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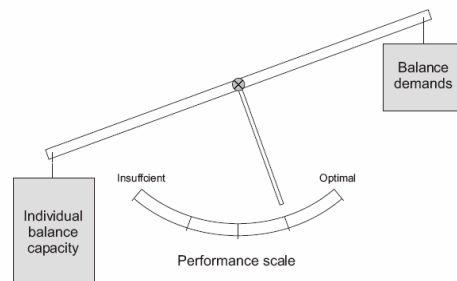
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Assessment of Postural Control in Relation to Balance and Falls

Ph.D. dissertation

by

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Center for Sensory-Motor Interaction

Aalborg University

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Preface

This dissertation is based on work carried out during the period February 2004 – March 2007 at Center for Sensory-Motor Interaction (SMI), Department of Health Science and Technology, Aalborg University, Denmark.

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Furthermore, I would like to thank Abraham T. Zuur for many good discussions and a massive assistance in the use of MatLab-software, as well as my other colleagues, Birte Dinesen and Mogens Nielsen, for inspiring conversations along the way.

Finally, I would like to give special thanks to my family, Annette, Anne and Theis, for their support and their patience with my never-ending learning process.

Uffe Læssøe
Gistrup, May 2007

Index

| | |
|---|-----------|
| PREFACE | 2 |
| LIST OF PAPERS:..... | 5 |
| 1. INTRODUCTION..... | 6 |
| BASIC STUDIES AND THEIR CLINICAL RELEVANCE..... | 7 |
| <i>Assessment Strategies</i> | 10 |
| THE CONCEPT OF BALANCE | 11 |
| <i>Mechanical Balance/Stability</i> | 11 |
| <i>Postural Control</i> | 12 |
| <i>Feed-Back and Feed-Forward Aspects of Postural Control</i> | 13 |
| <i>Premises for Postural Control</i> | 15 |
| ASSESSMENT OF POSTURAL CONTROL | 20 |
| <i>Outcome Measures</i> | 23 |
| REFERENCES | 24 |
| 2. FALL PREDICTION IN THE ELDERLY POPULATION | 26 |
| EPIDEMIOLOGY | 26 |
| SCREENING FOR FALL RISK..... | 27 |
| <i>Test Battery</i> | 29 |
| <i>Factors Related to Fall Risk</i> | 31 |
| <i>Construction and Validation of Test Battery</i> | 32 |
| <i>Publication Considerations</i> | 34 |
| REFERENCES | 34 |
| 3. FALL RISK ASSESSMENT IN AN ACTIVE ELDERLY POPULATION (PAPER I) | 37 |
| 4. FALL RISK IN AN ACTIVE ELDERLY POPULATION – CAN IT BE ASSESSED? (PAPER II)..... | 51 |

| | |
|--|-----------|
| 5. ARGUMENTS FOR AN ALTERNATIVE APPROACH TO BALANCE ASSESSMENT.... | 53 |
| EPIDEMIOLOGICAL AND METHODOLOGICAL CONSIDERATIONS | 53 |
| <i>Choice of Research Direction</i> | 55 |
| ALTERNATIVE STRATEGIES IN THE ASSESSMENT OF POSTURAL CONTROL | 55 |
| <i>A Dual Task Approach to Assessment of Postural Control</i> | 56 |
| <i>Protocols for Alternative Approaches to Postural Control</i> | 59 |
| REFERENCES | 60 |
| 6. ANTICIPATORY POSTURAL CONTROL STRATEGIES RELATED TO PREDICTIVE PERTURBATIONS (PAPER III)..... | 62 |
| 7. RESIDUAL ATTENTIONAL CAPACITY AMONGST YOUNG AND ELDERLY DURING DUAL AND TRIPLE TASK WALKING (PAPER IV) | 63 |
| 8. GENERAL DISCUSSION | 64 |
| CONCLUSIONS | 66 |
| PERSPECTIVES..... | 68 |
| <i>Assessment of Postural Control in Gait</i> | 68 |
| <i>Gait Variability</i> | 69 |
| <i>Alternative Methods for Evaluation of Gait Variability/Stability</i> | 70 |
| <i>Clinical Directions</i> | 73 |
| REFERENCES | 75 |
| SUMMARY | 78 |
| DANISH SUMMARY / DANSK SAMMENDRAG..... | 79 |

List of Papers:

Paper I

Fall Risk Assessment in an Active Elderly Population.

Laessoe U, Hoeck HC, Simonsen O, Sinkjaer T, Voigt M.

Manuscript not published.

Paper II

Fall risk assessment in an active elderly population – can it be assessed?

Laessoe U, Hoeck HC, Simonsen O, Sinkjaer T, Voigt M.

Journal of Negative Results in Biomedicine 2007, 6:2.

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doi:10.1186/1477-5751-6-2

Paper III

Anticipatory postural control strategies related to predictive perturbations.

Laessoe U, Voigt M.

Gait & Posture 2008 Jul; 28(1):62-8. Epub 2007 Nov 19.

[http://www.gaitposture.com/article/S0966-6362\(07\)00255-X/abstract](http://www.gaitposture.com/article/S0966-6362(07)00255-X/abstract)

doi:10.1016/j.gaitpost.2007.10.001

Paper IV

Residual attentional capacity amongst young and elderly during dual and triple task walking

Laessoe U, Hoeck HC, Simonsen O, Voigt M.

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1. Introduction

The consequences of falls in the elderly population are often considerable and serious. Fall risk can be reduced by targeted intervention, but the identification of individuals prone to falling remains to be a challenge. Balance assessment is relevant in this context, but no solid assessment strategy has yet been proposed.

The overall purpose of this Ph.D. project was to identify clinically relevant quantitative parameters as to predict fall risk in the population of community-dwelling elderly, who are not regarded as fragile.

The first approach implied the development of a test battery consisting of existing tests covering fall related aspects of postural control. The test battery was validated in a population of 96 community-dwelling elderly with respect to discrimination ability related to fall history and with respect to predictive ability related to fall incidence in a one-year follow-up period. The background for this approach is described in chapter 3. Results from the study are presented in chapter 4 and 5 (paper I and II), and aspects of the finding are discussed in chapter 5 and 8.

The second approach implied an investigation of age characteristics in specific aspects of postural control. Dual task assessment was used to evaluate automation of the postural control in two protocols. One protocol focused on proactive postural control during predictable perturbations in standing position, and the other protocol focused on complementary postural control capacity during walking. The background for this approach is described in chapter 1 and 5. Results from the studies are presented in chapter 6 and 7 (paper III and IV), and aspects of the findings are discussed in chapter 8.

The thesis is based on questions emerging from the clinical approach to patients presenting physical function deficits. However, it has also been based on the setting of mere basic science at Aalborg University. The first section of this thesis will therefore discuss the differences in the scientific approaches of basic and clinical research, respectively, in order to illustrate the character of the studies included in the thesis.

Basic Studies and Their Clinical Relevance

Clinicians working in the field of rehabilitation as well as other health professionals addressing the locomotor system are challenged when trying to assess the level of physical functioning of the patients, clients, or athletes.

In this context the term physical functioning is used as a general description of the way the body performs in relation to different (motor) tasks. It can be manifested as the capability to raise an arm, to stand still, to walk, to rise from a chair, to pick up a tiny object, to make a summersault, to lift a heavy weight, to run a marathon, etc. The concept of physical function covers a wide range of complex interactions between the body and its context, and is based on a wide range of mental factors and physical mechanisms in the body. As physical functioning often will be expressed as the capability to make functional movements, the illustration in figure 1.1 can picture the complexity of this research area. This illustration was given by Trew and Everett and shows that the study of human movement can be approached from a number of viewpoints (Trew & Everett 1997).

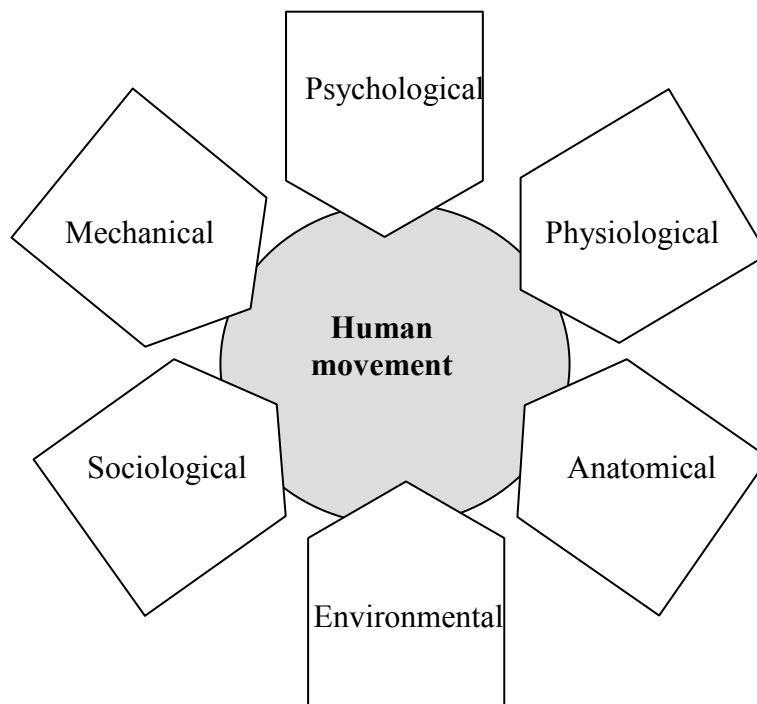


Figure 1.1. Illustration of the number of ways in which the study of human movement can be approached (adapted from Trew and Everett, 1997).

When physical functioning and movement coordination are studied, it must be considered whether the overall goal is firstly to understand the function of all involved elements and thereafter to combine these elements as to understand the integral whole, or whether the overall outcome pattern should be chosen as the starting point followed by a separation of the different elements (Hauvik 2000). While the first approach seeks for causal explanations, the latter approach focuses on general laws and principles for mechanisms and structures. One of these approaches is not superior to the other, but one may be preferred as more appropriate in relation to the specific phenomenon, which has to be addressed. Because of the many degrees of freedom in the body, identical movement patterns can be produced by an infinite number of combinations of the different movement elements (see section “Premises for Postural Control”). Studies of individual elements in isolation will therefore be difficult to generalize into a complete picture of the physical function as a whole. On the other hand, studies on general function will not describe the subsystems originating the movement patterns.

It would be ideal to have a thorough insight into all the mechanisms in the body as to have a better understanding of the physical function. This is what basic science is trying to provide to the greatest extent. In this scientific tradition the aim is to reach a general understanding of the elements and to unveil the causality of the mechanisms in the human body. Within nature science, mainly an approach of reductionism is used to provide the base for this understanding. In order to understand a complex mechanism, the individual elements are identified and the interactions between these elements are described. After a problem has been broken down into elements, it is necessary to design conceptual models in order to describe the interactions between the elements. Even though the scope of interest is the functioning of the body, it is often convenient to use mechanical models as to make these models comprehensible. As full insight into all relevant elements and their interaction is far from reached, the available conceptual models are unfinished and may be adjusted from time to time. Nevertheless, this scientific tradition has provided useful insight into movement control.

In the clinical field knowledge and conceptual models provided by the basic science helps the clinician to a better understanding of the problems presented by the patients. But, as complete knowledge of all aspects of the human nature is not available, and, as the conceptual models are not perfect, the clinician must also act upon his observations of the specific patient. The clinician will often have to accept that the patient’s problem is like a “black box”. The patient will react to different actions and interventions with different reactions, but it is not necessarily understood why these reactions occur. Many aspects of sensory-motor interaction have to be regarded as a “black box”. We might compare the “output” from

the box (e.g. the motor performance of an individual before and after training), but when we see a difference, we do not know exactly what has changed within the “box”.

In clinical research it can be necessary to refrain from the ambition of reaching full understanding of cause-and-effect relationships, but it is relevant to act upon the available empiric findings. In this area of research it becomes relevant merely to focus on which “input” causes which “output” (i.e. which treatment causes which benefit and improvement). It becomes highly relevant to identify methods which can characterize the individuals and identify specific symptoms of which the background is not fully understood.

In general terms, the two approaches can be described in this way: Basic science asks “why?” and seeks an understanding of the elements and their interactions. In the clinical field the question “how?” is relevant, and it becomes more important to make individual descriptions of the patients and their reactions to the treatment, than to fully understand the causality. And here the clinician must act upon the available empiric findings.

In an optimal synergy between basic and clinical science, empiric findings from clinical science provide information of human nature which will raise questions and challenge basic science. Basic science will gradually provide more solid knowledge and insight into human nature, which will inspire and challenge the clinical field. And the conceptual models and hypothesis provided by the basic science can be challenged and tested in the clinical research.

According to these considerations, a clinician may refrain from attempting to fully understand all underlying elements of the physical functioning, and concentrate on its expression. The clinical assessment strategy must be based on outcome measures reflecting the level of physical function. For diagnostic purposes, these outcome measures can be related to reference measures from a norm population. In this way the relative level of physical functioning of the individual patient can be described. This approach to the evaluation of physical function is, however, not a trivial matter.

The presented thesis has had the overall purpose of providing means for assessing the level of physical function in relation to postural control. The purpose has been to facilitate the categorization of individuals and the evaluation of the effect of different treatments, training methods, and other rehabilitation strategies.

Assessment Strategies

Within the last decades much focus has been directed towards the implementation of “evidence based medicine” (EBM). The concept of EBM has been defined as: “...the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research.” (Sackett et al. 1996). It is not surprising that the patients, the clinicians, and the politicians in charge of the financing of the health care sector would all like to see that the examination and treatment are provided according to the best evidence. Good methods to deliver relevant outcome measures are crucial if the clinical praxis shall be evaluated in order to implement EBM, but these methods are not always available.

There is a need for developing good assessment methods with outcome measures covering relevant aspects of the physical functioning. Better outcome measures can characterize and categorize the patients more precisely and thereby improve the diagnostic procedures and the outline of credible prognosis. In addition, this will facilitate the effect and quality evaluation of the treatment and the training offered to patients.

