dysfunction with a triaxial accelerometer. Arch Phys Med Rehabil 2008;89:1765-71.

Objective: To investigate the reliability, validity, and utility of a triaxial accelerometer to measure physical activity in the free-living environment in adults with and without neurologic dysfunction.

Design: Repeated-measures design.

Setting: General community.

Participants: Volunteer sample of 17 men and 30 women (age range, 28−91y) living in the community with stroke of greater than 6 months in duration (n=20), Parkinson disease (n=7), or multiple sclerosis (n=11), and healthy but sedentary controls (n=9).

Interventions: Not applicable.

Main Outcome Measures: Physical activity measured with the TriTrac RT3 accelerometer, 7-day recall questionnaire, and activity diary.

Results: The accelerometer reliably measured free-living physical activity (intraclass correlation coefficient, .85; 95% confidence interval, .74−.91; *P*=.000). The standard error of measurement indicated that a second test would differ from a baseline test by ±23%. Mean daily RT3 data collected in the first 3 days differed significantly from that of the mean daily RT3 data collected over 7 days. The RT3 appeared to distinguish level of mobility better than the 7-day recall questionnaire, and participants found the RT3 to be a user-friendly and acceptable measure of physical activity.

Conclusions: The triaxial accelerometer provided a stable measure of free-living physical activity, was found to distinguish between people with varying levels of mobility, and was well tolerated by participants. The results indicate that collecting data for 3 days was not reflective of data collected over 7 days.

Key Words: Exercise; Neurologic manifestation; Questionnaires; Rehabilitation.

INCREASING PHYSICAL ACTIVITY is an important health goal for both people with and without disability,[1-3] necessitating an accurate method of measuring daily physical activity. Physical activity questionnaires and diaries are commonly used but rely on recall and honest reporting and require people to have no cognitive deficits and no potential for bias in reporting results.[4-6] Motion sensors, such as pedometers and accelerometers, provide an objective method of measuring physical activity. Pedometers are simple to use and inexpensive but may be less accurate at slow speeds of walking.[7] Uniaxial and triaxial accelerometers measure the acceleration of movement and can quantify movement intensity, frequency, and duration.[8] Triaxial accelerometers capture movement in 3 orthogonal planes, potentially providing a comprehensive measurement of the variety of movements performed by people in their day-to-day life. However, the increased sensitivity of 3-dimensional measurement may reduce the reliability of data on repeated measurements; uniaxial accelerometers' 1-directional capture of movement may provide more stable data.[8]

The TriTrac RT3 accelerometer[a] is a triaxial accelerometer that may be suitable for sustained tracking of physical activity in the home environment. It is small (65g), capable of collecting and storing data in 1-minute epochs for 21 days, and has no external controls that can be manipulated during data collection.[9] To date the attributes of the RT3 have been investigated in the laboratory with mechanical devices,[8,9] treadmill walking,[10-13] and discrete physical tasks.[10,11,14] Populations tested have included healthy adults,[10,11,13] children,[11,12] and adults with MS.[14] Most studies reported good intramonitor reliability; however intermonitor variance has been demonstrated, indicating that the same monitor should be used for the same participant in a repeated-measures design.[8-13] One study has reported on the use of the RT3 outside of a laboratory, and in this study, the reliability of the RT3 to measure activity during a physical education program in school children with visual impairment was reported to be good.[15] To our knowledge, no study has investigated the attributes of the RT3 in measuring daily physical activity in the free-living environment.

The purpose of this study was to investigate the reliability, validity, and utility of the RT3 to measure physical activity in the free-living environment in adults with and without neurologic dysfunction. More specifically, we wished to explore the test-retest reliability and sensitivity of the RT3 in free-living compared with that of the 7-day recall questionnaire, and whether it was necessary to measure activity for 7 days as has

List of Abbreviations

CI	confidence interval
ICC	intraclass correlation coefficient
MS	multiple sclerosis
MVM	mean vector magnitude
PD	Parkinson disease
RMI	Rivermead Mobility Index
ROC	receiver operating characteristic

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Preliminary results presented to the Neurosymposium, Neurological Special Interest Group of the New Zealand Physiotherapy Society, May 12, 2007, Nelson, New Zealand.

