Objective measuring of Activities of Daily Living by patients with stroke

Masterthesis

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“ONDERGETEKENDE

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bevestigt hierbij dat de onderhavige verhandeling mag worden geraadpleegd en vrij mag worden gefotokopieerd. Bij het citeren moet steeds de titel en de auteur van de verhandeling worden vermeld.”

SAMENVATTING

• **Achtergrond** Patiënten met een beroerte laten vaak een aantal maanden na ontslag uit een revalidatiecentrum een verslechtering zien in hun algemeen dagelijks functioneren (ADL) ten opzichte van het moment van ontslag. Om de patiënt beter te kunnen monitoren na ontslag en sneller te kunnen ingrijpen bij verslechtering is INTERACTION ontwikkeld. INTERACTION bestaat uit kleding en schoeisel waarin sensoren zijn verwerkt, die zorgen voor kinetische en kinematische bewegingsanalyse. Hiermee kunnen de activiteiten van het dagelijks leven in kaart worden gebracht. Probleem hierbij is dat er op dit moment geen objectieve maat is om deze activiteiten te meten. Nu worden deze activiteiten gemeten met subjectieve vragenlijsten en aspecifieke klinische testen. Om INTERACTION in de toekomst in te kunnen inzetten in de praktijk is kennis nodig over de relatie tussen vragenlijsten en aspecifieke klinische testen van de loopvaardigheid en INTERACTION.

• **Doel** Het doel van deze pilot studie was de relatie tussen INTERACTION en ADL taken, ADL vragenlijsten en klinische ADL testen, gefocust op loopvaardigheid, te onderzoeken.

• **Methode** Door middel van een exploratieve cross-sectionele pilot studie werd de relatie tussen ADL taken (traplopen), ADL vragenlijst (Barthel Index), a-specifieke klinische testen die bestaan uit ADL (Berg Balance Scale, Timed Up and Go test en 10 Meter Loop Test) en INTERACTION (voetpositie (X,Y), Centre of Mass) onderzocht. Alle klinische testen, ADL taken en de vragenlijst werden gecorreleerd met een nieuw ontwikkelde statische en dynamische balansmaat, gemeten met INTERACTION. De mate van correlatie is berekend met behulp van de Spearman’s Rang correlatie en de Pearson’s correlatie coëfficiënt.

• **Resultaten** 8 patiënten [M=6/V=2, leeftijd 66.3 ± 7.8] hebben deelgenomen aan de studie. The correlatie tussen statische balans en de afzonderlijke onderdelen van de Berg Balance Scale varieerde van -0.4954 tot -0.7829. De correlatie tussen dynamische balans (10 Meter Walk Test, Timed Up and Go test, traplopen en de dynamische items uit de Berg Balance Scale) varieerde van 0.4039 tot 0.5191. Daarnaast is er een correlatie gevonden van 0.5294 tussen het gemiddelde van de statische balans, dynamische balans en quasi statische balans gecorreleerd met de Barthel Index.

• **Conclusie** Deze pilot studie heeft een gemiddelde tot sterke correlatie gevonden tussen ADL taken, ADL vragenlijsten en klinische ADL testen gefocust op loopvaardigheid en INTERACTION.

ABSTRACT

• Background Patients with stroke might show deterioration performance during their follow-up treatments in comparison with their motor capacity at the moment they were discharged from a rehabilitation centre. Monitoring of daily-life performance by stroke survivors at home is essential for optimal aftercare. Therefore a system (INTERACTION) which monitors Activities of Daily Living (ADL) performance was developed. INTERACTION consists of clothing and footwear in which sensors are processed. These sensors measured kinetics and kinematics by using force sensors and inertial motion sensors. Problem is that there are at present no objective measures to quantify or objectify daily-life activities. Currently, daily-life activities are measured by subjective questionnaires and a-specific clinical tests. Knowledge about the relationship between patients' daily-life performance, daily-life questionnaires and a-specific clinical tests of Walking Ability (WA) is necessary before INTERACTION can be used at home.

