

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/8541927>

# A pilot study of long-term monitoring of human movements in the home using accelerometry

Article in *Journal of Telemedicine and Telecare* · February 2004

DOI: 10.1258/135763304323070788 · Source: PubMed

CITATIONS

154

READS

1,573

6 authors, including:



**Adelle C F Coster**

UNSW Sydney

80 PUBLICATIONS 3,798 CITATIONS

SEE PROFILE



**Nigel Lovell**

UNSW Sydney

671 PUBLICATIONS 18,684 CITATIONS

SEE PROFILE



**B.G. Celler**

The Commonwealth Scientific and Industrial Research Organisation

290 PUBLICATIONS 8,697 CITATIONS

SEE PROFILE



**Stephen R Lord**

Neuroscience Research Australia

738 PUBLICATIONS 58,946 CITATIONS

SEE PROFILE

# ▶ A pilot study of long-term monitoring of human movements in the home using accelerometry

Merryn J Mathie\*<sup>†</sup>, Adelle C F Coster<sup>‡</sup>, Nigel H Lovell\*<sup>§</sup>,  
Branko G Celler\*<sup>†</sup>, Stephen R Lord\*\* and Anne Tiedemann\*\*

\*Centre for Health Informatics, University of New South Wales; <sup>†</sup>School of Electrical Engineering and Telecommunications, University of New South Wales; <sup>‡</sup>School of Mathematics, University of New South Wales; <sup>§</sup>Graduate School of Biomedical Engineering, University of New South Wales; \*\*Prince of Wales Medical Research Institute, University of New South Wales, Sydney, New South Wales, Australia

## Summary

We assessed the feasibility of using a waist-mounted, wireless triaxial accelerometer (TA) to monitor human movements in an unsupervised home setting to detect changes in functional status. A pilot study was carried out with six healthy subjects aged 80–86 years. The subjects wore a TA unit every day for two to three months. Each morning they carried out a short routine of directed movements that included standing, sitting, lying and walking. Important movement variables were measured. During the rest of the day, subjects were monitored for falls, and variables such as metabolic energy expenditure were measured. All subjects remained healthy; there was no overall change in functional status and there were only slight fluctuations in health status. No longitudinal changes were detected in any of the variables measured during the directed routine. There was a moderate correlation between weekly self-reported health status and energy expenditure: subjects reported a lower health status for weeks in which they expended less energy. The TA system was found to be practical for long-term, unsupervised home monitoring. All subjects found the system simple to use and the TA unit unobtrusive and comfortable to wear. High compliance rates were achieved: the TA units were worn on 88% of the days in the study, for an average of 11.2 hours per day.

## Introduction

Functional status is a determining factor in independent living and has a significant effect on quality of life, and there is consequently a need to measure it in the home. Traditionally, assessment of functional status in free-living subjects has been subjective, as it has relied on patient recall and clinician observation. Accelerometers offer a low-cost method of making objective measurements of human movements in the home environment<sup>1–5</sup>.

We undertook a pilot study to assess the feasibility of using a simple accelerometry system for unsupervised

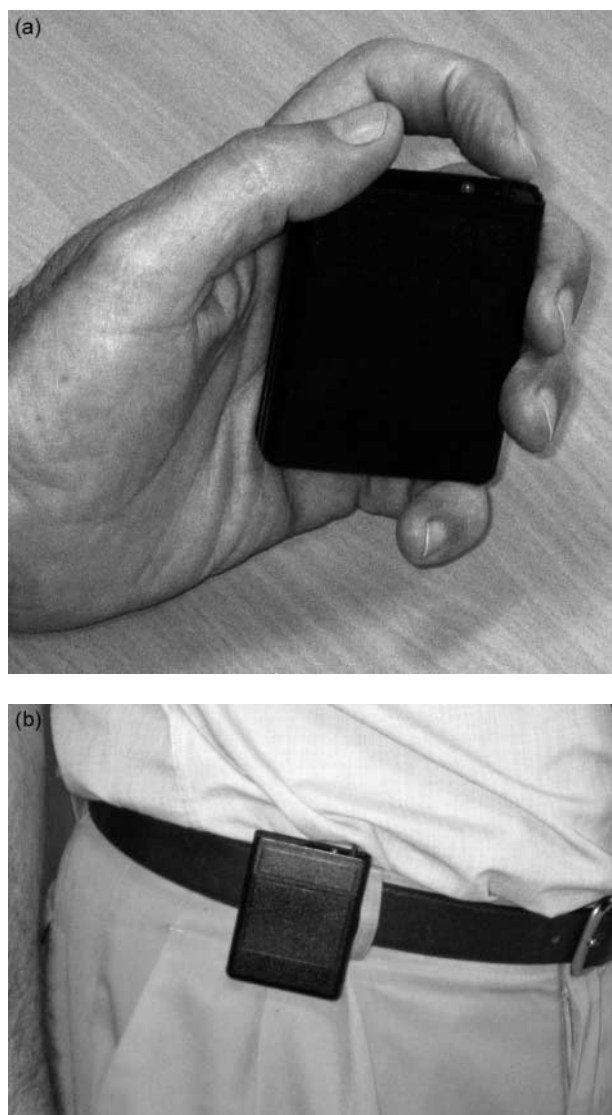
monitoring of functional status in the home over extended periods.