Supported by the University of Otago (research grant).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

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0003-9993/08/8909-00997$34.00/0
doi:10.1016/j.apmr.2008.02.027

been the case in many previous studies measuring activity in free-living.[16]

METHODS

Sampling

Volunteers with PD, MS, or stroke, and sedentary, healthy participants were recruited via local service organizations and public advertising. Sample size was calculated by the method described by Bonett,[17] using data obtained from a pilot study investigating the reliability of the RT3 to measure walking in people with MS.[14] To obtain an ICC with a 95% CI of width 0.2 using 2 repeated measurements, a sample size of 53 was calculated.

Inclusion criteria. Participants had to be of good health, living in the community, and able to walk independently within the home with or without appliances. Participants with neurologic dysfunction had to have a definite diagnosis of PD,[18] MS,[19] or stroke[20] of more than 6 months. Adult control participants were recruited if they self-reported to be sedentary. Exclusion criteria included the inability to understand the requirements of the study (eg, because of dementia or receptive aphasia) and the presence of short-term memory loss. Written informed consent was gained from all participants. The study was approved by the local regional ethical committee (no. LRS/05/09/029).

Equipment

The RT3 is battery operated and uses an integrated computer chip to measure movement across 3 orthogonal planes: vertical (x), anteroposterior (y), and mediolateral (z). The RT3 measures the mean acceleration (in m/s^2) for each of the 3 planes across set 1-second or 1-minute intervals and presents these data in a digital format called activity counts. The exact relationship between the acceleration data and the displayed activity count has not been described by the manufacturers. Activity counts for each plane can be summarized by calculating the MVM ($= [x^2 + y^2 + z^2]^{0.5}$), which is also expressed in activity units (*http://www.stayhealthy.com*). Because it is not possible to calibrate an RT3 unit, the reliability of each RT3 unit to measure motion per se was established in the laboratory prior to the start of the study with the use of repeated measurements both on a mechanical device and with discrete, standardized motor tasks. Six new monitors were tested and found to be reliable; no monitor had to be excluded.

Questionnaires used in this study included the RMI[21] and the 7-day recall questionnaire,[16,22] a validated, interviewer-administered questionnaire that asks respondents to recall activities they have performed over the past 7 days. It has been used in previous studies to investigate activity in adults with MS.[23,24] Participants were asked to keep a daily activity log in which they recorded, for each hour of the day, the activities they had been involved in, such as shopping or walking. This information was used to verify the collected RT3 data. A utility questionnaire was specifically developed for this study to evaluate participants' opinions of using the RT3.

Procedure

The following measurements were taken or recorded: weight, height, age, sex, and level of mobility (using the RMI[21]). The RT3 was programmed via computer interface with the participant's personal data (sex, age, height, weight) prior to testing and set to sample data for all 3 axes every minute. The participant was instructed when to wear the RT3 unit and how to complete the daily activity log. For participants unable to complete the daily diary, we made arrangements for another person to complete it under the participant's instruction. The RT3 was attached to the participant's waist belt in a central back position and switched on to start measuring and recording activity data; the time of activation was recorded. The central back position was chosen to locate the RT3 to be as close to the body's center of gravity as possible[25] and to allow for potential asymmetrical movement as a result of the neurologic condition.[14] Participants were asked to wear the RT3 during waking hours (except when bathing, swimming, or lying in bed) for 7 consecutive days while maintaining their typical weekly schedules. Seven days later, the RT3 unit was collected from the participant, the time this occurred was recorded, and the data were downloaded via the computer software. At this point, the 7-day recall questionnaire was administered. Eight weeks later the procedure was repeated, starting on the same day and time of the week (a Monday, Tuesday, or Wednesday) and using the same RT3 unit. Participants then completed the utility questionnaire. Participants were telephoned during the test week to ensure there were no problems and reminded to wear the RT3 and to complete the daily activity log.

Data Analysis

For each participant, the MVM from activity data (in activity units [AU]) for each 24-hour period, beginning at the time the RT3 was activated, was summed to provide a daily activity count. This daily activity data and the recorded data in the activity log were compared for obvious inconsistencies (eg, failure to wear the RT3, equipment failure). Data considered erroneous were not included in the statistical analysis. The mean daily data for the first 3 days and for 7 days of measuring were calculated. The 7-day recall questionnaire and RMI data were scored. The 7-day recall questionnaire scores were converted to kilocalories as described by Sallis et al.[22]

All statistical calculations were performed using the SPSS software[b] for Windows with the level of significance set at P less than .05. All demographic and measured data were analyzed descriptively.

