Evaluation of new concept for balance and gait analysis: patients with neurological disease, elderly people and young adults

Juho Merilahti, Tuula Petäkoski-Hult, Miikka Ermes, Heidi Lahti, Aarne Ylinen, Leena Autio, Esko Hyvärinen, Jari Hyttinen, and Mark van Gils

***Abstract*—Fall accidents among elderly are costly for the society. Gait and balance are reported to reflect best the risk of falling. We recorded gait and balance properties of 15 patients with neurological disease, 20 elderly and 19 young adults. During the Berg Balance Scale test and walk test we collected kinetic data with wearable 3D accelerometers. Results showed significant differences between different subject groups in features calculated from the accelerometer signals. We found that accelerometer signals collected during the walk test could be used to discriminate between subject groups divided according to their Berg Balance Scale score.**

I. INTRODUCTION

THE ratio between senior citizens and working age people will become and already is challenging in many countries. Supporting elderly people to live longer at home have has benefits for the citizens themselves and for the social and health care system. Our interests are on creating new service concepts utilizing technology for elderly users.

Fall accidents are a significant problem among elderly. Accidents could be decreased and possible help could be provided using technology. There are indications that balance and gait problems are the most significant independent factors to indicate the probability of future fall accidents [1]. There are also signs that by evaluating and treating several risk factors of falling we would have the best effectiveness to prevent becoming falls leading to fractures and lower costs of the social and health care system caused by fall accidents. [2]

By collecting the person's kinetic data (e.g. with accelerometers) several gait parameters can be determined [3], and balance of a person can be estimated [4]. We selected three different groups (patients with neurological disease, elderly people, and young adults) to participate in the study in which they performed a Berg Balance Scale test (BBS) [5] and a short walk test, during which we collected person's kinetic data. For example, Lajoie et al. showed that cut-off score of 49 in the BBS result could be used to distinguish between community-dwelling elderly fallers and non-fallers [6].

After the tests we interviewed participants about new services related to fall accidents and technology. Our objective was to find suitable technological solutions for identifying possible problems in balance or gait in the home environment.

Manuscript received April 30, 2008. This work was supported by Tekes (the Finnish Funding Agency for Technology and Innovation), Pikosystems Oy, Tietoenator Oyj, YH Länsi Oy, UPM-Kymmene Oyj, Turun Ortofysio Oy, Arcticare Technologies Oy, Suomen Ensiapupalvelu, and VTT Technical Research Centre of Finland.

Juho Merilahti is with VTT Technical Research Centre of Finland, Tampere, P.O. Box 1300, Finland (phone: +358 40 723 7107; e-mail: juho.merilahti@vtt.fi)

Tuula Petäkoski-Hult, Miikka Ermes and Mark van Gils are with VTT Technical Research Centre of Finland, Tampere, P.O. Box 1300, Finland ({firstname}.{lastname}@vtt.fi)

Heidi Lahti, Leena Autio and Aarne Ylinen are with The Pirkanmaa Hospital District, P.O. Box 2000, Finland (phone: + 358 3 311 611, {firstname}.{lastname}@pshp.fi)

Esko Hyvärinen and Jari Hyttinen are with Tampere University of Technology, Tampere, P.O. Box 692, Finland (phone: +358 3 311 511, {firstname}.{lastname}@tut.fi)

II. METHODS

A. Balance and gait material collection and analysis

The study was accepted by the ethical committee of the Pirkanmaa hospital district. The test protocol started with Berg Balance Scale (BSS) test which was explained to the participants and evaluated by a physiotherapist. The BBS test includes 14 small tasks (see Table 2, sitting unsupported is left out) which are normally present in daily activities such as retrieving object from floor or sitting to standing transition. After the BBS test the participants walked in a corridor 10 to 20 meters back and forth in their own pace and with their preferred footwear During the walk test gait realted data was collected.

The same physiotherapist evaluated all the participants and the tests situations were as identical as possible. The test location was set up as convenient for the participants as possible. For example, the patients participated in the tests in the hospital during their hospital visit and the elderly group took part in their living facility's gym or meeting hall.

In the BBS's instructions there is a rough discrimination in 3 different outcome groups; 0-20 points (weak), 21-40 (average), and 41-56 (good). The result could indicate how much a person needs support her/himself physically (wheel chair bound, walking with assistant, or independent). We did not have many participants with the BBS score under 20 and we divided participants into three groups for the analysis; less than 40 points (group 1), points between 40 and 49 (group 2), and over 50 (group 3).