## Methods

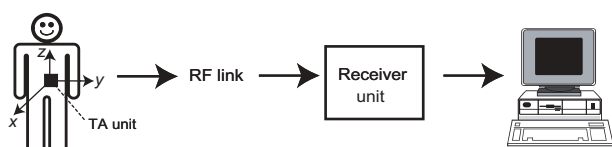
The system consisted of a wearable triaxial accelerometer (TA) unit (Fig 1) connected by a wireless link to a receiver unit and a computer (Fig 2)<sup>6</sup>. The TA unit contained two orthogonally mounted biaxial piezoresistive accelerometers (ADXL210, Analog Devices, MA, USA), a push button, a wireless transmitter and a 1.5 V battery (sufficient for 80 h of continuous transmission at up to 50 m). The components were enclosed in a small case (71 mm × 50 mm × 18 mm), which could be clipped to a belt. The computer was used for data-recording and to guide subjects through the directed movement routine (see

Accepted 28 January 2004

Correspondence: Nigel H Lovell, Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW 2052, Australia (Fax: +61 2 9663 2108; Email: N.Lovell@unsw.edu.au)



**Fig 1** The triaxial accelerometer (TA) unit. (a) The accelerometer unit, a push button and a wireless transmitter were contained in a small plastic case. (b) The unit was worn on the belt.



**Fig 2** The triaxial accelerometer (TA) unit transferred data via a wireless (radio frequency, RF) link to a receiver unit and thence to a personal computer for processing and storage. The directions of the three axes,  $x$ ,  $y$  and  $z$  are shown.

below). No direct interaction with the computer was required by the subject.

Approval for the study was obtained from the appropriate committee. Six healthy, elderly subjects (four women, two men, aged 80–86 years) who lived

independently at home were recruited. All subjects gave written informed consent.

## Experimental procedure

The study lasted 13 weeks. During an initial visit the monitoring system was installed in the subject's home and the subject was trained in its use. This included how to carry out the short directed routine of basic postures and activities. Subjects were given the following instructions on what to do in the morning:

- (1) Remove a battery from the recharger unit.
- (2) Insert the battery into the monitoring device.
- (3) Attach the monitoring device to your waist.
- (4) Go to the computer.
- (5) Push the mouse to 'wake up' the computer screen.
- (6) Once you are standing and ready to start the daily routine, press the button on the monitoring device to start.
- (7) Continue to follow the instructions given by the computer until the daily routine is complete.
- (8) Wear the monitoring device for the rest of the day.

Subjects were given the following advice regarding going out during the day:

If you are going out, you don't need to do anything—you can continue to wear the monitoring device while you are out. However, if you are concerned about losing the monitoring device while you are out, or do not want to wear it while you are out, then you can take it off and place it near the computer until you come home. When you come home again, simply pick up the monitoring device and attach it to your waist. You do not need to do anything else—there is no need to press the button.

Finally, subjects were given the following instructions for what to do before retiring at night:

- (1) Complete the daily health questionnaire for the day.
- (2) Remove the monitoring device from your waist.
- (3) Remove the battery from the monitoring device.
- (4) Place the battery in the recharger unit.
- (5) Plug in the recharger unit, turn on the power, and allow it to recharge overnight.

During this initial visit subjects' health and medical histories were recorded using the Stanford Health Assessment Questionnaire (HAQ) disability index and pain scale<sup>7–10</sup>, the COOP/WONCA health questionnaire<sup>11</sup>, and a customized medical history questionnaire. Subjects were also given a falls diary and copies of a daily health questionnaire to complete. In the event of a fall or stumble, subjects were asked to

Author:  
col 2:  
Need  
some  
brief  
detail  
on what  
this  
consisted  
of?

note the time and location, and the nature and cause of the fall.