RT3 data were analyzed for each of the 2 test periods, for both the 3-day period data (mean daily MVM over 3 days) and the 7-day period data (mean daily MVM over 7 days), with intraclass coefficients ($ICC_{2,1}$) using a 2-way random effects model with absolute agreement, and with the SE of measurement.[26] The ICC and SE of measurement were calculated as follows:

$$\text{ICC} = \frac{\text{between-subject variance}}{\text{between-subject variance} + \text{within-subject variance}}$$

SE of measurement

= square root of the within-subject variance

The strength of all correlations computed were determined as follows: 0.00 to 0.25, little or no correlation; 0.26 to 0.49, low correlation; 0.50 to 0.69, moderate correlation; 0.70 to 0.89, high correlation; and 0.90 to 1.00, very high correlation.[27]

To investigate whether daily activity data over 3 week days differed significantly from daily activity data measured over 7 days, the mean daily MVMs for each period were compared using a paired t test and its 95% CI for the difference. If the 95% CI lay below the smallest meaningful difference between the 2 measurements, they were determined to be equivalent. The level of agreement between the 2 scores was established with the Bland-Altman method.[28]

Table 1: Demographic Characteristics of Participants

Characteristics	Total (N=47)	MS (n=11)	PD (n=7)	Stroke (n=20)	Controls (n=9)
Sex					
Men	17	3	3	10	1
Women	30	8	4	10	8
Age (y)	63.7±15.5 (28–91)	50.7±11.8 (35–70)	75.3±7.7 (68–91)	72±7.1 (57–86)	51±18.1 (28–76)
RMI (total/15)	12.5±2.6 (4–15)	12.4±2.2 (8–15)	11.7±2.6 (7–15)	11.9±2.9 (4–15)	14.9±0.3 (15–15)
Height (cm)	165.4±8.0 (147–182)	164.9±9.5 (155–182)	160.6±8.5 (147–180)	166.2±6.8 (150–178)	167.8±7.4 (152–179)
Weight (kg)	76.7±15.9 (46–124)	69.2±14.2 (49–85)	79.4±6.4 (73–88)	83.2±18.5 (46–124)	70.1±11.1 (58–96)

NOTE. Values are n or mean ± SD (range).

The relationships of MVM and 7-day recall questionnaire data to level of mobility (measured by the RMI) were investigated using scatterplots, linear regression (R^2), and ROC analyses curves. The area under the ROC curve was calculated under the nonparametric assumption. The closer this area was to 1.0, the more accurately the activity data could be deemed to distinguish between levels of mobility. The hypotheses were that the greater the loss of mobility, the less activity the participant would perform, and that the accelerometer would be able to detect this better than the 7-day recall questionnaire.

RESULTS

Fifty-two participants were recruited into the study, but data were complete for only 47 (age, 64±15y; PD, n=7; MS, n=11; stroke, n=20; controls, n=9). Table 1 reflects the demographic characteristics of these participants; data were not normally distributed. Five participants did not complete testing because of monitor fault (n=3), development of an acute medical condition (n=1), and death (n=1).

The average number of hours of collected daily activity was 11 hours. No participants included in the analysis had less than 10 hours of collected RT3 data a day. Table 2 shows the MVM and 7-day recall questionnaire data collected for each of the test periods; these data were not normally distributed. Data considered to be outliers can be seen in the box and whisker graphs in figure 1, representing the distribution of the activity data (MVM) by diagnosis for each of the test periods. Inspection of the daily activity logs revealed that these outlying data were a result of the type of activity participants had engaged in, which varied considerably compared with other participants within the same diagnostic group.

Table 3 displays the ICCs and SE of measurement calculated for the RT3 MVM data collected over the 2 test periods as well as those collected in the first 3 days of each test period. The ICCs for the total group and for the diagnostic subgroups demonstrated high to very high correlation with the exception of the 3 day MS and stroke scores, which were only moderately correlated. Inspection of the box and whisker plots for the stroke subgroup indicated disparate data for 2 participants, and this was explained and verified by the varying degrees of weekly physical activity recorded in their daily activity logs. In table 3, the SE of measurement is presented as a percentage of the mean data for each parameter collected in the first week of data collection. The absolute reliability (SE of measurement, expressed as percentage) for the 7-day total data was 23%. The 95% CI for the total data had a width of .17, meeting the a priori power calculation of the study. The percentage SE of measurement for the 3-day data was larger at 27% and the 95% CI width was slightly greater (.21) than the a priori power calculation.