• Aim The aim of the pilot study is to investigate the relation between INTERACTION and patient's ADL performance, ADL questionnaires and a-specific clinical tests which consists of ADL activities focused on WA.

• Methods An explorative cross-sectional pilot study was used to determine the relationship between patient's ADL performance (climbing stairs), ADL questionnaire (Barthel Index), a-specific clinical tests consists of ADL (Berg Balance Scale, Timed Up and Go test and 10 Meter Walk Test) and INTERACTION (foot position (X,Y), Centre of Mass). All clinical tests, ADL performance and the questionnaire will be correlated by a newly developed static and dynamic balance measure, measured with INTERACTION. The degree of correlation is calculated by using of the Spearman’s Rank correlation and Pearson’s correlation coefficient.

• Results 8 patients [M=6/W=2, age 66.3 ±SD 7.8] participated in the study. The correlation between static balance and separate components of the Berg Balance Scale varied from -0.4954 to -0.7829. The correlation between dynamic balance and10 Meter Walk Test, Timed Up and Go test, climbing stairs and the dynamic items of the Berg Balance Scale varied from 0.4039 to 0.5191. There was a correlation of 0.5294 between the average of static balance, dynamic balance and quasi static balance to the Barthel Index.

• Conclusion This pilot study found a moderate to strong correlation between patient's ADL performance, ADL questionnaires and a-specific clinical tests focused on WA and INTERACTION.

Key Words: stroke - walking ability – activities of daily living – rehabilitation – clinical tests

INTRODUCTION

The incidence of stroke is increasing with aging of the population and is the second most common cause of death in the Western world (1-4).

Depending on the patient's impairments as a result of the stroke event, a rehabilitation program is started after discharge from the hospital. During the period of training in a rehabilitation centre, progression is evaluated by patient's Activities of Daily Living (ADL) performances by means of ADL questionnaires and a-specific clinical tests. ADL are routine activities that people tend to do every day. There are six basic ADLs: eating, bathing, dressing, toileting, transferring (included Walking Ability (WA)) and continence (5). WA is a basic condition for the ability to be independent at home and is necessary to be able to perform a lot of general ADL (6,7).

When it is expected patients ADL is sufficient to live at home, the patient is discharged. After discharge, the patient is more and more responsible for his own performance at home. A training program is imposed most of the time. Because of reduced control in patient's general performance, it is expected that patients show deterioration of performance during their follow-up treatments by visiting a clinician or physiotherapist in comparison with their ADL functions at the moment they were discharged (8).

Currently, the period at home is like a black-box for the physiotherapist and clinicians. There is no information about the patient's adherence to the prescribed training program. This makes observed functional progress or decline of motor function difficult to explain. Monitoring the daily-life performance of functional activities in the patient's environment is essential for optimal guidance of the rehabilitation therapy after admission to the rehabilitation centre. Therefore INTERACTION, which monitors daily-life performance of inter alia WA was developed. INTERACTION consists of a combination of two systems: Xsens Instrumented Force Shoes (IFS) and the MVN biomech system. The Xsens IFS measures ground reaction forces, centre of pressure, orientation of the feet during walking and other tasks, with a minimal influence on walking patterns (9-12). MVN biomech measures acceleration and orientation of all main segments of the human body (13,14). The combination of these two systems allows to measure the relative position of both feet. Both systems have been validated previously (9,14).

Before using INTERACTION at patient's home to measure WA, it is necessary to know if INTERACTION can differentiate between patients with various levels of ADL functions. Currently, there is no objective test to measure ADL. At present, ADL level is measured with ADL questionnaires (subjective) and a-specific clinical performance tests that consist of the most frequent ADL aspects. INTERACTION has been developed to gain an objective insight into ADL activities at patient’s home. Therefore knowledge about the relationship between patients' ADL performance, questionnaires and clinical tests consists of ADL performance is necessary before INTERACTION can be used at home.

The aim of the study is to investigate the relation between INTERACTION and patient's ADL performance, ADL questionnaires and a-specific clinical tests focused on WA.