Subjects were then left alone with the system for one week before being revisited. The initial training was repeated and initial feedback on the system was obtained. After this second visit, each subject was visited approximately every two weeks to collect the acceleration data stored on the computer and to ensure that the system was functioning properly. During these visits subjects were asked to report their perceptions of the system.

The COOP/WONCA health questionnaire was administered weekly until the end of the study period, either during a visit or by telephone. Mid-way through the study, a short-form physiological assessment developed by Lord *et al.*<sup>12–16</sup> was conducted to assess falls risk. At the conclusion of the study, the health and medical questionnaires applied at the start of the study were reapplied. Subjects were then formally interviewed to obtain feedback on their use of the TA system.

## Daily routine

Each morning the subject carried out a short routine of basic daily movements. At a time agreed with the subject, the computer issued an audible reminder and then guided the subject through the routine. The following instructions were both presented as text and voiced by the computer:

- (1) Press the button on the monitoring device when you are standing up and ready to start the testing.
- (2) Please remain standing for the next 30 seconds.
- (3) Please sit down.
- (4) Once you are seated, press the button on the monitoring device.
- (5) Please stay seated.
- (6) Now stand up again.
- (7) Once you are standing, press the button on the monitoring device.
- (8) Please stay standing.

- (9) Now walk around. Follow the same route that you always take during this testing programme.
- (10) Once you have finished and are standing beside your bed, press the button on the monitoring device.
- (11) Please stay standing.
- (12) Now lie down.
- (13) Once you are lying down, press the button on the monitoring device.
- (14) Please stay lying.
- (15) Now stand up again.
- (16) Once you are standing, press the button on the monitoring device.
- (17) Please stay standing.

This 11-movement routine (see Table 1) took less than 5 min to complete.

The plan for the daily routine (e.g. choice of chair to sit down on and walking route) were determined when the system was installed in the subject's home. Once the routine was established, it was carried out in the same manner every day.

## Analysis

All data were analysed retrospectively. From the movements performed in the daily routine, a set of variables was extracted (Table 1) and tracked longitudinally for each subject. Every second the signal was tested to determine whether the subject was wearing the device and, if so, whether the subject was engaged in activity or rest. The time stamp on each data sample was examined to determine whether or not any data had been lost. The amount of missing data was recorded hourly for each subject. This provided a measure of the reliability of the wireless communications.

The acceleration signals were median filtered (length 13 samples) to remove noise spikes and then high-pass filtered (cut-off frequency 0.25 Hz) to remove the component due to gravitational acceleration. The signal was then tested to determine whether the device

**Table 1** Variables measured for each of the movements in the set daily routine

	Movement <sup>a</sup>										
	1	2	3	4	5	6	7	8	9	10	11
Tilt angle	✓		✓		✓	✓	✓		✓		✓
Postural sway	✓										
Duration		✓		✓				✓		✓	
Energy expenditure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Step rate						✓					
Descriptive statistics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

<sup>a</sup>Movements are: 1, stand; 2, stand to sit; 3, sit; 4, sit to stand; 5, stand; 6, walk; 7, stand; 8, stand to lie; 9, lie; 10, lie to stand; and 11, stand.

was being worn by comparing the magnitude of the high-pass filtered signal, averaged over the last 60 s, to a preset threshold. If the value exceeded the threshold then the subject was deemed to be wearing the device. This method was based on the assumption that, because a conscious person is never completely still, the signal obtained from a body-worn TA would contain more signal movement than would the signal from a TA that was not being worn. This method had been tested in an earlier laboratory study (with 26 subjects) and a significant difference ( $P < 0.001$ ) had been found between signals when the device was worn by a person at rest compared with signals when the device was not being worn.

If the subject was wearing the TA unit then a measure of energy expenditure, the signal magnitude area (SMA), was computed for each 1 s of data. The SMA is the sum of the integrals of the magnitudes of the three acceleration vectors and is linearly related to the metabolic energy expended by the subject<sup>1</sup>. If the SMA exceeded a preset threshold then the subject was classified as being engaged in activity. The 1 s blocks of activity were joined to form periods of activity, and similarly for periods of rest<sup>6</sup>. All these periods were tested to detect falls.