A description of the physical functioning can be derived from the patient’s subjective description of the condition and from the general clinical observations made by the examiner. Such descriptions are relevant and can cover aspects which are difficult to quantify (Malterud & Hollnagel 1997). However, it is also useful to derive objective and quantitative outcome measures.

Quantification of the physical functioning can often characterize observations which are otherwise difficult for the clinician to describe. The use of new technology can provide methods to describe details in the physical functioning, which are difficult to register by normal clinical observations, and it may offer the possibility to register smaller changes in the level of functioning. It is, however, a problem that quantification most likely also will imply a simplification. It is therefore important to consider whether vital information is lost in this process.

The emphasis of the studies included in the thesis is identification of relevant characteristics of the physical functioning. In order to secure clinical relevance of the studies, we have deliberately tried to use research methods which are (or can be) clinically feasible. Instead of challenging sophisticated technology in the approach of the problems, we have worked with the choices of which parameters are relevant to evaluate and with the challenge of how to evaluate these parameters in a clinically feasible manner.

The studies included in the thesis are focused on balance and fall risk amongst elderly people. The next sections will therefore discuss the concept of balance and postural control. The more specific challenges, which occur when addressing the evaluation of fall risk, will be discussed in chapter 2.

The Concept of Balance

Physical function is a very broad term, and the assessment of the level of physical functioning level is covering a very wide field, as described above. In the following, only aspects of physical functioning, which refer to the concept of balance, will be addressed.

Balance is a concept which is used to describe interaction between different elements. When outcome measures for the balance performance have to be identified, some definitions must be made.

Mechanical Balance/Stability

The term balance (or equilibrium), as used in mechanics, is defined as the state of an object when the resultant load actions (forces or moments) acting upon it are zero (Newton's first law). The ability of an object to balance in a static situation is related to the vertical projection of the centre of mass (CoM), also referred to as the centre of gravity (CoG), and the area of the base of support (BoS) of the object in question. If the line of gravity of an object (CoG) falls within the BoS of the object in question, then the object is balanced. The object becomes unbalance, and will fall, if the CoG is displaced out of the base of support (Pollock et al. 2000).

The degree of stability depends on the amount of force which is required to move the object towards the balance limit. This will depend on the placement of CoM (vertically and horizontally), the mass itself and the dimension of BoS. In a dynamic situation not only gravity, but also inertia forces must be considered.

The human body is, however, not a rigid body, and it does not match the requirements as a reference body used for mechanical physics. The segments of the human body are linked by joints, which are characterized by their ability to move and by having at least one degree of freedom. The "base of support" provided by a hinge joint must therefore be described as a joint axis; and in a ball-and-socket joint the "BoS" is represented by the contact point with no extent. It is, however, possible for the human body to mimic a rigid body by making co-activation of the agonist and antagonist muscles

controlling the joint movements. This is potentially primary, perhaps primitive or unrefined, form of coordination which is present in early stages of learning a skilled movement (Shumway-Cook & Woollacott 2001). Furthermore, this can also be seen as a stiffening strategy, when a person becomes fearful in balance threatening situations. In most situations, however, the muscular control of joint movements is utilized in a more refined manner, which provides joint stability and a base for postural control.

Postural Control

Postural control has been defined as the control of the body's position in space for the purpose of balance and orientation (Shumway-Cook & Woollacott 2001).

In contrast to the template of a rigid body used in mechanical physics, the human body can actively be adjusted in the aspects of CoM, BoS, and joint momentum. The means of keeping balance in a standing position are postural corrections based on these adjustments.

Visible equilibrium corrections consist of adjustments in the posture of the body. The adjustments are counterbalancing actions of the extremities, the head, and the trunk which will reposition the centre of mass. The centre of gravity (CoG), which is the projection of CoM, will naturally be equally affected by these equilibrium reactions, and in this way the relationship between CoG and BoS can be controlled.

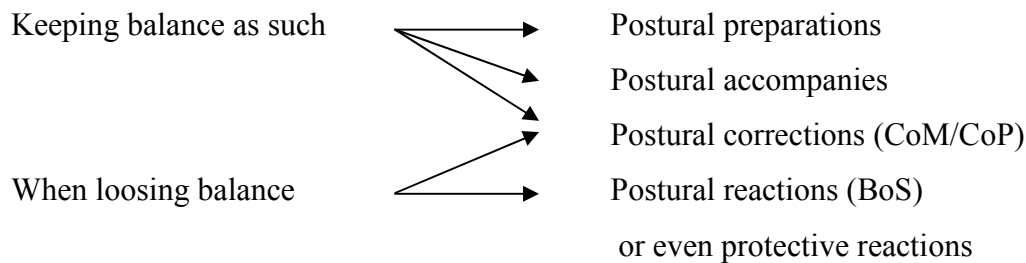
Less visible, but rapid, equilibrium corrections consist of the muscular adjustments of joint momentum (mainly ankle and hip joints), which will generate reaction forces from the support surface. The result of these minor corrections can be measured by a force platform as the centre of pressure (CoP). A muscle contraction in *m. triceps surae* will move the CoP forward towards the front foot, and a contraction in *m. tibialis anterior* will move CoP backwards. By using an inverted pendulum model of balance, it is understood that keeping the CoG in position can be obtain by adjusting the placement of the CoP (Winter 1995). CoP will constantly be guiding the CoG, which has been illustrated by a sheepdog guiding a flock of sheep.

When these postural corrections become insufficient, the base of support (BoS) must be adjusted. The feet can be moved to change the extent or the dimension of the ground support area. This action will be seen as protective stepping reactions. Additionally, the hands can be grasping onto a fixed point to give extra support.

All of these postural correction mechanisms can be referred to as the postural control. If balance is defined as the avoidance of falling, then the postural control is referring to the mechanisms used to keep the balance.

Balance reactions can be seen as a response to sensory information on a feedback basis, but when a balance threatening situation can be predicted, an anticipatory strategy can be used (Ghez & Krakauer 2000). Postural control strategies may therefore be either “reactive” (compensatory), “predictive” (anticipatory), or a combination (Pollock, Durward, Rowe, & Paul 2000). The postural control can be modelled as grouped into three different elements: Postural preparations, postural accompanies, and postural corrections (Frank & Earl 1990;Gahery 1987).

In summary, an observer must expect a subject to be reacting on two levels for avoiding a fall:



Feed-Back and Feed-Forward Aspects of Postural Control

There are three distinct categories of movement: reflexive, rhythmic, and voluntary (Ghez & Krakauer 2000). Reflexes are involuntary coordinated patterns of muscle contractions and relaxations elicited by peripheral stimuli. The repetitive rhythmic motor patterns, such as alternation contractions of flexors and extensors on either side of the body, may occur spontaneously, but are more commonly triggered by peripheral stimuli. The circuits for these rhythmic patterns lie in the spinal cord and brain stem. The third category, the control of voluntary movements, is even more complex and will be addressed more thoroughly in the following.

Voluntary movements are initiated to accomplish a specific goal and may be triggered by external events. They improve with practice as one learns to anticipate and correct for environmental obstacles that perturb the body. The adjustment for such external perturbations can be controlled in two ways:

1. Feedback control: Sensory signals are monitored, and the information is used to act directly on the limb itself as a moment-to-moment control. In mechanical terms, this would be called a servo-control system (figure 1.2).

Signals from sensors are compared with a desired state (a reference signal). The difference between these two signals represents an error signal which is used to adjust output. Such closed-loop feedback systems are characterized by their gain and their time lag. A high gain will produce a large correction to adjust for a small signal error and vice versa. The time delay across the loop between input and output is called the phase lag. If this phase lag is long and the conditions change rapidly, the specific feedback correction may not be appropriate by the time it is implemented.

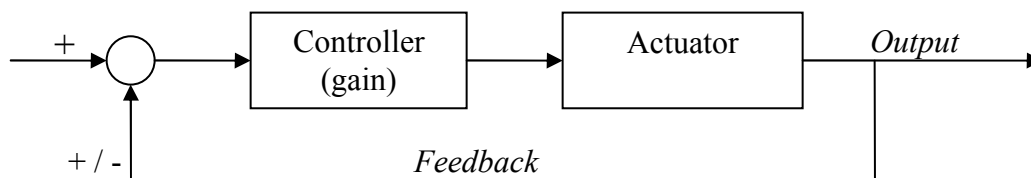


Figure 1.2. A given control system can be adjusted by feedback in a closed loop, and this model can illustrate one basic way of understanding the elements of postural control.

2. Feed-forward control or anticipatory control: Sensory information is used to detect imminent perturbations and to initiate proactive strategies based on experience. Unlike feedback systems, feed-forward control acts in advance of certain perturbations. The sensory signals do not directly affect the timing of the response, and this form of control will therefore be a mixture of an open and a closed loop. What should be emphasized is that experience is crucial in order to anticipate perturbations and to plan relevant motor strategies. An anticipatory postural control is therefore based on motor learning.

The task of steering a ship, which is also a challenge of controlling, can be used as an alternative illustration of these control models.

When a ship has to be kept on course, the compass provides the input signal and the rudder angle is output. The steering system has to be manipulated in an appropriate way (by a controller) in order to adjust the rudder angle (the effector). When the ship starts to sheer out of course, the rudder angle must be adjusted to counteract the sheering. The inertia of the system related to the weight of the ship will

unfortunately introduce a long phase lag. A self-steering device adjusted to a low gain with damped corrections will therefore have a slow impact and allow big course changes. When it manages to stop the sheering towards one side, it is likely to introduce a new strong turning inertia when trying to bring the ship back on course. This is an overcompensation which means that the ship will sheer strongly to the opposite side (a positive feedback). When instead a high gain is chosen for the self-steering device, the reactions to course deviation will be more vigorous. This will mean that the sheering is minimized, but the steering system will have to work constantly under high load to correct the rudder angle, and this will place a great strain on the system.

The large course deviations and loads on the system are of course most likely to occur when the weather is rough and the impact of the high waves on the ship changes rapidly. Under such conditions, the self-steering device does not work appropriately and a steersman must take over the wheel. The self-steering gear could only provide a feedback control as a reaction to the input given by the compass, but the steersman can sense the movement of the ship and adjust the rudder angle before a large course deviation occurs. This means that the steersman can provide a feed-forward (anticipatory) strategy as to make appropriate steering corrections in advance in order to minimize the sheering (negative feedback). The more experience the steersman has, the better he will be able to predict the impact of the waves on the course of the ship and the better timing will he provide in his steering. When the corrections to the wheel are done with a better timing, only smaller rudder angles are needed to keep the ship on course. As a result of the feed-forward strategy, the course will be kept within the best possible limits with least possible effort.

Regarding the postural control, the feedback for movement control also introduces a phase lag. If no feed-forward strategy is used, the movements will appear abrupt, even when a high “gain” is introduced, by using extra muscle activation. A person, who has trained a specific movement task, knows how to adjust the muscle force in advance. He may therefore avoid the larger corrections, and the movement will be performed with less energy.

Premises for Postural Control

According to the reflex theory suggested by Sir Charles Sherrington and others in the beginning of the 20th century, movements are dependent on chains or combinations of reflexes (Shumway-Cook & Woollacott 2001). Sensory input will be processed in CNS and develop motor output which will send feedback to the sensory system in a closed loop. These elements represent the physiological components of the individual which are of major relevance to the postural control. A simple figure to

illustrate this model of the postural control mechanism would consist of a loop with the incorporation of three (or four) elements (figure 1.3). Input from the sensory organs is processed in order to produce a postural control output. A new feedback may again be provided through the sensory organs.

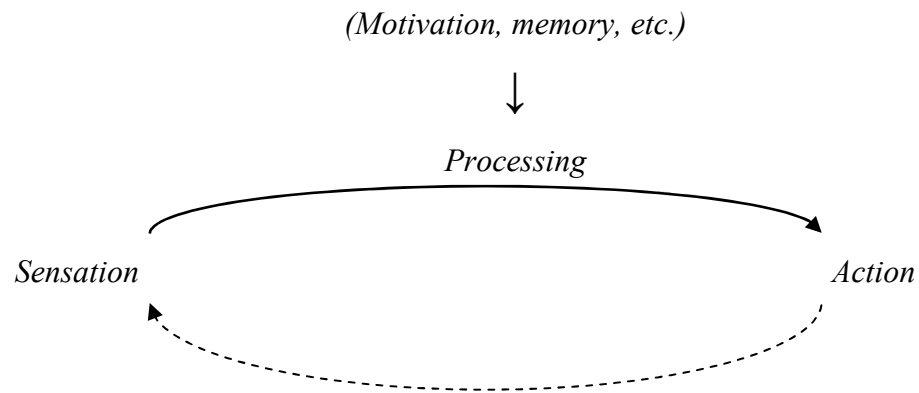


Figure 1.3. Modified reflex model illustrating the main components of the premises for postural control and their interaction.

It is understood that postural control for stability and orientation requires both perception (the integration of sensory information to assess the position and motion of the body in space) and action (the ability to generate forces for controlling body position system). The effector output on the action side is based on joint range of motion, muscle properties, and biomechanical relationships among linked body segments.

Sensory information for postural control is based on the visual sense, the vestibular sense, mechanoreceptors (providing sensory input from the skin pressure in foot soles etc.), and proprioceptors (providing information about body segment position and movements from joints etc.). The frame of reference in order to position the head in space can be visual, based on external cues in the surrounding environment, or vestibular, based on gravitational forces. The body can be oriented in relation to the head, based on information from proprioceptors in the neck, or it can be oriented with reference to the surrounding environment, based on somato-sensory information from contact with external objects.