METHODS

Subjects

An explorative cross-sectional pilot study was used to determine the relationship between patient's ADL performance, ADL questionnaires, a-specific clinical tests and INTERACTION. This study was part of a lager study which also focuses on arm and hand tasks. The study took place at the gait lab of Roessingh Rehabilitation Centre, The Netherlands. In order to be eligible to participate in this study, a subject must meet all of the following inclusion criteria: age between 35 and 75 years, at least 6 months post-stroke, ability to walk for over 10 meters (if necessary, with walking aid), ability to walk without specific footwear (ability to walk on sandals), ability to understand and perform instructions and questionnaires and provide written informed consent (IC). A potential subject who has more than one stroke event in their medical history would be excluded.

Measurements

The following patient characteristics would be measured to identify the study population: gender, age, height, weight, dominant side, affected side, time since stroke, use of additional walking aids, medication (spasticity related).

Outcome measures used in this study were the following measurements: Timed Up and Go test (TUG) (15), Berg Balance Scale (BBS) (16), 10 Meter Walk Test (10MWT) (17), Barthel Index (BI) (18) and the ADL activity climbing stairs.

At the same time of scoring these tests, the INTERACTION system measured distances and accelerations with the sensors.

TUG was used to measure WA of ADL activities (15). The interrater reliability is 0.96-0.99 (19,20) and the intrarater reliablity is 0.93-0.99 (19,21).

The TUG has a correlation of 0.95 with falling and a correlation of -0.81 with BBS, -0.61 with gait speed and -0.78 with BI (21).
BBS was used to measure balance problems by ADL (16). BBS is reliable (interrater reliability 0.97 (22) and intrarater reliability 0.98 (22)) and has a construct validity of 0.98 with TUG (23).
10MWT measured the speed of walking comfortably (measured 3 times) and maximum (measured 3 times) over a distance of 10 meters (17). For this study only walking comfortably was measured in context of an ADL activity. 10MWT has an interrater reliability of 0.93 (24) and an intrarater reliability of 1.00 (25).
With the BI, the degree of (physical or verbal) help that a person needs to ADL can be determined, irrespective of the underlying pathology (18). BI has an interrater reliability of 0.94 (26) and an intrarater reliability of 0.96 (26).
Another ADL task that would be measured was climbing stairs. Time of walking three stairs up, turn around and walking three stairs down will be measured.
The following aspects will be measured with INTERACTION: foot position (left toe X,Y position, right toe X,Y position, left foot X,Y position and right foot X,Y position) and Centre of mass (CoM). See Appendix 1(figure 1).

Procedures

The measurements would be performed in the gait lab of Roessingh Research and Development. Subject characteristics will be collected and the questionnaire BI about ADL activities of daily living will be completed. In the preparation phase, the Xsens MVN biomech straps with inertial motion sensors (Xsens Enschede, The Netherlands) and IFS with force/moment sensors (Xsens Enschede, The Netherlands) will be attached respectively to the patient's body and feet. After attaching, the system will be calibrated using the calibration procedures as described by the manufacturer.
Patients will start with tests of arm function in context of the full study after calibration. After finishing these tests, patients will perform the clinical ADL tests in the following order: BBS, TUG, 10MWT and climbing stairs. When these ADL tests are performed, all measurement systems will be removed of the patient's body. All of the data measured by the sensors of INTERACTION will be registered in MVN Studio (Xsens Enschede, The Netherlands).

Data analysis

Demographic data related to participants were analyzed by using descriptive statistics including mean, standard deviation (SD), median, and frequency (SPSS version 20). To correlate the aspects of INTERACTION with the clinical tests and questionnaire, a new measure of balance has been developed. A distinction is made between static ADL and dynamic ADL. The dynamic ADL measure reflects the overall outside distance of the CoM in relation to the Base of Support (BoS). The static ADL measure reflects the position of the CoM in the BoS calculated to the shortest distance to the edge of the BoS (overall). See Appendix 1(figure 2).