Variables from the periods of free movement were collated hourly and daily for each subject, and were tested for correlations with self-reported health status. These variables were: the times at which the system started and stopped collecting data each day; the percentage of transmitted data that was captured by the receiver unit; the percentage of time for which the TA unit was worn; and the total and mean SMA during periods of activity and rest.

## Results

All the subjects were healthy and functionally independent. They wore the device for a total of 432

days (88% of days in the study), for an average of 11.2 hours a day (range 1–17 hours). The omissions were due to: confusion about how to use the system during the first week of the study; technical difficulties with the system; and being away from home. Statistics for each subject are given in Table 2.

## User perceptions

The subjects were initially nervous about using the technology, for fear of damaging the equipment, particularly the computer. It was emphasized to the subjects that they could not cause any damage to the system. All subjects were given as much training and support in the use of the system as they required, both through the investigator visits and via the telephone. Within two weeks, all subjects reported that they could use the system easily.

Subject feedback with regard to the wearability of the TA unit varied. All subjects agreed that the unit was comfortable and that they forgot they were wearing it. Several subjects found that it was important to place the unit carefully in order to ensure comfort and prevent bruising. For example, one subject moved the unit's placement every few days. The other subjects each wore the unit at a single location of choice (front, right side or above the hip).

All subjects initially found changing the battery difficult but at the final assessment all agreed that it posed no problems. One subject found that the push button was difficult to reach as the TA unit became buried under soft tissue when attached at the waist.

All subjects stated that the system was easy to use and did not cause any inconvenience. None of the subjects interacted with the computer other than to follow the instructions given in the daily routine and all said that they would have preferred the system without the computer and with a smaller, less obtrusive receiver system.

**Table 2** Details of the subjects' functional status and use of the triaxial accelerometer (TA)

Subject	HAQDI score <sup>a</sup>	HAQPS score <sup>a</sup>	COOP/WONCA score <sup>b</sup>	Falls risk <sup>c</sup>	No. of days in study	No. (%) of days routine carried out	Mean hours TA worn per day
1	0.125	1.08	13	Mild	92	92 (100%)	12.9
2	0.125	0	14	Moderate	84	78 (92.8%)	8.8
3	0	0.92	11	Moderate	73	66 (90.4%)	11.0
4	0	0	12	Mild	60	59 (98.3%)	10.6
5	0.125	2.72	18	Mild	67	60 (89.6%)	10.9
6	0.25	0.9	15	Moderate	56	48 (85.7%)	12.8

<sup>a</sup>The Stanford Health Assessment Questionnaire disability index (HAQDI) and the pain scale (HAQPS) were scored from 0 to 3, with 3 indicating higher levels of disability or pain. The HAQDI and HAQPS were completed before and after the study. The HAQDI scores were the same for every subject in both assessments, and the HAQPS scores were approximately the same. The HAQPS scores before the study are presented here.

<sup>b</sup>The median of the weekly COOP/WONCA scores for each subject is presented. This questionnaire is scored between 6 and 30, with higher scores indicating worse health status.

<sup>c</sup>The falls risk was rated very low, low, mild, moderate or marked.

Author:  
col 1:  
Note  
that  
Table 2  
shows  
that the  
routine  
was car-  
ried out  
on 403  
days,

Author:  
col 1:  
Give  
refer-  
ence for  
this  
study?

Author:  
col 1:  
Explain  
here the  
units  
(g=gram/  
weight  
as an  
accelera-  
tion?)  
for the  
three  
accelera-  
tion vec-  
tors and  
SMA?

All the subjects felt that a personal alarm system that could automatically detect falls would be valuable. Monitoring at home to reduce the need to travel to the clinic was also seen as a positive feature. Five of the six subjects supported the concept of home monitoring to detect early changes in functional status, while the remaining subject felt that exercise programmes and environmental modifications would be more useful.

## Technical performance

Overall, the technical performance of the system was good. Usable data were reliably collected from all six systems throughout the study period (Table 3). The data capture rate represents the amount of data received by the receiver unit divided by the amount of data transmitted by the TA, expressed as a percentage. The median rate was 67% and the mean rate was 63%. As the wireless system included error checking (and erroneous data were discarded), all the data actually received represent valid measurements. Data were lost when the transmitter unit went out of range of the

receiver. Most of the data were lost when the subjects left the home while still wearing the TA unit. However, it was observed that some data were also lost from areas of the home more distant from the receiver unit, where the TA transmitter did not have sufficient power for data transmission. The magnitude of this effect was closely related to the state of the batteries, and it was found to increase in the latter stages of the study, as the batteries aged.