The processing of sensory information into motor command is far from trivial. The text placed in brackets in figure 1.3 implies that higher order functions are involved in this processing. This aspect is covered by a theory of hierarchical organization of the function of the central nervous system, which is widely accepted. This hierarchical theory has been put forward by many researchers with Hughlin Jackson as one of the first (Gurfinkel & Cordo 1998). The hierarchical organization is referring to the

organization of neuro-anatomical structures, the postural reflex development, and the motor development as illustrated in figure 1.4 (Shumway-Cook & Woollacott 2001). A newborn child will display primitive reflexes, but these reflexes will be controlled and modified by higher centres through maturation of the neural system and through learning. They might, however, reappear with different types of brain damage (Fiorentino 1981).

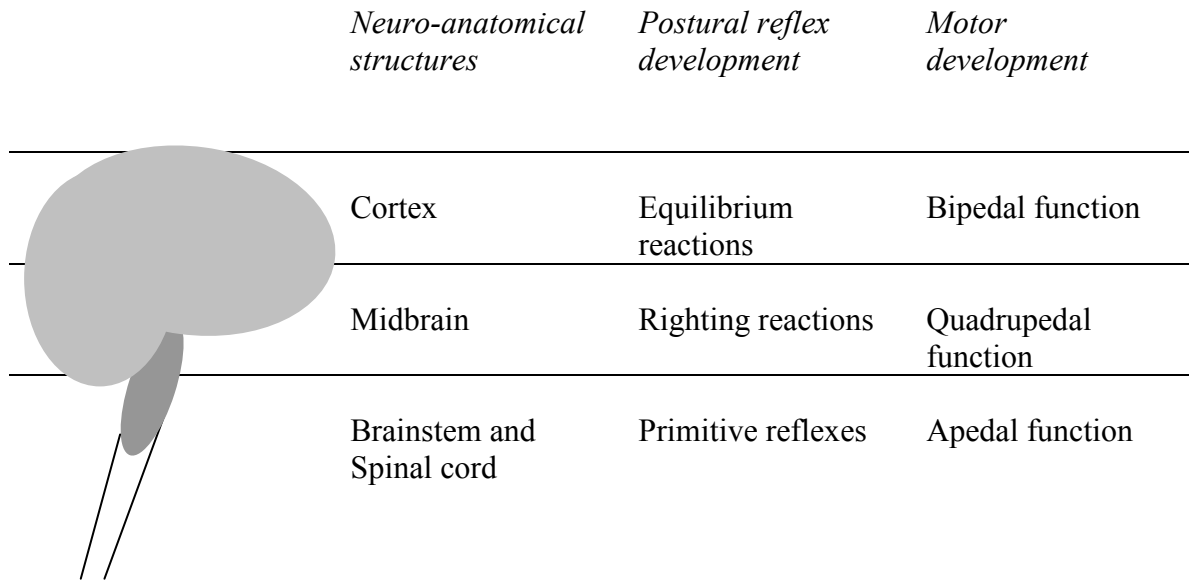


Figure 1.4. Illustration of the theory of hierarchical organization of CNS structure and processing (adapted from Shumway-Cook and Woollacott, 2001).

As discussed in the previous section, the feed-forward mechanisms are crucial in order to organize movements. The processing in relation to postural control is therefore based on both simple reflexes and advanced motor strategies, which have been learned and stored. Higher-level interactive processes are essential for mapping sensation to action and ensuring anticipatory and adaptive aspects of postural control.

An hierarchical model of posture control which includes both feed-forward and feedback strategies will therefore look slightly more complex as illustrated in (figure1.5) and described by Popovic and Sinkjaer (Popovic & Sinkjaer 2002)

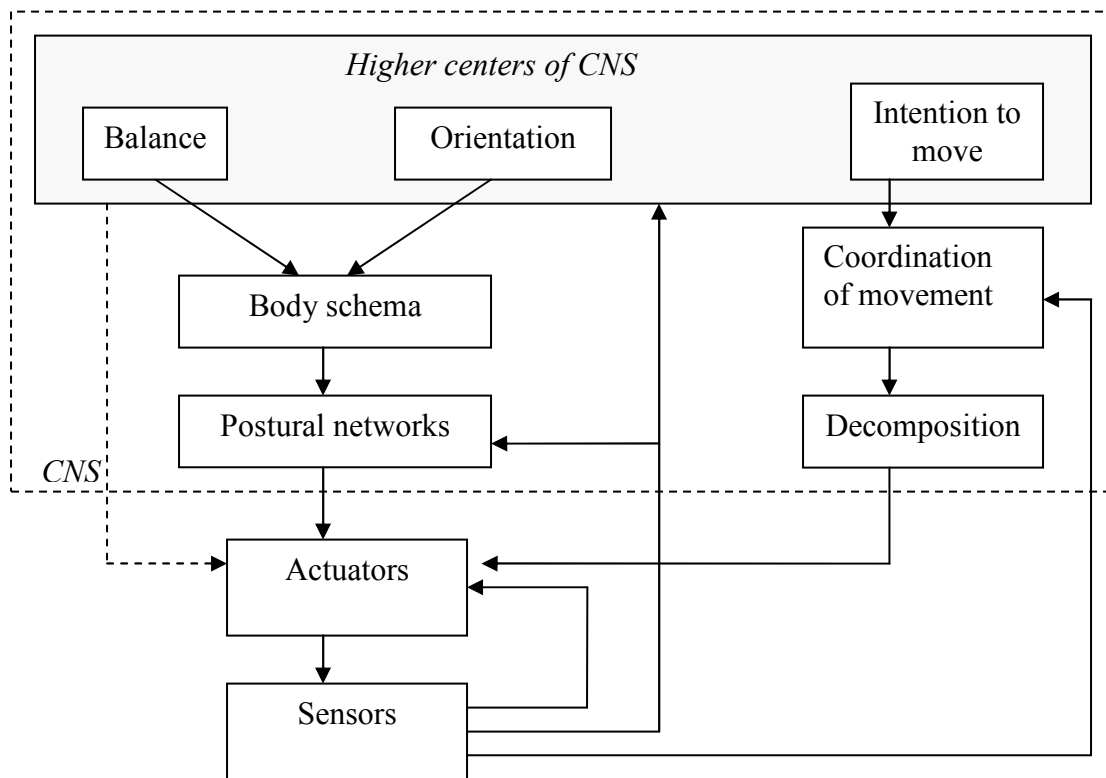


Figure 1.5. Hierarchical model of the main components involved in postural control (adapted from Popovic and Sinkjaer, 2002). The two references: body segment orientation and equilibrium control (balance) are leading to a body schema, which is an internal representation of the organization of the body.

The models based on the reflex theory and hierarchy theory might, however, not provide the full picture for understanding postural control. The interaction of musculoskeletal and neural systems in relation to the context in which the body is acting is very complex. As an additional aspect it is therefore relevant to adopt an approach to the postural control which is more “system oriented”. The postural control must be seen as the interaction among the many bodily oriented systems that work cooperatively to control stability and orientation of the body. This interaction can be illustrated in a conceptual model representing systems contributing to the postural control (figure 1.6) (Shumway-Cook & Woollacott 2001). Higher level cognitive aspects of postural control are the basis for adaptive and anticipatory factors. Adaptive aspects involve modifying sensory and motor systems in response to changing task and environmental demands. Anticipatory aspects prepare sensory and motor systems for postural demands based on previous experience and learning. Other cognitive aspects include such processes as attention, motivation, and intent.

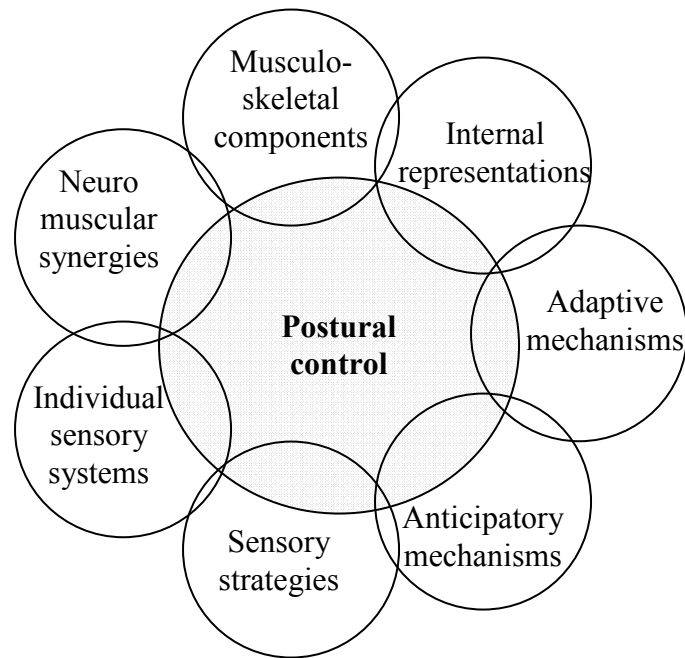


Figure 1.6. Model illustrating the main components of the premises for postural control and their interaction (adapted from Shumway-Cook and Woollacott, 2001)

Still, a complete understanding of the postural control is not achieved if it is approached as an isolated phenomenon only related to the individual factors of the body. The system must be understood in relation to external and internal forces acting on the body. This system theory approach was developed in the beginning and middle of the 20th century. It was first ascribed to Nicolai Bernstein who studied the movement control in the interplay with action of the entire body as a mechanical system (Gurfinkel & Cordo 1998).

The postural control depends on the appropriate interaction between large numbers of components. A movement with a successful coordination of all elements is expected to result in a harmonic movement pattern. But as two situations will never be quite alike, no fixed coordination strategy can be used. Bernstein studied athletic and labour movement and found that movements do not become identical although the ultimate motor outcome becomes highly reproducible (Latash 1998). In a study on the movement of hammering Bernstein filmed experienced industrial blacksmiths and showed the existence of variability in the human coordination. He found that while the trajectory of the hammerhead to a great extent was consistent between the hammer blows, the trajectories of the individual joints of the arm were very variable. In response to this experiment he formulated “the principle of non-univocality of movements”, which means that two movements are never performed in exactly the same way even though the end result (outcome measure) is the same (Hauvik 2000).

In summary: Postural control is an important aspect of physical functioning. Postural control performance must be seen in relation to the context of task and environment. The ability to perform a task with good postural control depends on the capacity of a complex interaction of musculoskeletal and neural systems. An assessment of the postural control performance reveals indirectly the character of this postural control capacity.

This leads on to the challenge of incorporating these aspects when assessing the postural control.

Assessment of Postural Control

The postural control is a complex mechanism, and different outcome measures have to be selected in order to reveal the level of the postural control.

Furthermore, it should be remembered that an assessment is not aiming alone at judging the postural control as a mechanism, but it is merely aimed at judging the ability or the capacity of an individual to perform a task with good postural control. This means that the assessment has to be context related.

Shumway-Cook and Woollacott (Shumway-Cook & Woollacott 2001) have suggested a model illustrating this aspect (figure 1.7).

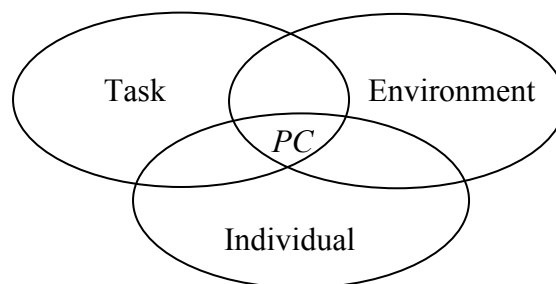


Figure 1.7. Postural control (PC) is influenced by factors related to the individual, the task, and the environment (adapted from Shumway-Cook and Woollacott, 2001).

The character of the environment and the task are highly relevant factors to consider in assessment of postural control capacity. The influence of environmental factors such as light conditions, concurrent distracting factors, special surface characteristics, etc. are affecting the requirements to the postural control. Similarly, it is easily understood that the balance demands during the task of walking and other locomotive activities are different from the demands when standing still. Shimada et al. found that walking balance function did not correlate with standing balance function, and they concluded that multifaceted evaluation is important to comprehend dynamic balance function (Shimada et al. 2003).

It must therefore be considered whether a test of the postural control is assessed in a more static position (ex. standing) or whether it is also including dynamic balance aspects (ex. walking). One must acknowledge that different tests are addressing different aspects of balance strategies (e.g. “feed-forward” versus “feed-back” mechanisms).

A taxonomy presented by Ann Gentile characterizes the level of a physical functioning demand in relation to different conditions (Gentile 1987;Huxham, Goldie, & Patla 2001). This taxonomy can also be used to illustrate the demands on the postural control (figure 1.8).

In this scheme it is seen that the demands to the postural control are not only influenced by the characteristics of the environment and the task, but also by the interaction between the individual subject and these elements. It is assumed that the demands are increasing when shifting from the condition of the upper left corner of the table towards the lower right corner, given that the tasks become more complex.

| | | Body stability | | Body transport | |
|-----------------------|---|-----------------|--------------|-----------------|--------------|
| | | No manipulation | Manipulation | No manipulation | Manipulation |
| Environmental context | Stationary No intertrial variability | | | | |
| | Stationary Intertrial variability | | | | |
| | Motion No intertrial variability | | | | |
| | Motion Intertrial variability | | | | |

Figure 1.8. Ann Gentile’s taxonomi for evaluating the level of difficulty of a functional movement task (adapted from Shumway-Cook and Woollacott, 2001). The demands are increasing when shifting from the condition of the upper left corner of the table to the conditions beneath or to the right.

Ann Gentile’s taxonomy describes the level of difficulty of a task and provides an indication of the challenge offered to the postural control. The individual capacity of postural control has to be evaluated

in relation to how well this challenge can be handled. Whether the postural control is successful is a question of whether the demands of the task and the environment are matched by the individual resources.

The interesting aspect to observe is therefore: either how well a specific challenge is handled, or how much the demands can be increased before the postural control capacity becomes insufficient to overcome the challenge. We have attempted to illustrate this interplay between capacity and demand in our own conceptual model of postural control (figure 1.9). In this model the characteristics of task and environment are combined in a common block called “balance demands”.