Dynamic ADL were: 10MWT, TUG, climbing stairs and the following items of BBS: sitting to standing (fast),transferring. Static ADL were the following items of BBS: sitting to standing (slow), standing unsupported, standing unsupported with eyes closed, standing unsupported with feet together, reaching forward while standing, pick up an object from the floor, turning while standing, turning 360 degrees, placing alternate foot on step while standing unsupported, standing unsupported one foot in front and standing on one leg.

Sitting unsupported was not measured in this study, because it was expected that all included subjects get the maximum score at BBS.

For each item of the BBS and every test, an individual balance measure with criteria has been developed. See Appendix 2.

The degree of correlation is calculated by using of the Spearman's Rank correlation (items BBS, BI correlated with INTERACTION) and Pearson's correlation coefficient (TUG, 10MWT, climbing stairs correlated with INTERACTION). The following classification of degree of correlation was used: .00-.19 very weak, .20- .39 weak, .40-.59 moderate, .60-.79 strong and .80-1.0 very strong (27).

RESULTS

8 patients [M=6/W=2, age 66.3 ± 7.8, height 1.76 ± 6.1, weight 87.9 ± 5.8] were recruited from May 2013 to June 2013 to the Roessingh Rehabilitation Centre, The Netherlands. All patients were independently at home. (BI score 20 ± 1.1) Detailed information about patient characteristics were given in Table 1.

Table 1. Characteristics of included patients

Patient Characteristics (n=8)	Total
Age, mean (SD), years	66.3 (7.8)
Gender, men/ women	6/2
Height, mean (SD), m	1.76 (6.1)
Weight, mean (SD), kg	87,9 (5.8)
Dominant side, left/ right	0/8
Affected side, left/ right	5/3
Time since stroke, mean (SD), months	34 (5.2)
Use of additional walking aids	
• None	6
• Ankle foot orthesis	2
• Cane	0
• Tripod/ Quadruped cane	0
• Walking frame	
• Other	
- Elbow crutch	1
Medication spasticity related, yes/ no	0/8

Spearman *ρ* correlation coefficients revealed a correlation of -0.4954 to -0.7829 between static balance and separate components of the Berg Balance Scale. Separate correlations were given in Table 2. The correlation between dynamic balance who consists of 10 Meter Walk Test, Timed Up and Go test, climbing stairs and sitting to standing fast varied from 0.4039 to 0.5191.

There was a correlation of 0.5294 between the average of static balance, dynamic balance (average) and quasi static balance (item 8 Berg Balance Scale) to the Barthel Index.

Table 2. Correlation values Activities of Daily Living

1. Static Balance	**Balance measure correlation** *Spearman's Rank correlation*(ρ)	**Interpretation of correlation coefficient** (27)
BBS item 1: Sitting to standing (slow)	ρ= -0.4954**	Moderate
BBS item 2: Standing unsupported	ρ= -0.6828**	Strong
BBS item 4: Standing to sitting	ρ=- 0.5337**	Moderate
BBS item 6: Standing unsupported with eyes closed	ρ=-0.7829**	Strong

BBS item 7: Standing unsupported with feet together	ρ= -0.5388**	Moderate
BBS item 8: Reaching forward while standing*	ρ= 0.5274**	Moderate
BBS item 9: Pick up an object from the floor	ρ= -0.6981**	Strong
BBS item 10: Turning while standing	ρ= -0.6122**	Strong
BBS item 11: Turning 360 degrees	ρ= -0.5826**	Moderate
BBS item 12: placing alternate foot on step while standing unsupported	ρ= -0.5859**	Moderate
BBS item 13: Standing unsupported one foot in front	ρ= -0.6185**	Strong
BBS item 14: Standing on one leg	ρ=- 0.6948**	Strong
2. Dynamic Balance	**Balance measure correlation** *Spearman's Rank Correlation (ρ)/ Pearson's Correlation Coefficient (r)*	**Interpretation of correlation coefficient** (27)
10MWT	r= 0.4039**	Moderate
TUG	r= 0.4966**	Moderate
climbing stairs	r= 0.4529**	Moderate
BBS item 1: Sitting to standing (fast)	ρ= 0.4831**	Moderate
BBS item 5: Transferring	ρ= 0.5191**	Moderate
3. Combined Balance	**Balance measure correlation** *Spearman's Rank Correlation (ρ)/ Pearson's Correlation Coefficient (r)*	**Interpretation of correlation coefficient** (27)
Barthel index	Static balance, Dynamic balance, Quasi static balance: r=0.5294**	Moderate