During the tests we collected kinetic data with two 3D accelerometers (8 bit, 75Hz, Alive Heart Monitor, Alive Technologies, Queensland, Australia); one attached to the person's lower back (lumbar spine) as in [3] and the other to a location which the person him/herself preferred as in

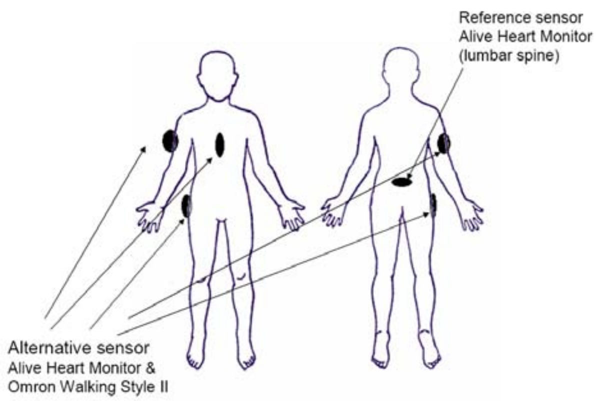

Fig. 1: alternative locations of the different sensors during the Berg Balance Scale and walk tests

Fig. 1 (alternative locations were on the upper arm, in the trouser pocket, on the hip, or on the chest hanging from the neck). In addition to this, an Omron Walking Style II pedometer was used during the walk test placed in the same location as the alternative accelerometer and a video was recorded for later analysis.

During the tests a researcher marked with computer software each task's starting and ending moment [7]. These entries were checked manually afterwards to assure their correctness.

We processed the accelerometer signal to find out differences between the three subject groups and between the different BBS results. Mean, minimum, maximum, standard deviation, root mean square (RMS), and absolute difference (difference of maximum and minimum) were calculated from the magnitude of the signal's resultant during the marked annotations. In addition to this, the power from 1.5 Hz to 2.5 Hz frequency band was calculated during the walking.

The Spearman correlations between different sensor locations were calculated for each parameter over the whole test protocol and solely during the walking. Variables were calculated with 2 seconds window using 1 second overlap between the windows. The shortest task/annotation lasted about two seconds.

TABLE 1: SUBJECT'S BACKGROUND INFORMATION AND ALTERNATIVE SENSOR LOCATION SELECTION COUNT (THREE MOST POPULAR)

Participant group / Feature	Patients	Elderly people	Young adults
Age average (range) [sd]	55.2 (40-68) [7.3]	76.8 (67-87) [5.6]	27.5 (36-21) [4.4]
BMI average (range) [sd]	28.0 (40.3-17.6) [7.1]	26.3 (33.0-19.1) [3.9]	23.0 (18.2-28.4) [2.7]
Male/Female	7/8	4/16	9/10
Berg Balance Scale average (range) [sd]	45.7 (56-16) [10.6]	45.9 (55-33) [6.8]	55.9 (56-55) [0.2]
Alternative sensor location	trouser pocket=1, upper arm=4, chest=9	trouser pocket=3, upper arm=2, chest=15	trouser pocket=14, upper arm=3, chest=1

B. *Interviews*

After the tests we interviewed the participants about their general technological experience and important qualities for possible new services utilizing technology (list of qualities were provided and the subject was asked to select three most important ones, see Table 5). Furthermore information was collected from personal health behaviour, experiences with fall incidents, and personal opinions about financing of possible new services. The interviews were recorded.

III. RESULTS

A. *Subjects and material collected*

Fifteen patients, 20 elderly persons and 19 young adults participated in the study (Table 1). Seven of the patients had diagnosis in celebrovascular diseases (ICD-10 I60-I69), one in injuries to the head (ICD-10 S00-S09), one in inflammatory disease of the central nervous system (ICD-10 G00-G09), and six in diseases of nervous system (ICD-10 G20-G26), of which the most had a Parkinson's disease.

We lost one person's accelerometer data from each group due to technical problems. Total duration of accelerometer data from the lower back is 26 hours and 25 minutes. Two pedometer readings were not gained.

Participants according to the BBS score were distributed following: ten persons in group 1, ten persons in group 2, and 31 persons in group 3.

B. *Data during the Berg Balance scale test*

Table 2 shows significant differences between the three groups in all the BBS's tasks for calculated variables from the accelerometer signal. Fig. 2 describes RMS variable value distribution during the standing unsupported task for each group. Difference is visible between the elderly people and the other two groups.