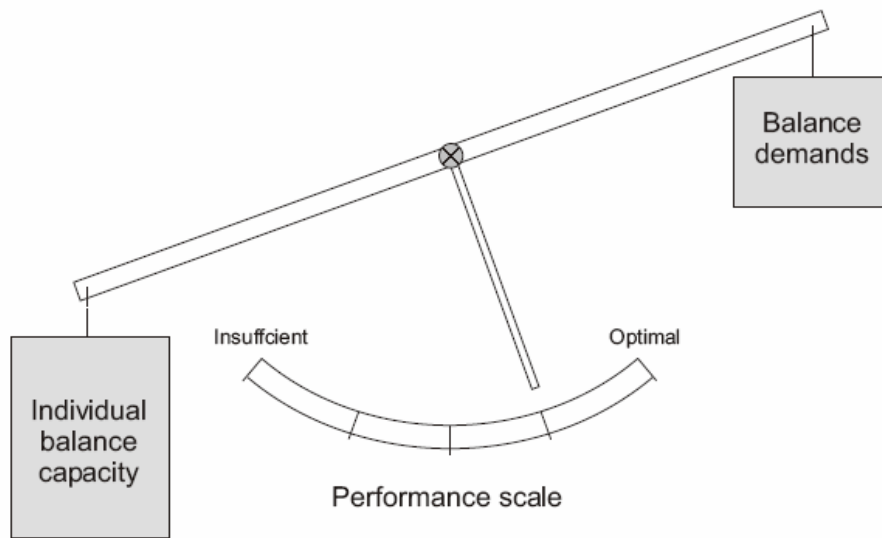


Figure 1.9. Conceptual model illustrating the elements of concern when assessing postural control. When the individual balance capacity outbalances the balance demands, a good performance will be reflected on the performance scale.

A normal subject will show a redundancy in the balance capacity in relation to the demands in the activities of normal daily living. A more fragile person may not have the same postural capacity, and the resources will be less redundant. But even a skilled ballet dancer or a well-trained gymnast can very well challenge themselves to a point where the postural capacity does not match the demands. They will then display equilibrium reactions, which were not planned, and the performance will look less perfect.

Our model illustrates this interplay between balance resources/capacity and balance demands. As long as the capacity outbalances the demands, a good postural control will be the result, and this will be

displayed on the performance scale. But when the capacity is minimized or the demands are increased, the result might be a less optimal performance as reflected on the scale.

Any person loses some of the neuromuscular resources in old age (Kandel, Schwartz, & Jessell 2000). We suggest that the normal strategy in order to overcome this problem is to adjust the demands in order not to challenge the balance capacity beyond the limits. But in some situations the demands will unintentionally be increased (as for instance, when rushing to cross the street in heavy traffic), and this could result in an overload and fall (i.e. “insufficient” on the performance scale).

In review of the research literature within the field of postural control assessment, it is seen that much effort has been used to find ways to manipulate the “demands” in ways which reveals new aspects of the postural capacity. One promising method is to challenge the patient by dual tasks (Mulder, Zijlstra, & Geurts 2002). We have incorporated this method in the presented studies, and we will discuss the dual task approach more thoroughly in chapter 5.

Outcome Measures

When the influence from the task and the environment is controlled, the only unknown variable is the individual factor. In this way, the level of the postural performance will indicate the condition of the individual factors related to the postural control capacity. In a test situation the task and environmental factor will be standardized, and we can concentrate on how to construct the measuring scale for evaluating the interplay between individual resources and demands.

It is obvious that a fall or the need for extra support is the ultimate sign (outcome measure) of insufficient postural control. This provides the model with a dichotomous scale: fall vs. no fall (or support needed vs. no support needed). Such a scale is useful in a test where the demands can be gradually increased until the need for support is revealed. This is seen in tests where the base of support area is decreased, as for instance when shifting from a standing position on two legs to standing on one leg. However, a dichotomous scale provides a highly gross measure, and other measures can be relevant in order to evaluate small differences in postural control.

An example of a different and more refined “scale” for balance evaluation in a standing position is the platform measure of COP movement as expressed in displacement, area, or speed. This can reflect the natural postural sway in a non-perturbed setting, or it can reflect reactions to perturbations.

The postural control while walking must be evaluated in different ways. The rhythm and coordination of the gait have been taken as an expression of postural control. The variability within these outcome

measures has especially gained much interest in recent years. In this assessment both basic temporal and spatial characteristics have been used as well as more refined kinematics and kinetic evaluations. These approaches will be discussed more thoroughly in chapter 8.

The technological progress is constantly providing new methods for evaluating the results of the interplay between demands and capacity. As an example, accelerometers have been proposed as measuring devices for the assessment of postural control. These tools have recently gained interest in the evaluation of gait function. As a result of the availability of this new measuring technique, a portable tri-axial accelerometer was included as a measuring tool in the following studies, and will be discussed in the relevant chapters.

These reflections on the assessment strategy and outcome measures have lead onward to the design of the studies presented in the following chapters. The more concrete description of these tools for evaluating postural control will therefore be presented by the description of their practical use. The next chapter will concentrate on fall risk assessment which naturally encompasses to a great extent the evaluation of postural control characteristics.

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2. Fall Prediction in the Elderly Population

The first goal for this Ph.D. study was to address fall prediction amongst elderly.

In this study a fall was defined as: “an event which results in a person coming to rest unintentionally on the ground or other lower level, not as a result of a major intrinsic event (such as stroke) or overwhelming hazard” (Tinetti, Speechley, & Ginter 1988).

A broad review of balance and fall literature was carried out in 2003 and 2004. The aim of this review was to provide an update on research areas addressed within this field in order to choose a focus for the approach of this study and to identify relevant methods to assess fall risk.

Epidemiology

Amongst elderly people bone fractures related to falls are frequent phenomena. These are often associated with physical decline, negative impact on quality of life, and reduced survival. Numerous studies on the annual incidence of falls have been published. In community dwellers the proportion of people sustaining at least one fall over a one-year period varies from 28-35% in the >65 year age group to 32-42% in the >75 year age group. Previous fallers have a two-third risk of having a fall in the subsequent year (Masud & Morris 2001).

Falls are a leading cause of injury-related deaths. In USA alone, no less than 15.400 deaths from falls occurred in 2001. The medical expenses related to falls amounted to more than USD 20 billion each year in USA, and these are increasing in the next 20 years towards an expected USD 32 billion a year (Bloem, Steijns, & Smits-Engelsman 2003). In a study from Denmark including community-dwelling elderly people attending a casualty ward, it was found that 41 out of 100 persons had had bone fractures from falling (Herlev kommune 2004). Bone fracture as a consequence of falling is more likely to occur when a person is suffering from osteoporosis with decreased bone mineral density, but osteoporosis is far from the only factor in fracture risk (McClung 2003). An inactivity-related osteoporosis can be adjoining other physiological phenomena related to inactivity. For instance, a decrease in muscle strength can be seen in elderly women with osteoporosis (Liu-Ambrose et al. 2003). When aiming at reducing the risk of bone fracture, one should therefore try to reduce the fall risk as well as prevent osteoporosis (Kamel & Zablocki 2002).

Screening for Fall Risk

The topic of fall prevention has been of great interest for many years. Many studies have addressed the assessment of balance in order to identify elderly persons in risk of falling. With background in these studies and in clinical experiences several screening procedures have been suggested.

A guideline for prevention of falls in elderly persons has been proposed by “The American Geriatric Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention” (AGS Panel on Falls Prevention 2001). This guideline includes a screening procedure at two levels as described in figure 2.1.

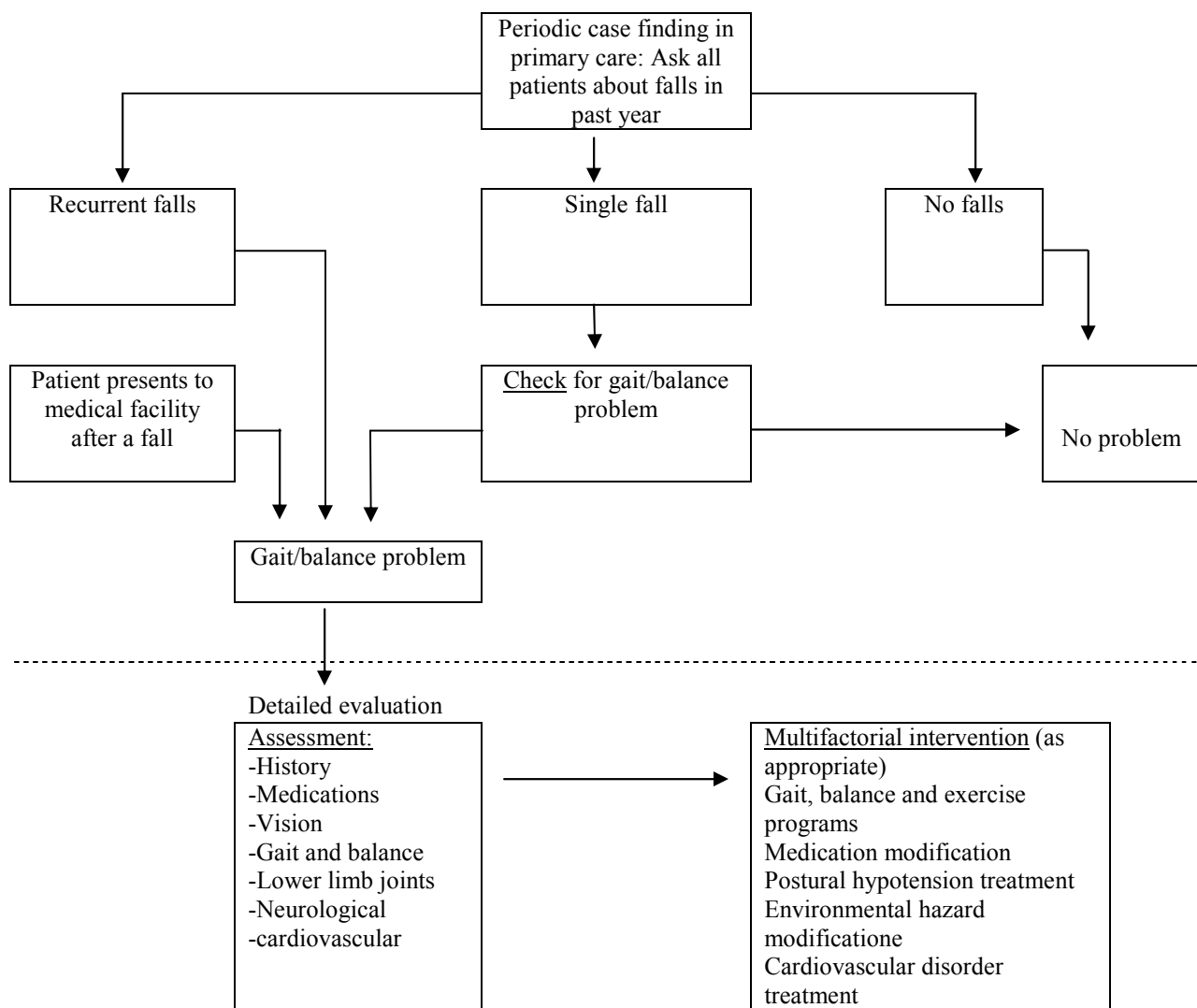


Figure 2.1. A guideline for prevention of falls in elderly persons presented as a flowchart (AGS Panel on Falls Prevention 2001).

At the first level in this screening, a basic check for gait/balance problems is suggested when a single fall has occurred. When gait/balance problems appear or if recurrent falls have occurred, a more comprehensive evaluation is proposed. At the second level, a detailed assessment is described which again includes gait and balance evaluation among other items.

A similar flowchart for fall risk screening has been suggested by Tinetti (Tinetti 2003). This flowchart also comprises of two assessment levels. In Tinetti's model for screening, an interview on previous falls and a brief screening test (ex. get-up-and-go test) should be performed for all patients >75 years. Positive findings of two or more falls or balance/gait difficulties decides whether a more detailed assessment of predisposing and precipitating factors should be performed. This second level of assessment comprises of several components: Circumstances of previous falls; Medication use; Vision; Postural blood pressure; Balance and gait; Targeted neurological examination; Targeted musculoskeletal examination; Targeted cardiovascular examination.

The two screening recommendations both agree that fall risk assessment should be performed at two levels. At the first level, a basic screening should be performed comprising of clinical feasible tests to be used at a minor suspicion of fall risk. At the second level, a more comprehensive assessment should be performed to address individual characteristics which could be expected to be indicators of fall risk or which could have an influence on fall risk.

In both recommendations a "gait and balance assessment" occurs as well at the first level, where fall risk is first estimated, as in the more detailed assessment. It is, however, not clear in which way this gait and balance assessment is to be performed the best.

The purpose of screening is to decide if actions of interventions should be proposed, but a precise evaluation of the fall risk is inherently difficult. A pragmatic approach was suggested by Moreland et al. in an article on "evidence-based guidelines for the secondary prevention of falls in older adults" (Moreland et al. 2003). They concluded that: "Balance exercises are recommended for all individuals who have had a fall and there is evidence for a program of home physiotherapy for women over 80 years of age regardless of risk factor status". It was also stated that: for community-dwelling older adults, there is strong evidence for multi-factorial specific risk assessment and targeted treatment (Moreland, Richardson, Chan, O'Neill, Bellissimo, Grum, & Shanks 2003).

The AGS Panel on Falls Prevention identified issues which should be given high priority for future research and analysis (AGS Panel on Falls Prevention 2001). One of the concerns which was

recommended for further research was put this way: “Can fall-prone individuals be risk stratified in terms of whom will benefit the most from assessment and interventions?”

In a WHO - Health Evidence Network report it was stated in relation to the assessment of fall risk:

“More research is required to clarify the most appropriated tools for use in different settings, in terms of simplicity of use, applicability, sensitivity and specificity.” (Health Evidence Network 2004).

As a comment from a geriatrician, Morley suggested: “A careful, in-depth examination of gait velocity and characteristics should be an essential component of a geriatric assessment ... Appropriate mobility assessment represents a futuristic view of modern geriatrics whose time has come” (Morley 2003).