BBS= Berg Balance Scale, 10MWT= 10 Meter Walking Test, TUG= Timed Up and Go test.
** This item belongs to the quasi static balance.*
*** All correlations were significant at the 0.05 level (2-tailed).*

DISCUSSION

The results of this study showed that there is a moderate to strong correlation between the measuring of static ADL focused on WA with INTERACTION and the static separate components of de BBS. There is found a moderate correlation between dynamic ADL and 10

Meter Walk Test, Timed Up and Go test, climbing stairs and sitting to standing fast. Also the BI correlated moderate to the average of static, dynamic en quasi static balance aspects.
To our knowledge, this was the first study that compared ADL activities focused on WA measured with sensors (INTERACTION), with usual clinical ADL tests, questionnaires and performances. The results showed that there is a moderate to strong correlation. This indicates that there are positive alternatives to replace the subjective and a-specific clinical performance tests to one objective ADL measure.
There were a lot of other studies who measured movements of patients with motion capture systems (Vicon ®) with good results (28-30). With this system movements of the patient will be converted by markers on the body of the patient and cameras to digital moving images. This system cannot operate without cameras and cannot be used everywhere. INTERACTION was developed to solve this problem. It works without markers and cameras and is portable to use everywhere.

To enable correlating kinetic and kinematic sensor data, data of clinical tests and questionnaires a new measure of balance has been created. This new balance measure was based on the difference between dynamic and static balance and a previous study that looked at the shift of the CoM into BoS measured with sensors (31). These two aspects were combined into a new balance measure of ADL to make a comparison between sensor data and data of the existing tests and questionnaires possible. This translation of subjective and a-specific test methods into objective ADL measures with sensors is a step forward, because measuring with these sensors is more specific (continuous kinetic and kinematic data) and it enables a better distinction between patients of different levels than regular clinical tests.

One of the problems with measuring with these sensor data is that the distances of the CoM to the edge of the BoS are relative small and the distinction between good balance and poorer balance is small. It could be possible that there is a measurement error, which can influence the outcome of an ADL task enormously.

Beside, this study looked at the X and Y position of the foot-, toe- and CoM coordination's, but the sensors give also coordination's in Z direction. The use of this Z direction, allows the calculation of the distance to a line more and more difficult. Because the X and Y direction are the most important directions, this pilot study looked only at these two directions.

Another limitation of this study is the measuring of ADL performance in a lab situation. Patients experienced difference in doing everyday activities in a lab situation in comparison when they are at home. In the lab situation patients have their full attention when they were performing a task. At home, there are several aspects that influencing the practice and patients are more easily distracted.
Other point which influences the reliability of the ADL measurements with INTERACTION are the walking activities of the patients by wearing the Xsens IFS. The sole of the sandal is three and a half centimetres high and the shoes are less flexible and heavy. Patients are not get used to walk on this shoes. By wearing these shoes there might occur a deviation in the gait pattern during ADL. In addition, the imbalance by these patients is already known. Wearing this shoes, balance problems could be larger. New enhancements of the sandals must ensure that the sandals are going to look as natural as possible and that they are as natural as possible to use.

Some of the patients who participate in this study were wearing an ankle-foot orthosis. This walking aid cannot be comfortably worn in a sandal. This resulted in an extra imbalance for these patients and has caused that these patients will score more badly than they should do at home.

The sensors of the MVN biomech system are placed by means of straps over clothes on the body of the patients. A disadvantage of this method is that the sensors of MVN biomech can shift. This can give an unreliable measure with incorrect results. This problem is almost unavoidable. The only solution to avoid this problem is to confirm the sensors internally.
For one patient, all the data couldn't be used, because of shifting the pelvic strap. When subjects have a lot of abdominal fat, the pelvic strap descended. This problem will be resolved when the sensors were processed in thin and light clothes.