Table 2: The Group Means Physical Activity Data Collected Over 7 Days or 3 Days for Each Participant Group

Test Period	Total (N=47)	MS (n=11)	PD (n=7)	Stroke (n=20)	Controls (n=9)
7 days					
Test period 1					
MVM (AU)	894,236±534,844	1,085,849±373,047	854,660±433,264	673,920±379,495	1,385,760±719,868
Test period 2					
MVM (AU)	852,528±510,239	965,707±398,308	754,492±470,446	573,403±266,993	1,490,363±510,675
7 days					
Test period 1					
7-d RQ (kcal)	2468±496	2180±454	2484±273	3645±572	2413±354
Test period 2					
7-d RQ (kcal)	2442±514	2166±486	2430±228	2633±607	2363±327
3 days					
Test period 1					
MVM (AU)	412,990±283,841	520,822±210,673	470,821±383,874	320,463±190,549	625,401±323,440
Test period 2					
MVM (AU)	379,142±271,720	430,842±174,992	408,617±460,806	250,269±116,847	611,578±291,424

NOTE. Values are mean ± SD.
Abbreviation: 7-d RQ, 7-day recall questionnaire.

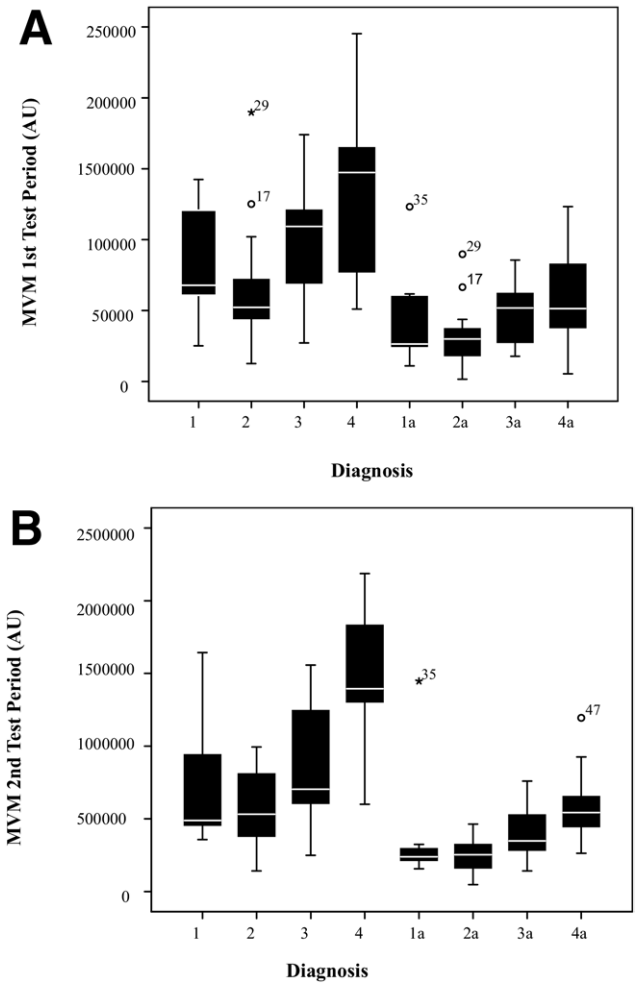

Fig 1. MVM (in AU) collected over 7 days and over 3 days for each test period versus diagnosis: (A) first test period and (B) second test period. Diagnosis legend: 1, PD; 2, stroke; 3, MS; 4, control group data collected over 7 days; 1a, PD; 2a, stroke; 3a, MS; 4a, control group data collected over 3 days. Legend: *participants with outlying results.

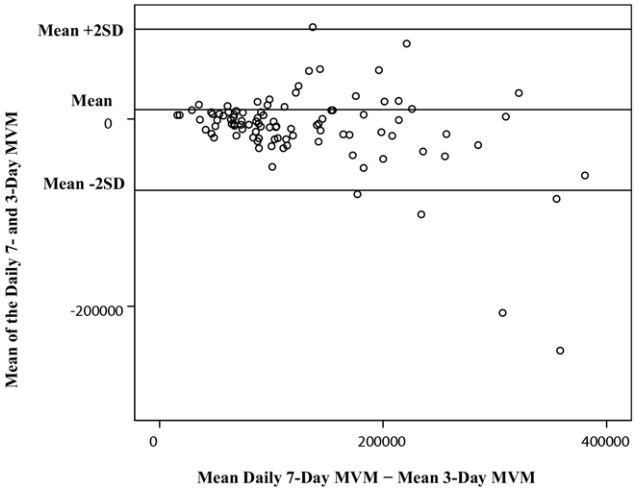

Fig 2. Bland-Altman analysis comparing MVM (in AU) collected over 7 days with that collected over 3 days.