The data capture rate varied between subjects (see Table 3), depending on the subject's routines and the layout of the home. For example, subject 2 spent large portions of the day away from the home while wearing the TA unit, which resulted in low data capture rates. In contrast, subject 5 spent most of each day in the home, and removed the TA unit before going out, which resulted in much higher rates of data capture.

Author:  
col 1:  
The median and mean values are vice versa in Table 3.

**Table 3** Mean, median and interquartile range (IQR) for data capture rate (%)<sup>a</sup> for each subject

Subject	Mean	Median	IQR
1	74	80	61–96
2	44	35	9–85
3	72	80	58–94
4	49	46	13–79
5	70	96	39–100
6	90	98	90–100
Grand mean	67	63	44–99

<sup>a</sup>The data capture rate represents the amount of data received by the receiver unit divided by the amount of data transmitted by the accelerometer, expressed as a percentage.

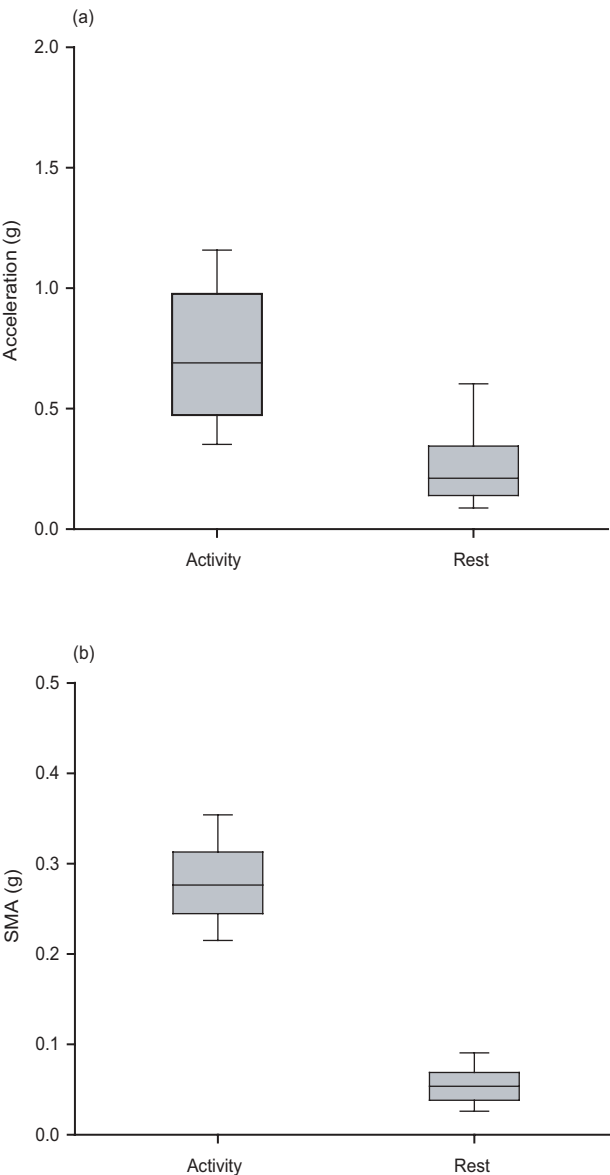
**Table 4** Mean (SD) values of the main variables for each movement taken across all iterations of the daily routine made by all six subjects ( $n=432$ )

	Movement <sup>a</sup>										
	1	2	3	4	5	6	7	8	9	10	11
Tilt angle (°)	13.5 (9.73)		29.4 (19.5)		13.0 (9.51)	12.8 (9.28)	12.4 (9.45)		82.6 (13)		16.3 (11.5)
Postural sway frequency (Hz)	0.27 (0.11)										
Postural sway amplitude ( $g$ )	$0.8 \times 10^{-3}$										
Duration (s)		4.78 (2.34)		3.5 (1.35)				6.42 (1.72)		6.0 (1.48)	
SMA ( $g$ )	0.03 (0.01)	0.28 (0.05)	0.06 (0.02)	0.26 (0.05)	0.04 (0.02)	0.28 (0.04)	0.06 (0.02)	0.32 (0.06)	0.07 (0.01)	0.26 (0.05)	0.09 (0.04)
Step rate (steps/min)						106 (15)					
Range x-axis ( $g$ )	0.18 (0.13)	0.79 (0.33)	0.28 (0.17)	0.65 (0.29)	0.28 (0.17)	0.73 (0.26)	0.28 (0.2)	1.15 (0.46)	0.22 (0.13)	1 (0.43)	0.66 (0.8)
Range y-axis ( $g$ )	0.18 (0.11)	0.64 (0.19)	0.21 (0.13)	0.5 (0.17)	0.25 (0.13)	0.74 (0.64)	0.25 (0.16)	1.09 (0.41)	0.21 (0.1)	1.05 (0.39)	0.55 (0.71)
Range z-axis ( $g$ )	0.15 (0.12)	0.82 (0.27)	0.28 (0.17)	0.53 (0.2)	0.26 (0.19)	1.04 (0.76)	0.26 (0.18)	1.46 (0.28)	0.3 (0.19)	1.12 (0.25)	0.66 (0.35)