According to these studies and considerations it was decided in the present PhD study to develop and evaluate a test battery including tests on balance and gait aimed at fall risk assessment in the community-dwelling elderly population belonging to the age-group in the seventies.

Test Battery

The general idea of assessing many performance parameters by combining specific tests in a test battery seems right for fall risk screening (Lord, Menz, & Tiedemann 2003).

However, because of the multi-factorial nature of fall risk, no high sensitivity should be expected from any fall prediction method. Trying to predict an infrequent future event such as falls is inherently difficult, and this calls for a realistic attitude regarding our abilities to forecast infrequent events (Ruchinkas 2003).

One of the best-known test batteries for balance evaluation is the Berg Balance Scale. In a one-year follow up study including 113 elderly residents, this test battery predicted the occurrence of multiple falls (Berg et al. 1992).

In a six months follow-up study on elderly residents (n=66), the Berg Balance test demonstrated 53% sensitivity and 92% specificity when using 45 (out of 56) as a generalized cut-off score (Bogle Thorbahn & Newton 1996).

A score on the Berg Balance scale combined with self-reported history of imbalance predicted fall risk with a sensitivity of 91% and specificity of 82% in a case control study on 44 community-dwelling elderly (Shumway-Cook et al. 1997).

A study, which re-analysed data from the two previous studies, yielded a sensitivity of 64% and a specificity of 96% by using a cut-off point of 45 on the Berg Balance Scale

(Riddle & Stratford 1999).

In a case-control study by Chiu et al., which included elderly fallers from a fall clinic, the sensitivities/specificities of chosen test batteries were: Berg Balance Scale: 88% / 77%; Tinetti Mobility Score: 82% / 65%; Elderly Mobility Scale: 59% / 59% (Chiu, Au-Yeung, & Lo 2003).

The Physiological Profile Approach (PPA) has in two prospective studies been reported to correctly classify subjects into multiple and non-multiple fallers with an accuracy of 79% and 75%, respectively (Lord, Menz, & Tiedemann 2003).

In a six months follow-up study on 78 elderly in residential care the Mobility Interaction Fall chart (including an observation of mobility level, 'Stops walking when talking', the diffTUG, a test of vision and a rating of concentration) produced a positive predictive value for the classification of 78% and negative predictive value of 88% (Lundin-Olsson, Nyberg, & Gustafson 2000).

The very different performance of the different test batteries and the different evaluation of the same test battery in different studies must be ascribed to different study populations and the different design of the studies.

When focus is placed merely on the balance assessment in the population of more healthy and active elderly, it becomes difficult to find good suggestions for a valid test battery for fall risk assessment.

A study on community-dwelling elderly evaluated Berg Balance Scale, Functional Reach test, Lateral Reach test, and Step-up test in a six months follow-up period and found poor fall prediction (Brauer, Burns, & Galley 2000).

The Tinetti balance and mobility scale was used in a one-year follow-up study on fall risk, which included 60 community-dwelling elderly as a reference group. In this population the nine task test battery had a 62% sensitivity and 70 % specificity when using 10 as cut off value (Verghese et al. 2002).

In a prospective study including 225 community-dwelling elderly +75 years, the Tinetti balance scale produced 52% sensitivity and 70% specificity at a cut-off score of 36 (Raiche et al. 2000).

Another study on community-dwelling elderly adults who were active and independent had a one year follow-up period (Boulgarides et al. 2003). Five balance tests (Modified Clinical Tests of Sensory Interaction for Balance, The 100% Limits of Stability tests, both of which were done on platform, Berg Balance Scale, Timed Up and GO test, and Dynamic Gait Index) combined with health and demographic factors did not predict falls. The authors suggest that new screening tests are needed for community-dwelling elderly adults who are active.

New tests are still being developed based on new methods and other risk parameters. By constructing a new test battery, an opportunity would therefore be offered to exploit the advantage of recognizing and implementing these new tests.

Factors Related to Fall Risk

When trying to predict falls in the elderly population, the multifactorial nature of postural control makes things very complicated. According to the model suggested by Shumway-Cook and Woolacott, presented in chapter 1 figure 1.7, three aspects could be considered regarding fall risk: 1) the individual factors, 2) task characteristics, and 3) environmental factors. The selection of tests for a test battery must therefore consider these aspects and must be designed in relation to the specific population, which shall be addressed.

1. Individual factors: The American Geriatric Society Panel on Falls Prevention (AGS Panel on Falls Prevention 2001) identified in a review based on 16 studies the most common individual risk factors for falls:

| | |
|----------------------|--------|
| Muscle weakness | RR 4.4 |
| History of falls | RR 3.0 |
| Gait deficit | RR 2.9 |
| Balance deficit | RR 2.9 |
| Use assistive device | RR 2.6 |
| Visual deficit | RR 2.5 |
| Arthritis | RR 2.4 |
| Impaired ADL | RR 2.3 |
| Depression | RR 2.2 |
| Cognitive impairment | RR 1.8 |
| Age > 80 years | RR 1.7 |

The panel concluded the list by stating: “Perhaps as important as identifying risk factors is appreciating the interaction and probable synergism between multiple risk factors...” (AGS Panel on Falls Prevention 2001).

2. Task: When assessing fall risk one thing is to evaluate the capability of the individual. The main thing, however, is to consider, whether the capability of the individual matches the balance demands, as

we illustrated in fig. 1.9. It is not unimportant whether the elderly subject is still attending activities of high risk or is sedentary, and this aspect complicates the assessment.

A very fragile person or a person with a poor postural control might be very well aware of this, and she might not be in risk of falling if she does not challenge herself beyond her limits. Another person might be a very healthy and fit individual, and this person might live a very active life (skiing, running, dancing, and attending other sporting activities). Thereby she will from time to time happen to challenge herself beyond her limits and be in increased risk of falling.

Gregg et al. (1998) described a U-shaped relationship between physical activity level and fall incidence (i.e. colles fractures) amongst elderly (+65 years of age). This implied that both sedentary and very active elderly were more at risk than average (Gregg et al. 1998).

Causality is not easy to find either. For instance, the observation of higher fall risk in subjects with a history of falls could indicate a physiological deficit. But it might also be a result of fear of falling causing “stiffening strategies” which has been shown to increase fall risk (Allum et al. 2002; Wolf et al. 1996). On the contrary one could argue that a fall history and fear of falling should have made the person aware of her limitations causing her not to challenge herself beyond her limits.

3. Environment: There are many threats (“risk factors”) in the environment and in the tasks that can cause loss of balance.

One study (from Miami) described that trips and slips were the most prevalent causes of falls, accounting for 59% of falls. Falls most often occurred during the afternoon and while subjects walked on level or uneven surfaces. Falls by men most often resulted from slips whereas falls by women most often resulted from trips. Moreover, women and men differed in the time of the year in which falls occurred, with men falling most often during winter and women during summer (Berg et al. 1997).

An Australian research group reported that approximately 56% of falls occurred outside the house, a number decreasing with age (Lord, Sherrington, & Menz 2001). Furthermore, a Swedish group found that risk factors for indoor and outdoor falls are different (Bergland, Jarnlo, & Laake 2003).

Construction and Validation of Test Battery

Paper I and Paper II, which are included in the next two chapters, evaluate the performance of a new test battery in relation to fall prediction in an active community-dwelling elderly population.

The tests included in the battery were selected according to the reflections in the previous sections. In the test selection process, it was chosen to focus on an assessment of the individual physiological factors related to fall risk. However, considerations regarding task and environment meant that the tests were selected in order to reflect the fact that high demands are facing active community-dwelling elderly as compared with institutionalised or sedentary elderly. The illustration in figure 2.2 serves as an overview of the selection process.

Tests with a focus related to general postural control regarded:

Standing performance; General physical function in a combined task; Gait cadence; Gait variability; Vision; Dual task performance

Tests with a focus related to postural correction response regarded:

Stepping ability; Reaction time; Lower extremity strength

A more comprehensive discussion of the selection process and argumentation for the choices of the specific tests as well as a detailed description of the tests included in the test battery are provided in paper II.

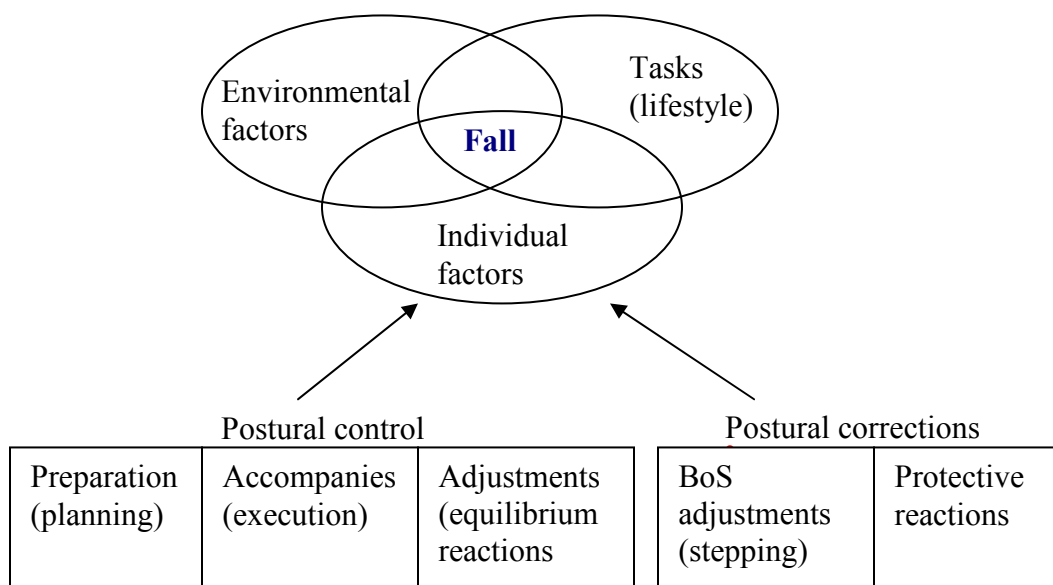


Figure 2.2. Illustration of the selection criteria for inclusion of tests for the fall risk assessment test battery.

Publication Considerations

Paper I presents a case control study based on a subgroup of the population tested for paper II. The analyses are based on the same test battery and the same testing situations. The detailed test descriptions for paper I and II are therefore identical. Paper I was submitted, but not accepted for publication, before the results from the follow-up period of paper II were available. It was quite interesting to experience that several editors expressed that there was little interest in papers addressing fall risk characteristics. We would like to quote one editor: "Journal ... is less interested in risk factors and predictors of falls-- these data are well described and confirmed. The field is moving in the direction of interventions in prevention of falls." In our review of the literature we had seen that the research area of fall risk evaluation had been blooming within a decade, but now the interest was apparently saturated.

As a consequence of the negative results in the follow-up analysis, it was decided not to proceed with the publication of the data from the case control analysis presented in paper I. Still, in order to illustrate the divergence, which can occur due to different study designs, we have chosen to include paper I in this thesis in spite of its overlap to paper II.

We will discuss these methodological considerations in chapter 5.

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3. Fall Risk Assessment in an Active Elderly Population

(Paper I)

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Abstract

The purpose of this study was to evaluate the inclusion of dynamic balance tests in a test battery for fall risk assessment in an active and healthy elderly population. In view of a literature study nine tests were selected. Thirty-five community-dwelling females (mean age 74 years) with a fall history and an age matched group of 36 females were tested. The fallers had a significantly lower score than the non-fallers (6.5 versus 7.0 on a 0-10 scale; $p < 0.01$). Tests addressing leg strength, dual task and gait variability showed significant group differences individually. The test battery had a sensitivity of 71% and specificity of 58% at a cut-off value of 7.0. Tests on dynamic postural control contributed significantly to the capability of the test-battery to identify fallers. The inclusion of this type of tests in the fall risk screening is appropriate when addressing an active and healthy elderly population.

Introduction

Amongst elderly people bone fractures in relation to falls are frequent phenomena. These accidents are often associated with physical decline, negative impact on quality of life and reduced survival (Bloem, Steijns, & Smits-Engelsman 2003). Amongst community-

dwelling elderly the proportion of people sustaining at least one fall over a one-year period varies from 28 – 35% in the +65-year age group to 32 – 42% in the +75-year age group (Masud & Morris 2001).

Many studies have found that interventions can reduce the rate of fall in a population of elderly (Gillespie et al. 2001). Exercises comprising of balance training and strength training have proven the best effect (Robertson et al. 2002). For community-dwelling elderly, there is strong evidence for multi-factorial specific risk assessment and targeted treatment (Moreland, Richardson, Chan, O'Neill, Bellissimo, Grum, & Shanks 2003). It is therefore relevant to try to identify the elderly individuals in need of training. The very old and more fragile are a natural target group. Thus, evidence is found for a program of home physiotherapy for women over 80 years of age regardless of risk factor status (Moreland, Richardson, Chan, O'Neill, Bellissimo, Grum, & Shanks 2003). But also healthy and active elderly in the seventies should be screened for fall risk in order to be offered training if need be.

A literature study indicated that tests addressing dynamic postural control and motor planning should be relevant in the assessment of fall risk. This comply with the guidelines from the American Geriatric Society which emphasize the relevance of gait assessment in fall risk screening (AGS Panel on Falls Prevention

2001). Several research groups have tried out test batteries for addressing fall risk in the elderly (Boulgarides, McGinty, Willett, & Barnes 2003; Chiu, Au-Yeung, & Lo 2003; Lord, Menz, & Tiedemann 2003). However, these test batteries have to a minor extent assessed specific gait characteristics. Our hypothesis was that the fall prediction rate of a test battery could be improved by including tests on feed-forward strategies and dynamic balance components as seen in specific tests on gait performance.

Nine tests were selected for a test-battery, and the aim of the study was to validate this test battery in relation to fall risk screening in an active elderly population.