Standard deviation differed between the BBS group 1 and group 2 in sitting to standing, transfer, and retrieving objects from floor tasks ($P < 0.01$). Also minimum and standard deviation values during the standing on one leg task differed significantly between group 1 and group 2 ($P < 0.01$).

C. *Data during the walk test*

Table 3 presents differences in accelerometer signal during the walk test which was performed after the BBS test. Variable values during the walk test seem to differ systematically between the different participant groups, and between group 1 and group 3. However, these variables do not differ with P value less than 0.01 between group 2 and group 3. In Fig. 3 is a box plot of the frequency variable between participated groups.

D. *Correlations between different locations of the sensors*

Table 4 presents average Spearman correlations for

TABLE 2: ACCELERATION SIGNAL VARIABLES WHICH DIFFERED SIGNIFICANTLY DURING THE BERG BALANCE SCALE TEST BETWEEN DIFFERENT PARTICIPANT GROUPS (E = ELDERLY PEOPLE, P = PATIENTS, A = YOUNG ADULTS)

Variable \ Task	Sitting to standing	Standing unsupported	Standing to sitting	Transfers	Standing with eyes closed	Standing with feet together	Reaching forward while standing	Retrieving objects from floor	Turning trunk (feet fixed)	Turning 360 degrees	Stool stepping	Tandem standing	Standing on one leg
Minimum	p&a**						e&a**	e&a*** p&a***					e&a** p&a***
Maximum	e&p** p&a**							e&a**					
Standard deviation	e&p* p&a**		p&a***	e&a**	p&a**		e&a**	e&a*** p&a***					e&a*** p&a***
RMS	e&p** p&a**	e&p*** e&a**	e&p** p&a**			e&p**	e&p**	e&p** p&a***	e&p**			e&p** e&a**	
Absolute difference	p&a**							e&a*** p&a**					e&a** p&a***
Mean	e&p**	e&p*** e&a**	e&p**	e&p**	e&p**	e&p**		e&a** p&a***	e&p**	e&p** p&a***		e&a** e&p**	

** P < 0.01, *** P < 0.001

each parameter between the reference (lower back) and the alternative sensor locations (trouser pocket, the upper arm, or the chest). These were the three locations which the participants preferred the most for placing the sensor.

We calculated correlations during the whole test protocol and solely during the walking. Fig. 4 presents Bland-Altman plot of standard deviation variable during the walk test. It shows that sensor located in a trouser pocket overestimates standard deviation with the bigger values and underestimates with the smaller values.

E. Interviews

Nineteen out of 20 elderly people responded to interviews. Sixteen persons had experienced unpleasant fall accidents (seven reported injuries caused by a fall). Ten said that the fear of falling does not restrict their daily activities. However, eight reported reducing activities outside due to the fear. Seventeen said that their living environment felt safe to move around. Eleven could or would use technology-based solutions to gain help in fall risk management. Table 5 lists the most important qualities a technology-based instrument should have according to all the interviews.

All patients agreed to be interviewed. Nine had experienced a fall most likely related to their medical condition (two with a more serious fall accidents). Six felt the fear of falling restricts their daily activities. However, all the participants considered that their interior living environment was safe doing daily activities. Eight could use technology in fall risk management related issues.

IV. DISCUSSION

We tried to find out value of using the 3D accelerometer signal when measuring balance and gait of a person with a wearable sensor. We compared calculated variables from the signal between the different participant groups (patients with neurological disease, elderly people, and young adults). We also compared the variables between different Berg Balance Scale (BBS) score groups (3 groups: less than 40 points, 40-49 points, and more than 49 points).

We found that several variables differed significantly (Table 2) between different participant groups during the different BBS tasks. Especially standard deviation, root mean square amplitude, and mean amplitude were promising, which differed between the groups during most of the tasks. However, the tasks included in the BBS

TABLE 3: DIFFERENCES BETWEEN DIFFERENT PARTICIPANT GROUPS AND DIFFERENT BERG BALANCE SCALE (BBS) RESULT GROUPS DURING THE WALK TEST FOR DIFFERENT VARIABLES

Variable \ Task	Participated groups	BBS groups
Minimum	e&a**	1&3**
Maximum	e&a**	1&3***
Standard deviation	e&a*** p&a***	1&3***
RMS	e&a*** p&a***	1&3***
Absolute difference	e&a**	1&3***
Mean	e&p**	1&3***
Minimum	p&a***	1&3**