<sup>a</sup>The movements are the same as in Table 1.

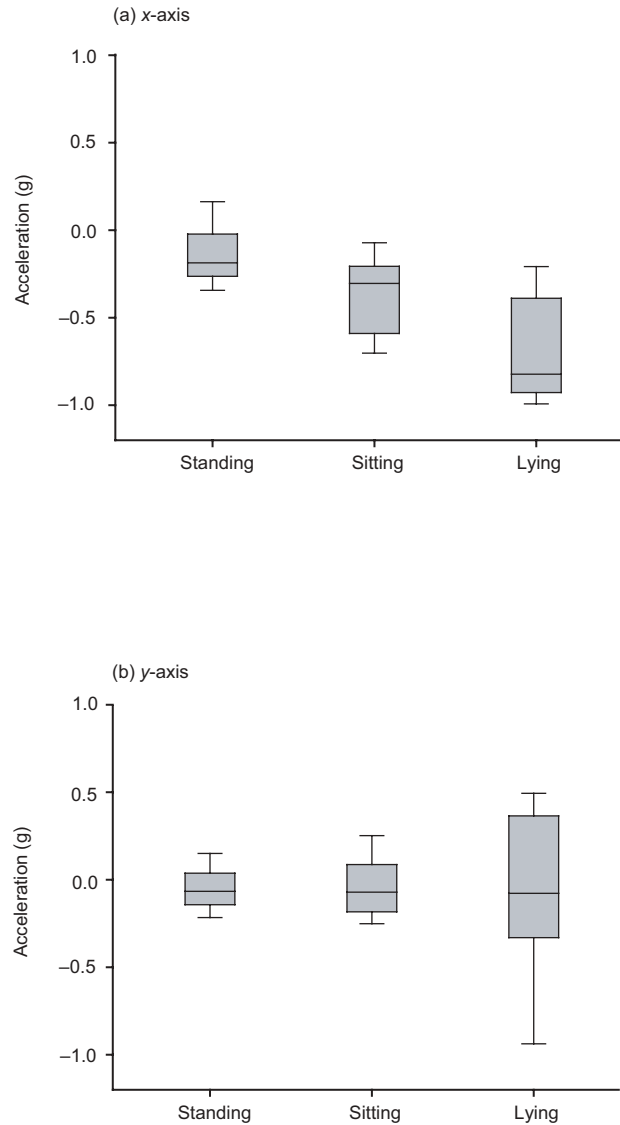
Author:  
Table 2  
gives a  
total of  
403 daily  
routines?

Author:  
Please add  
footnote  
to explain  
'Range'  
(in each  
axis) and  
how/why  
the unit is  
'g'?



**Fig 3** Difference in (a) acceleration and (b) signal magnitude area (SMA) between activity and rest during the directed routine for all six subjects. The box indicates the interquartile range (IQR) for the data (i.e. the middle 50% of the data). The line through the box represents the median value. The whiskers represent the 10th and 90th centiles.