Before starting this study, the sample size of this study was calculated. It was estimated that 10 patients would be necessary to have a sufficient sample size for this part of the study. Unfortunately there were 8 patients enrolled into this study. Because this study is part of a lager study, the inclusion of new patients is still ongoing. To other research questions of the complete study a larger number of patients is necessary.

This pilot study was the first part of a larger study. In the future there will be a number of follow up studies to investigate whether INTERACTION actually can be used at home. The following points are aspects for further research.
The MVN biomech version which was used for this study makes it impossible for the patient himself to attract this system. New versions of MVN biomech should allow that patients can wear the clothes with sensors under their own clothes and independently can attract it. The mock up version of these clothes was already tested and a few modifications were made.

As already mentioned the Xsens IFS have to be developed as much as possible as normal shoes/ sandals. Most important point to develop is a thinner sole and a shoes variant with a closed heel, so that also patients who walked with an ankle-foot orthosis have more stability during walking.

Further research is also needed to the reliability and validity of the newly developed balance measure. This balance measure is a combination of other research aspects by patients with stroke, but the combination of these aspects into a new measure is never been researched even like the comparison with existing (ADL) measures.

CONCLUSION

This pilot study found a moderate to strong correlation between patient's ADL performance, ADL questionnaires and a-specific clinical tests focused on WA and the measuring with INTERACTION.

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REFERENCES

1. Donnan GA, Fisher M, Macleod M, Davis M. Stroke. The Lancet 2008; 37:1612-1623.

2. Kollen B, Kwakkel G, Lindeman E. Functional recovery after stroke: a review of current developments in stroke rehabilitation research. Reviews on recent clinical trials 2006; 1:75-80.

3. World Health Organization. The top 10 causes of death. Online, accessed on April 3, 2012. Address: http://www.who.int/mediacentre/factsheets/fs310/en/index.html

4. World Health Organization. The atlas of heart disease and stroke. Online, accessed on April 3, 2012. Address: http://www.who.int/cardiovascular_diseases/resources/atlas/en

5. Veerbeek JM, Kwakkel G, van Wegen EE, Ket JC, Heymans MW. Early prediction of outcome of activities of daily living after stroke: a systematic review. Stroke 2011; 42:1482-1488.

6. Bohannon RW. Strength deficits also predict gait performance in patients with stroke. Percept Mot Skills 1991; 73:146-151.

7. Kloosterman CM, Reenalda J, Wagenaar RC, Speksnijder CM. Early prediction of walking ability after stroke: a systematic review *Submitted.*

8. Kottink AIR, Hermens HJ, Nene AV, Tenniglo MJB, Groothuis-Oudshoorn CG, IJzerman MJ. Therapeutic effect of an implantable peroneal nerve stimulator in subjects with chronic stroke and footdrop: a randomized controlled trial. Physical Therapy 2008; 67: 437-448.

9. Liedtke C, Fokkenrood SAW, Menger JT, Van der Kooij H, Veltink PH. Evaluation of instrumented shoes for ambulatory assessment of ground reaction forces. Gait & posture 2007; 26:39-47.

10. Van den NoortJ, van der Esch M, Steultjens MP, Dekker J, Schepers M, Veltink PH, Harlaar J, Influence of the instrumented force shoe on gait pattern in patients with

osteoarthritis of the knee. Medical & biological engineering & computing 2011; 49:1381-1392.

11. Schepers HM, Koopman H, Veltink PH. Ambulatory assessment of ankle and foot dynamics. IEEE Transactions on Biomedical Engineering 2007; 54:895-902.

12. Schepers HM, van Asseldonk E, Buurke JH, Veltink PH. Ambulatory estimation of center of mass displacement during walking. IEEE Transactions on Biomedical Engineering 2009; 56:1189-1195.