Methods

Participants

A case-control study was conducted in a population of community dwelling healthy elderly females between 70 and 85 years of age. The elderly were invited to participate in the study by announcements at senior community centers and by verbal contacts. A population of 106 elderly was tested with the test battery. From this population a group of 35 females with a history of at least one balance related fall within the last two years was identified. An age-matched control group consisted of 36 females with no such fall history. In this context a

balance related fall was defined as: “an event which results in a person coming to rest unintentionally on the ground or other lower level, not as a result of a major intrinsic event (such as stroke) or overwhelming hazard” (Tinetti, Speechley, & Ginter 1988).

The elderly were excluded if they reported any of the following: a) major musculoskeletal disorder; b) significant pain that limited daily functions; c) dependence on gait auxiliaries d) ear infection within two weeks prior to the test; e) fall within one month prior to the test; f) dependence on special care to stay in community; g) known uncorrected visual or vestibular problems or h) cognitive impairment (Mini Mental State Examination (MMSE) < 23) (Foreman et al. 1996). Informed consent was obtained from all participants prior to inclusion in the study and the study was approved by the local Ethics Committee.

Nine tests were selected for a test-battery, ranging from specific tests on muscle strength to general tests on performance in combined tasks (table 1). In order to make the test-battery practical in a clinical setting, the following criteria were set: each test should be clinically applicable; total testing time should not exceed half an hour; conduction of the test should not require a stationary setting. The selected tests have all been described and evaluated in scientific journals. Each test is described in the appendix in order to give an overview of the test procedures. A more detailed insight in the tests

might, however, require the reader to consult the referred literature.

Procedures

The elderly were tested at the premises of the senior community centres. The participants were introduced to each test in the test-battery by a demonstration and they were allowed to do a pre-trial test. The participants were also interviewed about age, height, weight, fall

history and health problems. Self estimated health was scored on a scale from 1 - 5 (1 being “very bad” and 5 being “very good”). Balance confidence and fear of falling was scored using the Activity-specific Balance Confidence scale (ABC) (Powell & Myers 1995). The physical activity level of the participants was assessed by using the Physical Activity Scale for the Elderly (PASE) (Loland 2002; Washburn et al. 1993).

Table 1. A listing of the nine tests selected for the test battery. The last column indicates whether the test was used in an original or a modified form. In the appendix descriptions of the testing procedures are provided.

| Test focus | Method | Form |
|-----------------------------|--|----------|
| 1 Standing balance | “FICSIT-4 scale” + one leg eyes closed (Rossiter-Fornoff et al. 1995) | modified |
| 2 Stepping ability | “Four Square Step Test” (FSST) (Dite & Temple 2002) | original |
| 3 General physical function | “Timed Up and Go” (TUG) (Podsiadlo & Richardson 1991; Shumway-Cook, Brauer, & Woollacott 2000) | original |
| 4 Reaction time | Step reaction on visual cue (Lord & Fitzpatrick 2001) | modified |
| 5 General leg strength | “Timed Stand Test” (TST) (Csuka & Mccarty 1985) | original |
| 6 Dual task | Gait speed decrease in a “dual task” (Gulich & Zeitler 2000) | modified |
| 7 Gait variability | Trunk acceleration autocorrelation (Moe-Nilssen & Helbostad 2005) | modified |
| 8 Gait cadence | Step cadence at gait speed 1.1 m/s (Moe-Nilssen & Helbostad 2005) | modified |
| 9 Vision | Visual acuity, contrast and field (Donders 1855) | original |

Data Analysis

Signal processing of the accelerometer signals and the trigger signals on reaction time was performed in MatLab (ver. 6.1, MathWorks Inc.). Data organization was done in Excel (2002, Microsoft Corp.), and the statistics were conducted in SPSS (ver. 12.0, SPSS Inc.).

To determine the differences between the case and the control group characteristics, Student's t-tests (for nominal data) and Mann-Whitney U tests (for ordinal data) were used.

To provide an overview, mean values, standard deviations and 95% confidence intervals (CI) were presented from all tests. The individual test scores were converted into 0 - 10 scales with higher values presenting better performance.

Some of the data, however, originated from ordinal scales and therefore Mann-Whitney U tests were used for evaluating the significances of differences between the outcome scores from these tests. The normalized test scores were averaged into a total score for the test battery.

The discrimination ability of the test battery in relation to the variable "faller" and "non-faller" was evaluated by a selected cut-off value (crude discrimination rates) and by logistic regression. A backwards stepwise logistic regression was used to evaluate whether any of the tests in the battery were non-essential.

Results

The group of non-fallers was successfully age-matched to the group of fallers. Only self-estimated health showed significant difference between the two groups (table 2).

In each individual test, the non-faller group scored better than the faller group, but in only three of the tests these differences were significant. These tests were 5) General leg strength, 6) Dual task and 7) Gait variability (table 3). The test scores are presented in the converted form in figure 1.

Table 2. Group characteristics of Fallers and Non-fallers

| | Fallers (n=35) | | Non-fallers (n=36) | |
|---------------------|-------------------|--------|-----------------------|---------|
| Age | 74.3 | (3.5) | 74.0 | (3.3) |
| BMI ^a | 28.0 | (5.5) | 25.6 | (4.5) |
| Health ^b | 3.9 | (0.07) | 4.4 | (0.6) * |
| PASE ^c | 106 | (50) | 118 | (45) |
| ABC ^d | 85 | (16) | 92 | (5) |

*a. Body Mass Index, b. Self estimated health on a scale from 1-5, with 1 being very bad and 5 being very good, c. Physical Activity-based Scale for the Elderly, d. Activity-specific Balance Confidence Scale. Values are Mean and SD (.). * $p=0.003$.*

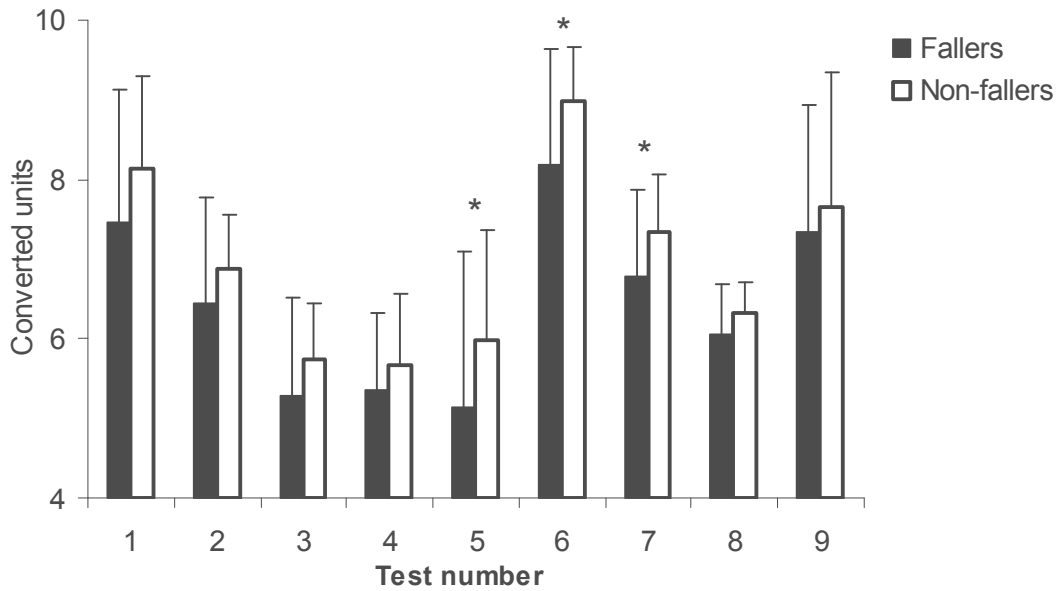


Figure 1. Converted and averaged scores from the nine different tests in the test battery presented by means and standard deviations. * $p < 0.05$

Table 3. Test scores from the nine tests in the test battery (raw data) presented for the group of Fallers and of Non-fallers and presented as differences between the two groups

| | Fallers | Non-fallers | Differences |
|-------------------------------|-------------|-------------|---------------------------|
| 1. Standing balance (0-6) | 4.5 (1.0) | 4.9 (0.7) | -0.4 (-0.8 – 0.0) |
| 2. Stepping ability (s) | 10.7 (4.0) | 9.4 (2.1) | 1.3 (-0.3 – 1.7) |
| 3. General performance (s) | 9.4 (2.4) | 8.5 (1.4) | 0.9 (-0.3 – 1.9) |
| 4. Reaction time (s) | 0.9 (0.2) | 0.9 (0.2) | 0.0 (-0.1 – 0.1) |
| 5. General leg strength (s) | 29.1 (11.7) | 24.1 (8.2) | 5.1 (0.3 – 9.8) * |
| 6. Dual task (%) | 36 (29) | 20 (13) | 16 (5 – 27) * |
| 7. Gait variability (no unit) | 0.84 (0.05) | 0.87 (0.04) | -0.03 (-0.05 – (-0.01)) * |
| 8. Gait cadence (s^{-1}) | 1.8 (0.1) | 1.7 (0.1) | 0.1 (0.0 – 0.1) |
| 9. Vision (0-7) | 5.2 (1.1) | 5.4 (1.2) | -0.2 (-0.8 – 0.3) |

Test scores for Fallers and Non-fallers are presented by Mean and SD ().

Group differences are presented by Mean and 95% confidence interval (). * $p < 0.05$

The total score in the test battery was significantly lower in the group of fallers. This group had an average score of 6.5 (SD 0.9) on the normalized 0 - 10 scale whereas the non-faller group scored 7.0 (SD 0.4) leaving a difference of 0.5 (CI: 0.2 – 0.8) ($p < 0.01$) (figure 2).

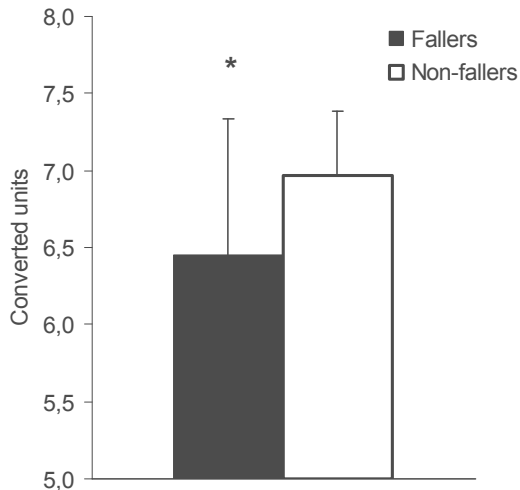


Figure 2. Averaged total scores from the test-battery presented by means and standard deviations. * $p < 0.01$

Discrimination

A cut-off value of 7.0 in the test battery resulted in a sensitivity (correct classification of fallers) of 71% (CI: 53% - 84%) and a specificity (correct classification of non-fallers) of 58% (CI: 42% - 73%).

By using logistic regression it was seen that an increase of one unit in total score resulted in a decrease in fall risk equivalent to a decrease in odds ratio of 0.29 (CI: 0.12 – 0.70). In the logistic regression the tests were able to obtain

73.2% correct classification of the subjects by 65.7% sensitivity and 80.6% specificity. The different tests contributed to these discrimination rates with various weights. The formula for the regression indicated that the test on vision and reaction time contributed very little to the classification in this population: $\text{Logit } P = 17.56 - (0.41 \text{ standing balance}) + (0.16 \text{ stepping ability}) + (0.55 \text{ general physical function}) + (0.03 \text{ reaction time}) - (0.38 \text{ general leg strength}) - (0.70 \text{ dual task}) - (0.59 \text{ gait variability}) - (0.93 \text{ cadence}) - (0.03 \text{ vision})$. By applying a backward stepwise regression the tests that contributed the least to the classification were removed one by one. In this way it was possible to see, whether the test-battery performed just as well in a slimmer version with fewer tests. It was seen that the same discrimination rates could be obtained by using only five of the ten tests. These tests were: 1) Standing balance, 5) General leg strength, 6) Dual task, 7) Gait variability and 8) Gait cadence. However, only 6) Dual task and 7) Gait variability remained significantly relevant for the discrimination.

Discussion

In this population of healthy community-dwelling elderly females the case group of fallers scored significantly lower than the age matched control group in the selected test

battery. The test battery had a crude sensitivity and specificity of 71% and 58% at a cut-off value of 7.0. Tests on gait variability and on dual task performance contributed significantly to the capability of the test battery to discriminate between fallers and non-fallers. The study population had a physical activity level which could be expected for this age group. The activity level was evaluated by the PASE questionnaire and the scores were 106 and 118 for fallers and non-fallers respectively. This is comparable to a PASE-score of 117 reported in a cross-sectional study of a group of community-dwelling women with a mean age of 75 years (Loland 2002).

Test evaluation

Some comments should be given on the application of the individual tests: The original test on balance in a standing position (FICSIT-4 scale) was expanded by the task of standing on one leg with eyes closed. This modification meant that a ceiling effect was avoided, and some group difference could be observed. We experienced that “Timed up and Go” was too easy a test for this population. Both groups scored well below 12 s, which has been recommended as a cut-off score for identifying mobility deficit (Bischoff et al. 2003). This also applied to the “Four Square Step Test”, which would have been a challenging test in a more fragile group of elderly. The tests on reaction time were very sensitive to the motivation of the

participants, and an actual difference in reaction capacity might have been partly disguised. Strength was assessed as repetitive dynamic force production by “Timed Stand Test”. This test worked fine in the clinical setting and in spite of its lack of specificity, it came out with a significant difference between the two groups. Walking was not a very challenging task for the elderly in this population, but the sensitive measure (trunk accelerometry) still detected some differences in gait parameters in the groups. The ongoing methodological development of this measuring tool will probably make its use even more clinically relevant within a few years. The adding of a second task in the dual task test was quite challenging for many of the participants, and some individuals almost gave up counting backwards. It would have been interesting to have had a recording of the counting performance. Almost everyone in this population wore well regulated glasses and no group differences were observed in the vision tests. These considerations lead to the conclusion that some of the tests should have been even more challenging and more precise to reveal differences in the performance of these active community-dwelling elderly.