Paired Student *t* test analysis demonstrated a significant difference between the 7-day and 3-day data ($P=.03$). Bland-Altman analysis (fig 2) of these data showed good levels of agreement because most data points clustered around the zero line (mean of the difference) and only 6 (6%) of 96 data points fell outside of the mean of the difference ±2 SD range (9938±43,150 AU). However, this analysis indicated that the 3-day mean daily MVM data could differ from the 7-day mean daily MVM data by 86,300 AU. Given that the mean daily MVM ± SD for the 7-day and 3-day data were 124,831±74,373 AU and 132,252±92,394 AU, respectively, this difference may be considered large.

Scatterplot and regressional analysis established that the RMI data accounted for only a small percentage of the variation in activity data; RT3 data (MVM) had a slighter higher linear correlation with the RMI data ($R^2=.12$, 16%) than the 7-day recall questionnaire data ($R^2=.01$, 1%). An ROC analysis of these parameters revealed that the area under the curve for the MVM data was .72 (b=.02) and for the 7-day recall questionnaire was .61 (b=.13), indicating that the RT3 accelerometer was more sensitive in distinguishing between people with varying levels of mobility than the 7-day recall questionnaire.

The results to the closed questions of the utility questionnaire are provided in table 4. Question 1 asked whether wearing the accelerometer every day for 7 days was an acceptable method to measure daily activity. Questions 2, 3, and 4 enquired how easy it was to remember to wear the accelerometer every day, whether it interfered with the daily routine, and whether it was annoying to wear. Question 5 checked whether

Table 3: Test-Retest Reliability Data for Each Participant Group

Test Period	Total (N=47)	MS (n=11)	PD (n=7)	Stroke (n=20)	Controls (n=9)
7-Day MVM test period 1 vs test period 2					
ICC	.85	.83	.81	.68	.82
95% CI	.74–.91	.49–.95	.29–.96	.36–.86	.42–.96
P	.00	.00	.01	.00	.002
SEM (AU) (%)	204,435 (23)	182,637 (17)	198,273 (23)	187,556 (28)	261,362 (19)
3-Day MVM test period 1 vs test period 2					
ICC	.84	.62	.90	.54	.97
95% CI	.70–.91	.12–.88	.57–.98	.16–.79	.87–.99
P	.00	.01	.001	.00	.00
SEM (AU) (%)	111,588 (27)	130,465 (25)	133,923 (28)	110,860 (35)	54,423 (9)

Abbreviation: SEM, SE of measurement.

Table 4: Utility Questionnaire Data (N=47)

Question	Test Week 1			Test Week 2		
	Mean (Median)	SD	Range	Mean (Median)	SD	Range
Question 1 (1 = not acceptable; 9 = very acceptable)	7.5 (8)	1.5	2–9	7.2 (8)	1.8	1.5–9.0
Question 2 (1 = difficult to remember; 9 = no problem)	7.2 (8)	2.2	1–9	7.0 (8)	2.0	1.5–9.0
Question 3 (1 = interfered greatly; 9 = did not interfere at all)	7.8 (8)	1.2	2.5–9.0	7.5 (8)	1.6	2–9
Question 4 (1 = most annoying; 9 = not annoying at all)	7.4 (8)	1.5	2.5–9.0	7.2 (8)	2.2	1–9
Question 5	Yes = 18 (38%), No = 26 (55%) Maybe = 3 (7%)			Yes = 11 (23%), No = 33 (70%) Maybe = 3 (7%)		
Question 6	Yes = 42 (89%), No = 1 (2%) Maybe = 4 (9%)			Yes = 40 (85%), No = 2 (4%) Maybe = 5 (11%)		

NOTE. Values are in centimeters.

the participant would mind wearing the accelerometer again as part of a research project. Question 6 sought to establish whether the accelerometer was a user-friendly method of measuring daily activity. The 1 open-ended question, which asked participants to comment on using the RT3, resulted in 67 statements from 35 participants. These statements were grouped into common themes as follows: positioning the RT3 in the middle of the back was uncomfortable (especially when sitting or driving), 24 (36%) of 67; participants were worried that the RT3 would fall off, especially in the toilet or bathroom, 17 (25%) of 67; keeping the diary was burdensome, 4 (6%) of 67; the RT3 was too big, 2 (3%) of 67; and some participants found the RT3 easy to wear and had no problems, 10 (15%) of 67.