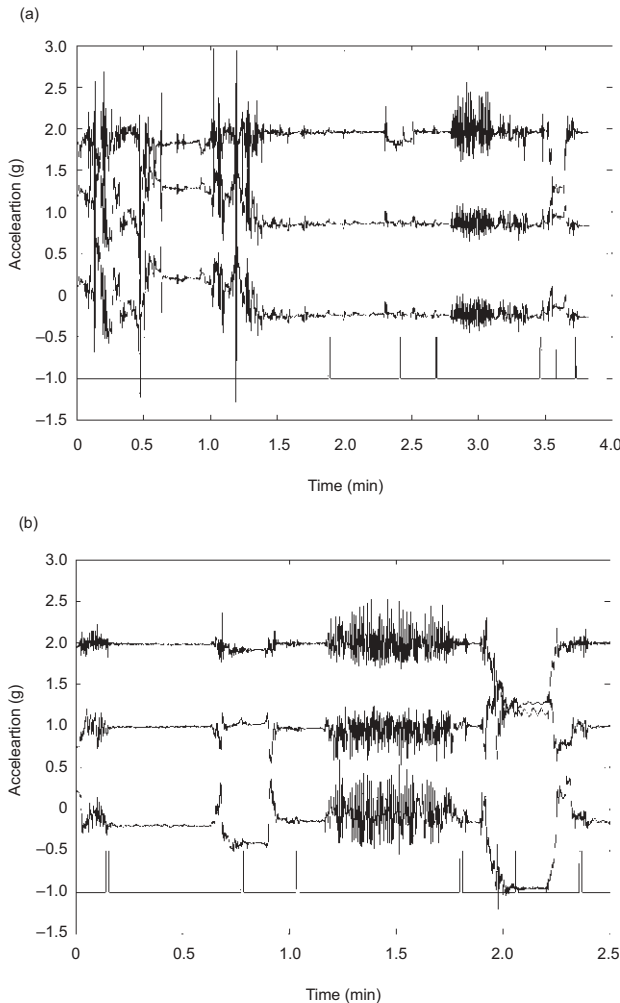
about carrying out the routine correctly but within two weeks all subjects could complete it without difficulty. No other longitudinal changes were detected in the signals from the directed routine, which suggests that the functional status of each of the subjects remained stable throughout the study period. This is in agreement with the self-reported health status from the weekly administration of the COOP/WONCA questionnaire, and the assessments performed at the beginning and end of the study, which showed no change in functional status over the study period.



**Fig 4** Mean accelerations in (a) the x-axis and (b) the y-axis, during the directed routine for all six subjects. The box and whiskers have the same definition as those in Fig 3.

### Free movement

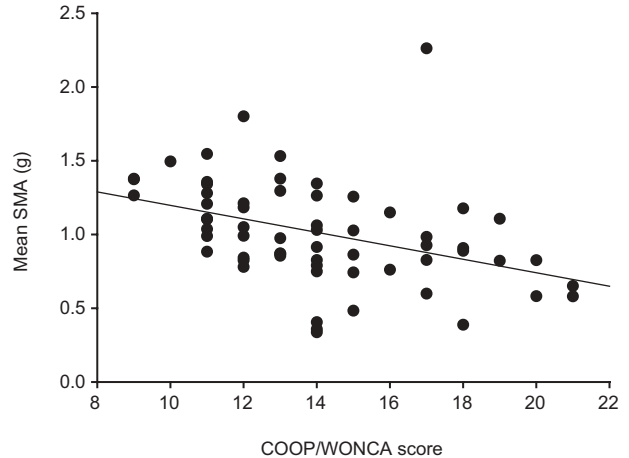
The data from the periods of free movement were tested for hourly and daily trends in the amount of data captured, percentage of time that the unit was worn, amount of time spent in activity and mean SMA. In addition, correlations were sought between self-reported health status, time spent in activity and mean SMA using the complete data from all subjects. A moderate correlation ( $r = -0.51$ ) was found between COOP/WONCA score and mean SMA (Fig 6), which indicates that in weeks when subjects felt less well they also expended less energy. No falls occurred during the study period.



**Fig 5** An example of the learning effect on the daily routine signal. (a) The trace obtained from subject 1 on the first day of use, and (b) the trace obtained from the same subject five days later. The second trace is smoother than the first and contains less extraneous movement and fewer pauses during activities. The three signals have been shifted vertically for clarity. The traces represent, from the top: z-axis, y-axis, x-axis and button press.

## Discussion

The purpose of this pilot study was to assess the feasibility of using a TA unit for continuous, long-term monitoring in the home. The high compliance rates and the subject feedback (gained in response to set questions in a formal interview at the conclusion of the study) indicate that the system could be used continuously for long periods. This was probably due to the system's simplicity, the unobtrusive nature of the TA unit (subjects forgot that they were wearing it) and the computer-generated reminders to wear the unit. During the study, each subject was contacted at least once a week by one of the investigators and this



**Fig 6** Mean weekly signal magnitude area (SMA) and COOP/WONCA scores in all six subjects. In the COOP/WONCA questionnaire, lower scores indicate better health status. SMA is linearly related to metabolic energy expenditure, so a decrease in SMA indicates a decrease in energy expenditure. The straight line indicates the correlation ( $r = -0.51$ ) between COOP/WONCA score and mean SMA: when subjects felt less well they expended less energy.

regular contact may have contributed to the high compliance rates achieved.