Fall Risk Factors

A major problem, when predicting fall risk, is the multi-factorial mechanisms of falls. The influence of the environmental factors, the

difficulty of the task which is performed as well as the individual physiological and psychological factors have to be considered (Shumway-Cook & Woollacott 2001). To be able to cope well in daily-life situations the balance demands in the environment and in the tasks must be matched by the individual balance capacity of the elderly. A very fragile person or a person with a poor postural control might be very well aware of her lacking capacities. Therefore she will try not to challenge herself beyond her limits and she might not be in risk of falling in spite of her low physical capacity. Another person, who is a healthy and fit individual with a good balance capacity, could live a very active life (walking in all kinds of weather, dancing, and attending other sporting activities). From time to time this person might challenge herself beyond her limits and thereby she would have an increased risk of falling. In the test battery in this study the fall risk was assessed only by evaluating the physical capability of the individual, but in relation to fall risk it is merely critical whether the balance capacity of the individual matches the individual balance demands (Gregg, Cauley, Seeley, Ensrud, & Bauer 1998). The lifestyle characteristics of healthy elderly people are of large diversity. Test batteries for fall risk screening in this population could therefore probably be improved by relating the individual balance capacity to the individual activity level and balance demand of the elderly.

Discrimination Ability

The discrimination rates were not affected by neglecting the results from four of the tests, but in a population of more fragile elderly these tests would probably have contributed to the discriminative capability of the test battery. The general idea of assessing many performance parameters by combining specific tests in a test battery seems right for fall risk screening (Lord, Menz, & Tiedemann 2003). Because of the multi-factorial nature of fall risk no high sensitivity should be expected from any fall prediction method (Ruchinkas 2003). In a case-control study by Chiu et al., which included fallers from a fall clinic, the sensitivity/specificity of chosen test batteries were: Berg Balance Scale: 88% / 77%; Tinetti Mobility Score: 82% / 65%; Elderly Mobility Scale: 59% / 59% (Chiu, Au-Yeung, & Lo 2003). The test battery used in our study did not show high discrimination rates either. It must, however, be recalled, that the fallers in this study were not recruited from a fall clinic or from any other selected population, nor had the fallers any other known distinction from the non-fallers.

Perspectives

The tests addressing feed-forward control contributed significantly to the discrimination rates. This indicates that the original idea of incorporating tests with a focus on feed-forward strategies and dynamic balance components was

right. Specific assessment of gait characteristics in combination with tasks of increasing difficulty seems relevant when addressing balance performance in this group of active and healthy elderly.

Considering the growing population of elderly and the consequences of falling in this group it is relevant to try to improve screening procedures to predict fall risk. The individual physiological balance capacity of the elderly is only one factor in the fall risk pattern. Nonetheless it is a relevant factor to address in the identification of the elderly who could benefit from physical training. The measurement of balance during walking is relevant in this identification and new tests should be elaborated upon in relation to this assessment.

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Appendix

A description of the test procedures for the nine individual tests of the test battery:

1. Standing balance

A test procedure was chosen which was used in the FICSIT-studies (Rossiter-Fornoff, Wolf, Wolfson, & Buchner 1995). This procedure included the principles from the “Guralnik test”, which is commonly used in the clinic (Guralnik et al. 1994). The procedure was expanded to avoid a ceiling effect by adding the task: “standing on one leg with eyes closed”. The participant was asked to stand for 10 seconds with the feet in parallel, semi-tandem, and tandem position as well as to stand on one leg with eyes open and with eyes closed. Scores were given according to the ability to perform the tasks: Parallel refused \approx 0.0; Parallel <10 s \approx 0.5; Semi-tandem <10 s \approx 1.5; Semi >10 s - failed tandem \approx 2.0; Tandem <10 s \approx 3.0; Tandem >10 s, one leg <10 s \approx 4.0; One leg >10 s \approx 5.0; One leg eyes closed <10 s \approx 5.5; One leg eyes close >10 s \approx 6.0. The 0-6 score was converted into a 0 - 10 scale.

2. Stepping ability

A test procedure called “Four Square Step Test” (FSST) was used for evaluating stepping ability (Dite & Temple 2002). Two sticks (height 2.5 cm and length 80 cm) were placed on the floor forming a cross. This cross indicated four squares (1, 2, 3, 4). The participant was asked to step as quickly as possible from one square to another in the order 1-2-3-4-3-2-1. They were asked to touch the ground with both feet in each square while facing in the same direction at all times. After a pre-trial, the faster of two trials was used for evaluation. A score between 0 – 30 s was inversely converted into a 0 - 10 scale.

3. General physical function

“Timed Up and Go” test (TUG) is a widely used and a validated test for general physical performance in the elderly (Podsiadlo & Richardson 1991; Shumway-Cook, Brauer, & Woollacott 2000). In this test the participant was sitting on a chair (height \approx 46 cm.). A line was drawn on the floor three meters in front of the chair. The

participant was asked to rise from chair, walk the three meters to cross the line, turn around, walk back, and to sit down on the chair again. The time for this procedure was recorded by a stopwatch. A score between 0 – 20 s was inversely converted into a 0 - 10 scale.

4. Reaction time

The time for a step reaction to a visual cue has been shown to relate to fall risk (Lord & Fitzpatrick 2001). In our set-up, the participant was asked to stand in front of a wall at a distance of half a meter. A red and a green light were mounted on the wall at eye height of the participant and a red and a green footplate were placed 30 cm in front of the participant's feet 30 cm apart. The lights were alighted manually in a random order five times each, and the participant was asked to step onto the footplate matching the colour of the light as quickly as possible. The whole procedure was repeated having the foot plates placed at each side of the participant at a distance of 30 cm.

A step on the footplates triggered a pressure sensitive contact. This signal and the trigger time from the lights were recorded and the signal times were subtracted to find the reaction time. A mean reaction time from all trials was given. A score between 0 - 2 s was inversely converted into a 0 - 10 scale.

5. General leg strength

Muscle strength is known to be related to falls risk (AGS Panel on Falls Prevention 2001). A widely known clinical test for leg muscle strength called "Timed Stand Test" (TST) was used (Csuka & Mccarty 1985). Time needed to stand up from a chair ten times was recorded. The height of the chair was adjusted to the participant's leg length to maintain a knee angle at 90 degrees when sitting with the feet supported on the ground. The participant was instructed to rise and sit as fast as possible, and the time was recorded using a stopwatch. A score between 0 – 60 s was inversely converted into a 0 - 10 scale.

6. Dual task - gait automation

It can be challenging to perform two tasks at the same time (dual task) if attention is needed in both tasks.

Walking should be an automated function and should not require much attention, and it should be possible to perform a cognitive task while walking. However, elderly fallers seem to walk slower when performing a dual task (Verghese, Buschke, Viola, Katz, Hall, Kuslansky, & Lipton 2002). To test this phenomena a modified "Walking and Counting test" was used (Gulich & Zeitler 2000). The participant was asked to walk a ten meter distance as quickly as possible. Then the same task was performed while now counting backwards in a 3-step sequence from 80. The walking time was recorded by a stopwatch, and the decrease in speed was given in percent. A 0 – 200% score was inversely converted into a 0 - 10 scale.

7. Gait variability

Walking is a challenging task, in which successful motor planning and fine tuned postural control are required to produce a smooth gait pattern. To reveal inadequacy in these matters, different gait measures can be used. During walking the reaction forces from the floor are reflected in the trunk. An accelerometer placed at the lower back would move up and down, from side to side, and forward at alternating accelerations according to these forces. The recording of these alterations in acceleration offers a means of quantifying the gait. Measures on temporal stride-to-stride variability in the gait has proven to be predictors of fall risk (Hausdorff, Rios, & Edelberg 2001). By using accelerometry, even more information on the gait pattern is recorded, and a variability in the acceleration pattern between strides will be an indicator of the gait characteristics (Moe-Nilssen & Helbostad 2005). In this study the gait characteristics were measured by a tri-axial accelerometer placed at the participant's lower back at the L3 segment. Data from the accelerometer were stored in a portable data-logger carried behind the participant by the investigator. The participant was asked

to walk a 14 meter distance on a flat floor. A trigger signal was manually activated when passing two markers on the floor. These markers were ten meters apart, and the participant would start and stop walking respectively two meters before and after the markers. In this way a steady state gait for ten meters could be evaluated upon. The walking sequence was repeated six times at different speeds, - twice at individual preferred speed, twice at fast speed, and twice at slow speed. The raw data from the accelerometer were low-pass filtered at 50 Hz once in the forward and once in the reverse direction. The data were re-oriented to a vertical–horizontal plane for each gait speed as proposed by Moe-Nilssen (Moe-Nilssen 1998a; Moe-Nilssen 1998b). Furthermore, an unbiased autocorrelation of the anterior-posterior accelerations was performed for each gait sequence which represented approximately eight strides (Moe-Nilssen & Helbostad 2004). The autocorrelation for a cyclic signal will produce peaks equivalent to the periodicity of the signal. The amplitude of the peak representing two phase shifts will relate to the variability between the strides. An autocorrelation coefficient of 1.0 would indicate that there is no variability at all between the gait strides, whereas a smaller coefficient would reflect a larger variability. The autocorrelation coefficients were averaged for the six different gait sequences. A score between 0.5 and 1.0 was converted into a 0 - 10 scale.

8. Gait cadence

Gait speed has been seen as an indicator of fall risk (Dargent-Molina et al. 1996). The gait speed is a product of step length and cadence, and more detailed information might be gathered from recordings of the cadence. Step time was estimated from the interval between autocorrelation peaks given by the accelerometer measures, and this step time was inverted into a cadence given for each gait speed. As cadence is increasing with increasing gait speed the cadence was normalized to 1.1 m/s (Moe-Nilssen & Helbostad 2004). The cadence was furthermore normalized (to a body height of 1.65m) by

the square root of the height, as cadence is inversely proportional to the square root of body size (Moe-Nilssen & Helbostad 2005). A score between 1 - 3 steps/s was inversely converted into a 0 - 10 scale.

9. Vision

Impaired vision is an important and independent risk factor for falls (Lord & Dayhew 2001). Three tests were chosen to assess the vision as a feed-forward means for planning of gait and other movements: a. Visual acuity was assessed by using poster constructed for this purpose (Landolt's C¹). It was placed at a three meter distance in a light condition at approximately 400 lux. The participant was tested binocularly wearing normal glasses for walking. The test log-scores were converted into a rank scale: $\leq 0.0 \approx$ Normal vision (3 points); $0.1 - 0.4 \approx$ Subnormal (2 points); $0.5 - 0.9 \approx$ Weak sight (1 point); $> 1.0 \approx$ Very weak sight (0 points). b. Pelli-Robson Contrast Sensitivity Test² was used to assess the participant's ability to detect contrasts. The log contrast sensitivity scores were converted into a rank scale: $\geq 1.8 \approx$ Normal (2 points); $1.36 - 1.8 \approx$ Subnormal (1 point); $\leq 1.35 \approx$ Weak (0 points). c. The visual field was tested using a confrontation test a.m. Donders (Donders 1855). The test was carried out for one eye at the time in the horizontal, the 135°, and the vertical plane. The performance was scored in ranks of 0 - 2 for each direction: $> 60^\circ \approx$ Normal (2 points); $30 - 60^\circ \approx$ Reduced (1 point); $< 30^\circ \approx$ Very reduced (0 points). A sum of these score ranged from 0 to 12, which again was ranked in three categories: $12 \approx$ Normal (2 points); $7 - 11 \approx$ Reduced (1 point); $\leq 6 \approx$ Very reduced (0 points). Data from these three tests on vision were added and presented as a common 0 - 7 score, which was converted into a 0 - 10 scale.

¹ Landolt "C" Translucent chart for 3-meter testing cat.no.2206, Precision Vision®, IL, USA.

² Pelli-Robson Contrast Chart 4K, Clement Clark Int. Ltd., Essex, UK.

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4. Fall Risk in an Active Elderly Population – can it be assessed?

(Paper II)

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5. Arguments for an Alternative Approach to Balance Assessment

Epidemiological and Methodological Considerations

As seen in paper I and II, the evaluation of the test battery in two different epidemiological designs could lead to different conclusions. This should be looked upon with great concern.

The cohort design (follow-up design) is regarded as a stronger design compared with the case-control design. In the cohort design, a possible selection bias is to a larger extent avoided. In this design, a study group is followed during a set period of time, and both the latter cases as well as the “controls” are facing the same circumstances and are influenced by the same uncontrolled factors during the follow-up period (Juul 2005). Still, a risk of intervention bias does occur in prospective studies. In our study the elderly might have become aware of potential deficits in their balance performance during the testing session, and this information may have influenced their behaviour during the follow-up period. The downside of the Cohort design is, however, mainly the time factor. The duration of the follow-up period is a difficult factor to handle in many studies, which are limited to a shorter period of time. The case-control design is therefore very popular and widely used despite its limitations.

In the case-control design firstly the cases are identified and thereafter the controls can be selected from the selected criteria set to match the case group the most. Such criteria could regard age, height, weight, gender, etc. It is, however, a challenge to identify and match all aspects which could have an influence on the outcome. In addition, it is even more difficult to match the groups if also the interaction of these aspects may be relevant.

In paper I (chapter 3) a “case group” was selected according to self reported fall history. A history of one or more balance-related falls within the last two years prior to the examination included these participants in the case-group. As a larger number of subjects had been tested in order to be evaluated for fall incidence in the follow-up period of paper II, a “control group” with no fall history could be

selected from this population of elderly. The challenge in this process was then to determine a selection strategy, which would let the selected control group match the case-group. In a non-homogeneous group, such as the one included in this study, it is inherently difficult to evaluate all relevant factors. The selected matching criteria were age and gender. With the large number of factors related to fall risk in mind, it is, however, obvious that many fall-related factors characterizing the group of fallers may have been overseen and therefore might not have been represented in the control group. In other words, the two groups might not be comparable, and when finding a difference between the two groups, this difference could be related to other factors than only those related to fall risk. As seen in the results from paper I, this could regard the differences in physical activity level and fear of falling.