13. Luinge HJ, Veltink PH. Measuring orientation of human body segments using miniature gyroscopes and accelerometers. Medical and Biological Engineering and Computing 2005;43:273-282.

14. Roetenberg D, Luinge H, Slycke P. Xsens MVN: full 6DOF human motion tracking using miniature inertial sensors. Xsens Motion Technologies BV, Tech. Rep. 2009.

15. Podsiadlo D, Richardson S. The timed" Up & Go": a test of basic functional mobility for frail elderly persons. Journal of the American geriatrics Society 1991; 39:142-148.

16. Berg KO, Wood-Danphinee S, Williams JT. Measuring balance in the elderly: preliminary development of an instrument. Physiotherapy 1989; 41:304-311.

17. Collin C, Wade D. Assessing motor impairment after stroke: a pilot reliability study. J Neurol Neurosurg Psychiatry 1990; 53:576-585.

18. Mahoney FI. The Barthel Index. Maryland state medical 1965; 14:61-65.

19. Deathe AB, Miller WC. The L test of functional mobility: measurement properties of a modified version of the timed “up & go” test designed for people with lower-limb amputations. Physical therapy 2005;85:626-635.

20. Podsiadlo D, Richardson S. The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. Journal of the American Geriatrics Society 1991;39:142-148.

21. Morris S, Morris ME, Iansek R. Reliability of measurements obtained with the Timed "Up & Go" test in people with Parkinson disease. Physical therapy 2001;81:810-818.

22. Blum L, Korner-Bitensky N. Usefulness of the Berg Balance Scale in stroke rehabilitation: a systematic review. Physical therapy 2008;88:559-566.

23. Kwakkel G. Klinimetrie van CVA-patiënten. Amsterdam: VU academisch ziekenhuis 2000.

24. Leerar PJ, Miller EW. Concurrent validity of distance-walks and timed-walks in the well-elderly. Journal of geriatric physical therapy 2002;25:3-7.

25. Van der Burgt GCM, van Opstal M, Nelissen LH, Theunissen CTH, Lenssen AF. Klinimetrie bij CVA-patiënten: een onderzoek naar de interbeoordeelaars-betrouwbaaerheid van de Trunk Control Test, de Functional Ambulation Categories en de 10-meter looptest. Nederlands tijdschrift voor fysiotherapie 2005;115:154-157.

26. Koolstra M, Smeets CJ, Harmeling- van der Wel BC, Kwakkel G. Klinimetrie na een beroerte een praktische handleiding. Amersfoort: Nederlands Paramedisch instituut, 2004

27. Portney LG, Watkins MP. Foundations of clinical research: applications to practice. United States: Pearson Education 2009; P.892

28. Lucareli PR, Greve JM. Alteration of the load-response mechanism of the knee joint during hemiparetic gait following stroke analyzed by 3-dimensional kinematic 2006;6:295-300.

29. Caillet F, Mertens P, Rabaséda S, Boisson D. Three dimensional gait analysis and controlling spastic foot on stroke patients 2003;46:119-31.

30. Kotiadis D, Hermens HJ, Veltink PH. Inertial Gait Phase Detection for control of a drop foot stimulator Inertial sensing for gait phase detection 2010;32:287-97.