DISCUSSION

The 8-week test-retest reliability of the RT3 accelerometer was good for data collected over 7 days (ICC=.85; 95% CI, .74−.91; *P*=.000) and 3 days (ICC=.84; 95% CI, .70−.91; *P*=.000). The absolute reliability for the total data, as calculated with the SE of measurement, indicated that a second test would differ from a baseline test by ±23% (±204,435 AU), signifying that if the RT3 was to be used as a measure of change in physical activity levels, the minimal detectable difference would have to be greater than 23% of the baseline measurement to allow for normal variance in weekly physical activity. Matthews et al[29] reported that intraindividual variance accounted for 30% to 45% of the overall variance in accelerometer counts in healthy adults (n=92) measured over 21 consecutive days (using the Computer Science Applications accelerometer). A 23% variation could therefore be considered a reasonable fluctuation in weekly activity patterns. It is not clear, however, what a 23% change in RT3 activity data would mean clinically. What increase in level and type of activity would this represent? It would probably depend on the level of activity the person was engaged in at baseline. An increase of 23% on a very sedentary lifestyle would be far more meaningful than the same increase in activity in a person who was extremely active.

The good test-retest reliability found in our study was similar to that found for other types of accelerometers during free-living activity monitoring trials. The ActiGraph accelerometer yielded an ICC of .93 while monitoring activity counts a day for 7 days in a sample of people with MS[30] and the StepWatch step activity monitor an ICC of .86 and .89 over 7 days in adults with and without neurologic disorders, respectively.[31]

Wearing an activity monitor for 1 week could be considered by some people to be onerous; however, the result of this study found the mean daily data collected in the first 3 days, despite its stability, to be significantly different from those collected over 1 week. The study by Matthews et al[29] demonstrated the variable nature of daily physical activity, and these researchers proposed that a 7-day monitoring period provides the most reliable measurement of physical activity. In our study, the first 3 days of each test period were week days, but because most participants in the study were unemployed, this was not considered a problem. However, employment may not be an issue, because Motl et al[30] demonstrated high reliability for both the pedometer and the ActiGraph accelerometer for all combinations of and types of days over a 1-week period in 193 adults with MS, 56% of whom were employed. To standardize for potential initial motivation in wearing the RT3, we chose to use the first 3 days of data collection for our analysis; however, further analysis could include comparing 7-day data with other groupings of 3-day data as undertaken by Motl.[30]

The RT3 was found in this study to be able to distinguish between levels of mobility; this was not apparent when the 7-day recall questionnaire data were plotted against the RMI data. Previous laboratory-based studies have demonstrated the RT3's ability to distinguish between different velocities of treadmill walking and between low-intensity activities.[11,13] However, 1 study showed that as the intensity of activity increases, the degree of differentiation decreases, and suggested that the RT3 may be best suited to measuring activity in sedentary groups,[11] such as used in our study.

Participants did not find the RT3 a problem to wear and considered it to be a user-friendly, acceptable method for measuring physical activity. However, the location of the RT3 in the middle of the back was considered by 36% of participants to be uncomfortable, especially when sitting and driving, and it is suggested that the RT3 be worn on the side of the waist in the future. Some participants (25%) were worried the RT3 would fall out of the provided holster. A more secure holster such as used for mobile cellular phones that are firmly attached to a belt would possibly be more secure than the present commercially supplied clip-on holster.

Although the findings of this study are supportive of the use of the RT3 as a measure of free-living physical activity, the daily physical activity log kept by participants allowed us to verify RT3 data that appeared incorrect. This would imply that the RT3 should be used in conjunction with a simple daily activity log, which detracts from the utility of the instrument, but together provides a fairly comprehensive description and measure of daily physical activity.

Study Limitations

Our test-retest duration in this study could be considered long at 8 weeks and may have been a limitation. This duration was chosen because 8 weeks appears to be the minimum reported time for exercise to optimize muscle strength and

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