** P < 0.01, *** P < 0.001

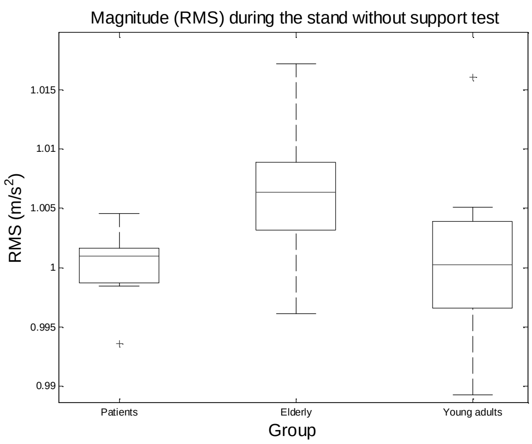

Fig. 2: Root Mean Square (RMS) of acceleration signal during the standing unsupported test for different participated groups

TABLE 4: SPEARMAN CORRELATION COEFFICIENT BETWEEN DIFFERENT ACCELEROMETER SENSOR LOCATIONS COMPARED TO THE REFERENCE SENSOR (LOWER BACK)

Whole test phase	Location / Variable	In the trouser pocket (N=10)	On the chest (N =31)	On the upper arm (N=10)
	Minimum	0.65	0.66	0.67
	Maximum	0.73	0.70	0.75
	Standard deviation	0.79	0.77	0.76
	RMS	0.67	0.65	0.65
	Absolute difference	0.83	0.76	0.78
	Mean	0.28	0.18	0.24
Walking				
	Minimum	0.41	0.49	0.37
	Maximum	0.46	0.37	0.34
	Standard deviation	0.73	0.67	0.73
	RMS	0.74	0.67	0.74
	Absolute difference	0.49	0.43	0.55
	Mean	0.62	0.46	0.42

test could be hard to distinguish automatically from the signal and would be more fruitful to utilize the method in supervised conditions.

Results of the BBS score groups were different compared to results with the participant groups. Differences between three BBS score groups were not significant in so many tasks as with the participant groups. Interesting would be to discriminate between groups having points less and more than 49. The significant difference in this case was found during the stand with eyes closed and standing with feet together tasks ($P < 0.05$).

It would be interesting to study if the classification to the different BBS score groups will be possible by using variable values during the different BBS tasks. However, there are problems when collecting data during tasks like tandem standing or standing on one foot when a subject is not able to perform the test until the end. For example, most of the participants were able to stand 10 seconds with their eyes closed and the results with accelerometer during this task would be more reliable to use.

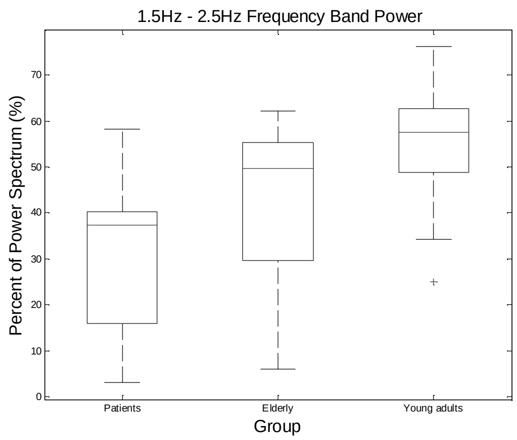

Fig. 3: Portion of the 1.5Hz-2.5Hz frequency band of the acceleration signal compared to whole power spectrum

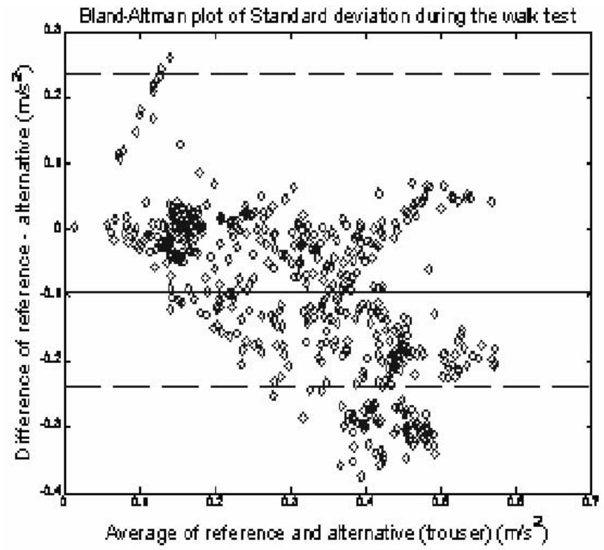

Fig. 4: Bland-Altman plot of standard deviation calculated from the reference sensor and from the sensor located in trouser pocket during the walk test