31. Hof AL, Gazendam MGJ, Sinke W E.The condition for dynamic stability. Journal of Biomechanics 2005; 381–8.

APPENDIX 1. DETERMINING DISTANCE OF A POINT TO A LINE

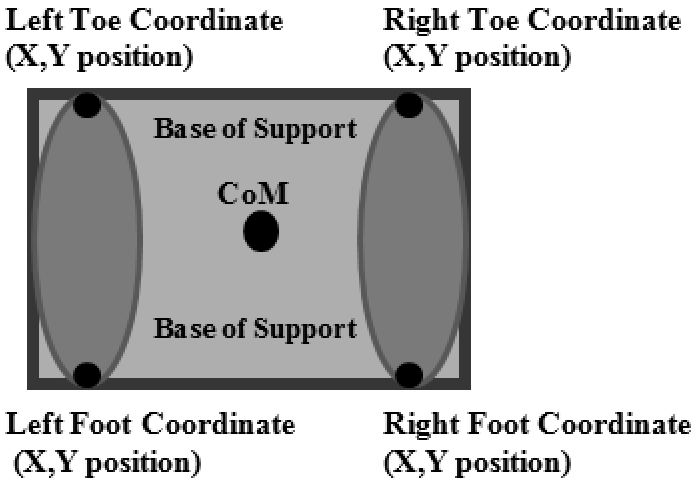

Figure 1. Visual view of used INTERACTION data

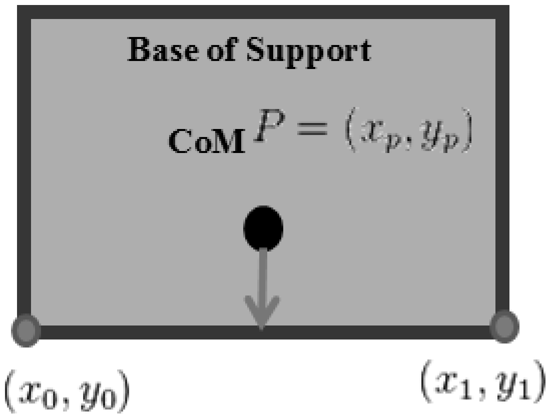

Figure 2. Distance determination

Determine the distance of a point $P = (x_p, y_p)$ to a line between the points (x_0, y_0) and (x_1, y_1), by means of:

$$d(P, l) = \sqrt{(x_p - x_0 - \lambda_q(x_1 - x_0))^2 + (y_p - y_0 - \lambda_q(y_1 - y_0))^2}$$

with:

$$\lambda_q = \frac{(x_1 - x_0)(x_p - x_0) + (y_1 - y_0)(y_p - y_0)}{(x_1 - x_0)^2 + (y_1 - y_0)^2}$$

APPENDIX 2. BALANCE MEASURING WITH INTERACTION

STATIC BALANCE	**CRITERIA**
BBS item 1: Sitting to standing (slow)	There is a distinction made between fast(dynamic balance) and slow (static balance) rise from a chair. Slow rise from a chair: (CoM inside BoS) Good balance: CoM moves to the edges of BoS.
BBS item 2: Standing unsupported	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 4: Standing to sitting	See criteria BBS item 1.
BBS item 6: Standing unsupported with eyes closed	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 7: Standing unsupported with feet together	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 8: Reaching forward while standing	Good balance: CoM moves forward to the edges of BoS.
BBS item 9: Pick up an object from the floor	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 10: Turning while standing	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 11: Turning 360 degrees	Movement of CoM relative to middle BoS. Good balance: little as possible movement displacement of CoM to unaffected side.
BBS item 12: placing alternate foot on step while standing unsupported	Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 13: BBS item 13: Standing unsupported one foot in front	Criteria 1: Good balance: BoS as small as possible. (footposition 1 line) Criteria 2: Good balance: CoM moves as little as possible to the edges of the BoS.
BBS item 14: Standing on one leg	Good balance: Standing on one leg and CoM moves as little as possible to the edges of the BoS.
DYNAMIC BALANCE	**CRITERIA**
10MWT	Good balance: The greater the distance between CoM and BoS, the better the balance.
TUG	Good balance: The greater the distance between CoM and BoS, the better the balance.
climbing stairs	Weight distribution affected – non affected

	side. Good balance: minimal weight difference between affected and unaffected side.
BBS item 1:Sitting to standing (fast)	There is a distinction made between fast and slow rise from a chair. <u>Fast rise from a chair:</u> CoM outside BoS Good balance: The greater the distance between CoM and BoS, the better the balance.
BBS item 5: transferring	See criteria BBS item 1, item 4 and 10MWT.
QUESTIONNAIRE	**CRITERIA**
Barthel index	Mean value Static Balance (items static balance without BBS item 8),Mean value Dynamic Balance (items dynamic balance), Mean value Quasi static balance (BBS item 8) calculated tot average overall value.