Technical modifications that would enhance the system include: a cradle recharging system for the unit (although none of the subjects complained about changing the rechargeable battery); replacement of the computer and receiver with a small, dedicated unit; and redesign of the TA unit to buffer data records and to transmit with more power, to increase the transmission range. This might lead to improved subject satisfaction, reduced cost and more reliable operation of the system.

Healthy subjects were selected as they were more likely to remain living independently at home during the study period, which was important, given the small size of the cohort. One consequence of this was that the health status of each of the subjects remained steady throughout the study period, apart from small fluctuations due to minor illnesses. As a result, no longitudinal trends were detected in any of the measured variables. However, the moderate correlation found between self-reported health status and energy expenditure suggests that this measure may provide an independent measure of health status, although more work is required to investigate this hypothesis. It may be expected that the magnitude of this correlation would increase if patients with fluctuating health status were monitored in this manner.

The results of this pilot study demonstrate the technical feasibility and usability of a single waist-mounted TA system as an instrument for unsupervised home monitoring of human movements.



## References

- 1 Bouten CV, Koekkoek KT, Verduin M, Kodde R, Janssen JD. A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity. *IEEE Transactions on Biomedical Engineering* 1997;**44**:136–47
- 2 Currie G, Rafferty D, Duncan G, Bell F, Evans AL. Measurement of gait by accelerometer and walkway: a comparison study. *Medical and Biological Engineering and Computing* 1992;**30**:669–70
- 3 Evans AL, Duncan G, Gilchrist W. Recording accelerations in body movements. *Medical and Biological Engineering and Computing* 1991;**29**:102–4
- 4 Aminian K, Robert P, Buchser EE, Rutschmann B, Hayoz D, Depairon M. Physical activity monitoring based on accelerometry: validation and comparison with video observation. *Medical and Biological Engineering and Computing* 1999;**37**:304–8
- 5 Mathie MJ, Coster ACF, Lovell NH, Celler BG. Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement. *Physiological Measurement* 2004;**25**:R1–20
- 6 Mathie MJ, Coster ACF, Lovell NH, Celler BG. Detection of daily physical activities using a triaxial accelerometer. *Medical and Biological Engineering and Computing* 2003;**41**:296–301
- 7 Bruce B, Fries JF. The Stanford Health Assessment Questionnaire: a review of its history, issues, progress, and documentation. *Journal of Rheumatology* 2003;**30**:167–78
- 8 Ramey DR, Fries JF, Singh G. The Health Assessment Questionnaire 1995 — status and review. In: Spilker B, ed. *Quality of Life and Pharmacoeconomics in Clinical Trials*. 2nd edn. Philadelphia: Lippincott-Raven, 1996: 227–37
- 9 Fries JF, Spitz PW, Young DY. The dimensions of health outcomes: the Health Assessment Questionnaire, disability and pain scales. *Journal of Rheumatology* 1982;**9**:789–93
- 10 Fries JF, Spitz P, Kraines RG, Holman HR. Measurement of patient outcome in arthritis. *Arthritis and Rheumatism* 1980;**23**:137–45
- 11 Nelson E, Wasson J, Kirk J, *et al.* Assessment of function in routine clinical practice: description of the COOP Chart method and preliminary findings. *Journal of Chronic Diseases* 1987;**40** (suppl. 1):55–69
- 12 Lord SR, Sambrook PN, Gilbert C, *et al.* Postural stability, falls and fractures in the elderly: results from the Dubbo Osteoporosis Epidemiology Study. *Medical Journal of Australia* 1994;**160**:684–5, 688–91
- 13 Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *Journal of the American Geriatrics Society* 1991;**39**:1194–200
- 14 Lord SR, Castell S. Physical activity program for older persons: effect on balance, strength, neuromuscular control, and reaction time. *Archives of Physical Medicine and Rehabilitation* 1994;**75**: 648–52
- 15 Lord SR, Clark RD. Simple physiological and clinical tests for the accurate prediction of falling in older people. *Gerontology* 1996;**42**:199–203
- 16 Lord SR, Clark RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. *Journal of Gerontology* 1991;**46**:M69–76