According to our results, accelerometer signal during the walking seems promising to discriminate between different BBS score groups although we found significant difference between group2 (40-49 points) and group3 (more than 49 points) only when using frequency band power ratio between 1.5Hz and 2.5Hz ($P < 0.05$). If we want to automatically observe personal health status according to Berg Balance Scale, walking would be easiest to distinguish from the accelerometer signal during daily activities and calculate variables during the recognized walking. For example, a wearable accelerometer could give valuable information about long term fall risk status. Most of the elderly in this study preferred a sensor placed on the chest (hanging on the neck) and it would be important to study whether we can

TABLE 5: PARTICIPANTS SELECTIONS OF THE MOST IMPORTANT FEATURES FOR TECHNOLOGY BASED SOLUTION RELATED TO FALL PROBLEM

Participant group	**Elderly**		**Patients**		**Young adults**	
Feature	**Important**	**Least important**	**Important**	**Least important**	**Important**	**Least important**
Peer support possibility	1	1	4	2	0	3
Communication possibility	5	1	3	0	2	2
Individually modifiable	1	1	5	0	5	1
Easy to use	11	1	6	0	15	0
Affordability	7	1	2	1	1	3
Mobility	6	0	8	1	7	1
Unobtrusiveness	0	3	0	4	6	2
Easy to learn	8	0	1	0	4	0
Communal promotion	1	0	1	1	1	4
Reliability	10	0	12	0	15	0

get similar quality results from the chest. Table 4 shows that standard deviation and root mean square have the highest correlation during the walking between the reference and on the chest measurements. A sensor located in the subjects pocket seemed to reflect best the different variables during the whole test period compared to the reference sensor signal. The results obtained from the lower back can be problematic if used directly for other sensor locations as seen in Fig. 4.

According to the interviews easy-of-use, reliability and mobility were seen as the most important features of a technology-based solution which could provide help in fall related problems such as in detection or in follow-up of the risk factors. Elderly users also emphasized affordability and easy of learning qualities. Unobtrusiveness was not so important to the elderly people and to the patients as compared to the young adults, something that was already suspected in [8]. The patients commented most to the peer support group feature which might reflect their bigger need for it.

We have planned to include wearable 3D accelerometers in field studies where we collect long term data from the participant and give him/her feedback on the collected data. We planned to select variables calculated from the signal according to these results and follow individual progress from these. We will include in the field study two patients and one elderly person, who might benefit this type of a follow-up.

ACKNOWLEDGMENT

We would like to thank Lempäälän Ehtookoto personnel, Viola-koti personnel and Hopealahti personnel for their great help. We would also like to thank Ilkka Korhonen and Juha Pärkkä for their comments.

REFERENCES

[1] D. A. Ganz, Y. Bao, P. G. Shekelle, L. Z. Rubenstein, “Will my patient fall?”, *JAMA*, January 3; 297: 77 - 86, 2007

[2] T. L. N. Järvinen, H. Sievänen, K. M Khan, A. Heinonen, P. Kannus, “Shifting the focus in fracture prevention from osteoporosis to falls”, *BMJ*, 336, pp. 124-126 , April 2008

[3] R. Moe-Nilssen, “A new method for evaluating motor control in gait under real-life environmental conditions. Part 2: Gait analysis”, *Clinical Biomechanics*, 13:328-335, 1998

[4] R.E. Mayagoitia, J.C. Lötters, P.H. Veltink, H. Hermens, “Standing balance evaluation using a triaxial accelerometer”, *Gait and Posture,* 2002, 16, pp. 55-59, 2002

[5] S. Wood-Dauphinee, K. Berg, G. Bravo, JI. Williams, “The Balance Scale: Responding clinically meaningful chances“ *Canadian Journal of Rehabilitation*, 10:35-50 , 1997.

[6] Y. Lajoie, S.P. Gallagher, **“**Predicting falls within the elderly community: Comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers”, *Archives of Gerontology and Geriatrics*, 38 , pp. 11-26, 2004

[7] J. Pärkkä, L. Cluitmans, P. Korpipää, "Palantir Context Data Collection, Annotation and PSV File Format" *Pervasive 2004 Workshop Proc.: Benchmarks and Database Context Recognition*, pp. 9-16, 2004

[8] I. Korhonen, J. Pärkkä, M. Van Gils, ”Health Monitoring in the Home of the Future” *IEEE Engineering in Medicine and Biology Magazien*, May/June 2003