Even though the selected test battery did not produce very high discrimination rates in the paper I - case control study, it was still acceptable as compared with many of the existing test batteries, which were referred to in chapter 2.

It is interesting to see that the performance of the test battery in the case control study appeared promising while the results from the cohort study changed this view.

In our review on the balance and falls literature, we found many studies presenting tests which appeared to be valid and good at predicting falls. But these expectations have not always been confirmed by prospective studies. It is often seen that good discriminative rates are presented in a case-control study design, while the following cohort studies give another picture (Boulgarides, McGinty, Willett, & Barnes 2003; Lin et al. 2004; Shumway-Cook, Baldwin, Polissar, & Gruber 1997). The Four Square Step Tests (FSST), which was included in the present test battery, can serve as an example. This test has been evaluated in a case control study with three groups of age and gender matched community-dwelling elderly including fallers with multiple falls, non-multiple fallers and healthy comparisons (Dite & Temple 2002). The reported sensitivity of 85% and specificity of 88% in identifying multiple fallers were very promising. The test compared well with other tests and the concept of the testing procedure was sound. When this test was evaluated in our follow-up study as part of the selected test battery it did, however, not provide a strong predictive contribution in this population.

The necessity for prospective studies must therefore be underlined in the evaluation of tests meant for prediction.

Choice of Research Direction

Our first study (paper I + II), in which different tests were used in the test battery for fall prediction, gave some experiences, which could lead in two directions:

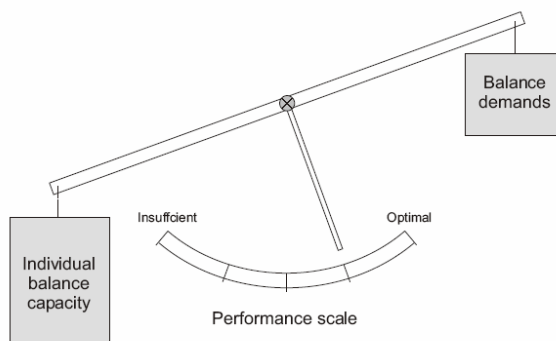
1. For the purpose of identifying elderly in risk of falling it would be relevant to find ways to characterize the demands on the postural control. When it has been realized that it is the redundancy of postural control capacity in relation to postural

performance which is crucial for the postural control, it becomes evident that both the capacity and the demands must be assessed. This was already addressed in chapter 1 and illustrated by figure 1.9. Different ways have been suggested for evaluation of the postural demands.

Interviews or questionnaires focusing on relevant items might be relevant. As an example, a three-year follow-up

study on community-dwelling elderly indicated that the presence of dogs/cats in the household, educational level, and alcoholic consumption were relevant factors to enquire about in relation to fall risk (Pluijm et al. 2006).

2. Another choice of direction could be to elaborate on the assessment strategy used to assess the individual postural control capacity. This is the direction, which was taken in the following studies of this Ph.D. project.



Alternative Strategies in the Assessment of Postural Control

In order to investigate the postural control, relevant tools for the assessment of postural control capacity are required. The wish to gain further insight into the postural control and the wish to enhance the assessment methods will therefore be adjoining one and another in the following studies.

As we discussed in the very beginning of chapter 1, the general attempt to understand the aspects of postural control is related to basic science. But in parallel to this approach we try to make use of assessment methods which can be beneficiary to the clinical practice. This position is chosen deliberately in order to facilitate the clinical applicability of the studies, and the more general character of the work should be recognized.

A Dual Task Approach to Assessment of Postural Control

Instead of testing specific individual premises for postural control we are following a system approach appreciating the complex interaction and synergism of musculoskeletal and neural systems.

For this purpose the following two studies are testing the participants in a complex (but standardized) setting, and they are assessing the postural control using rather general outcome measures. Both protocols are using a dual task approach in order to evaluate the effect of additional challenges.

Recently, focus has been directed towards the interaction between cognitive factors and motor performance when assessing the functional capacity of a patient (Huang & Mercer 2001). The use of a dual task approach is strongly encouraged by Mulder et al. (Mulder, Zijlstra, & Geurts 2002). They have argued that most tests which are used to assess physical performance allow the subjects to compensate for their deficits by utilizing other control strategies (e.g. visual and/or cognitive regulation of task performance). To reveal early signs of deterioration in the postural control system a so-called dual task assessment can be used, in which the subject must perform an attention demanding task in parallel with an automated motor task (e.g., walking). Dual task paradigms are typically used to investigate the attentional demands of a motor task and to examine the effects of concurrent cognitive or motor tasks on motor performance (Fraizer & Mitra 2007; Schmidt & Lee 2005). The latter approach is sometimes referred to as a divided attention or “time-sharing” paradigm. When one task is more demanding a greater proportion of the performer’s limited processing capacity must be allocated to this task in order maintain an acceptable level of performance (Huang & Mercer 2001). As the central processing capacity is limited, a primary task with higher attention demands will leave less residual processing capacity for a concurrent secondary task (figure 5.1). An additional concurrent attention-demanding cognitive task or motor task may therefore exceed the available resource capacity. Dual-task interference will only occur if the available central resource capacity is exceeded, resulting in impaired performance in one or both tasks (Abernethy 1988). Dual task paradigms can be used to investigate the attentional demands on walking and to examine the effects of a concurrent cognitive or motor task on walking. The competition between the attention demands of walking and a concurrent attention-demanding task may result in gait alterations (Dubost et al. 2006). By the application of this approach it should be possible to demonstrate to which degree a primary motor task is performed in an automated way (with minimal attentional requirements) leaving adequate attentional capacity for the performance of a secondary task.

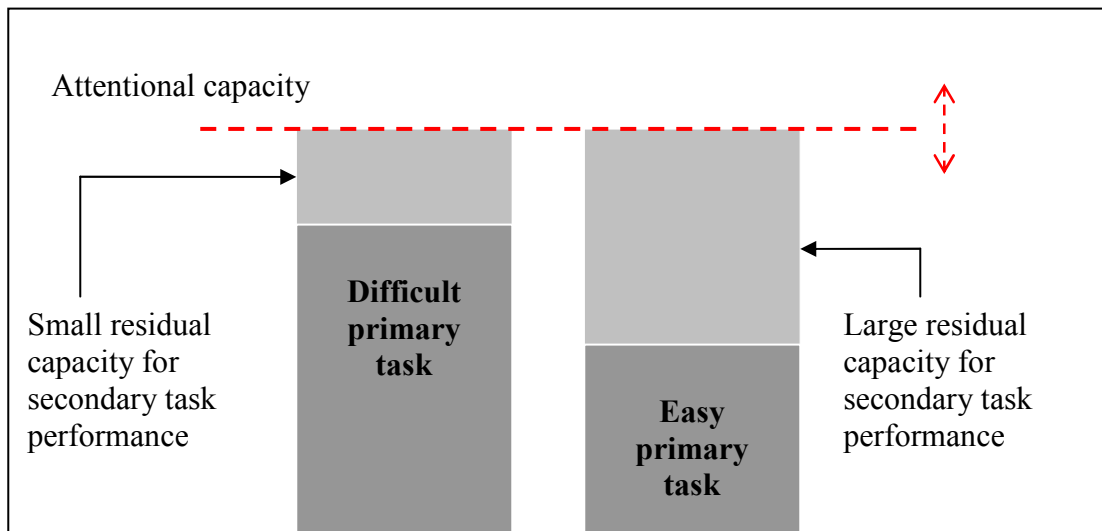


Figure 5.1. Conceptual model of a dual task approach. A difficult primary task will occupy a large proportion of the available attentional capacity leaving a limited residual capacity for a concurrent secondary task, and this may be reflected in a poorer performance in either one tasks. (adapted from Abernethy, 1988).

Voluntary movement automation is traditionally viewed as a fixation of the results from a learning process, which takes place in the motor system during repetition of a motor act. In the section on premises for postural control (chapter 1), it was described how Bernstein observed that sensory corrections and their interaction with different levels of the control system appeared to be central to movement automation (Hauvik 2000). Only high variability in automated movements allows reaching of a high accuracy when unexpected forces intrude.

The postural control is dependent on sufficient and correct information, but it is a challenge to make a selection of only the relevant information as not to be overwhelmed by excessive input. It is also important to organise the information processing in a way which allow higher cognitive functions to work more or less independently of the motor performance. When addressing automation of movement the proverb “Repetition is the mother of learning” should apparently be rephrased as “Repetition of solving is the mother of learning” as the main functional purpose of automated movement repetition, according to Bernstein, is the creation and testing of optional control tactics (Latash 1998).

The organisation of motor control takes place through motor learning. Fitts and Posner articulated a model of motor learning and attention demand which is often referred to in this aspect (figure 5.2). Their

three stages of motor learning consist of: a cognitive (verbal) stage; an associative stage (gradual decrease in errors; development of internal (sensory) reference of correctness); and an autonomous (automatic) stage (Shumway-Cook & Woollacott 2001).

The first stage requires conscious attention to each part of the movement where as the third stage leaves cognitive resources for other tasks. The movement of the first stage becomes slow, cautious, and uncertain compared with the more competent practice of the next stages.

It must be expected that the attentional capacity for a given postural control situation will be occupied to a different degree by a given motor task with respect to the degree of its automation. This will influence the residual attentional capacity which is left available for other processing tasks.

When sensory or motor deficits occur, the complex generation of movement might have to be restructured. This requires to some degree a new learning process. According to the three-stage model of Fitts and Posner, it can be suggested that the subject then will have to execute the postural control at an associative or a cognitive stage. When the benefits from the movement automation are lost, the subject is therefore more vulnerable to cognitive distractions. This will be revealed when a dual task approach is applied in the evaluation of the postural control.

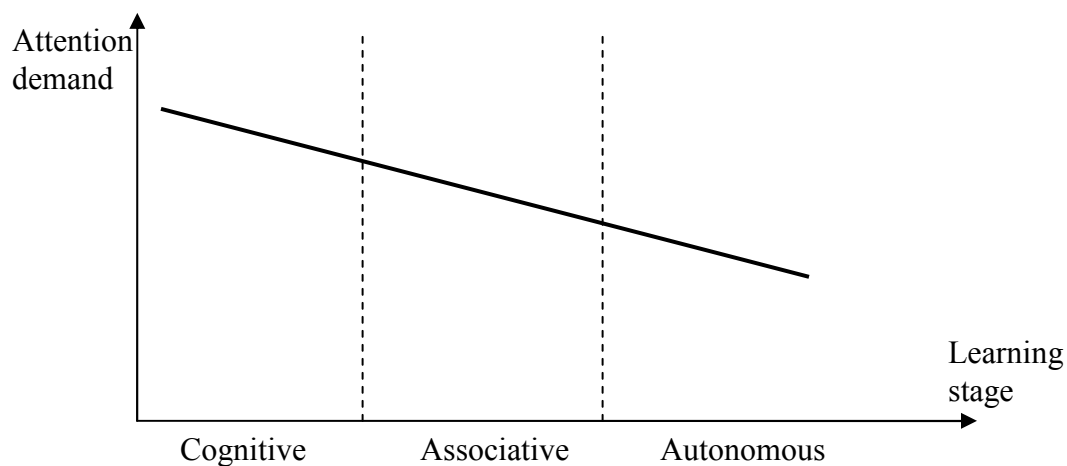


Figure 5.2. Fitts and Posner's three-stage model of attention demand in relation to motor learning.

Protocols for Alternative Approaches to Postural Control

Paper III focuses on the postural control feed-forward strategy in relation to age.

As mentioned in the section on postural control and the section on feedback and feed-forward aspects of postural control (chapter 1), an anticipatory strategy can be used when a balance threatening situation can be predicted (Ghez & Krakauer 2000; Pollock, Durward, Rowe, & Paul 2000). The anticipatory control has been illustrated in relation to sequential voluntary movements (Patla, Ishac, & Winter 2002), but also different types of rhythmic movements have a strong element of predictability.

When the balance is disturbed by a sequential perturbation, the postural control mechanisms are not voluntary in the sense that it is the body acting on the context. But if the perturbations come in a rhythmic pattern an opportunity is given to prepare for the next perturbation. However, little is known about the characteristics of anticipatory strategies and postural preparations in relation to predictable perturbations. This aspect is addressed in paper III in chapter 6.

Paper IV focuses on the automation of gait in relation to age.

Gait is an example of a movement pattern which is both a voluntary and a rhythmic movement. It offers the opportunity to plan the movement pattern not only for the next step, but also for the following steps. More fragile elderly people seem to have a decreased automation of gait and this can be related to fall risk. Institutionalized elderly persons, who are unable to maintain a routine conversation while walking, have a high risk of falling; and a test named “Stop Walking When Talking” (SWWT) can predict falls in this group of elderly people (Lundin-Olsson, Nyberg, & Gustafson 1997). In a one year follow study on community-dwelling elderly a divided attention task of similar test, “walking while talking” (WWT), had a more modest predictive sensitivity of 46% and specificity of 89% (Verghese, Buschke, Viola, Katz, Hall, Kuslansky, & Lipton 2002).

However, no clear consensus exists on the relevance of this approach as expressed in a recent review by Bloem et al.: “After the initial enthusiasm about the potential importance of dual tasking, recent observations have limited its use for fall prediction” (Bloem, Steijns, & Smits-Engelsman 2003).

We believe that the influence of the complexity of the primary motor task, used for the dual task approach, has been somewhat overlooked. A simple walking task may be automated to a level which is not vulnerable to the competition for attention from an additional cognitive task. It is likely that a dual task tests with a more complex primary motor task will be more sensitive and reveal deficits in the postural control of elderly which otherwise would be disguised. Paper IV in chapter 7 is addressing this aspect.

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6. Anticipatory postural control strategies related to predictive perturbations

(Paper III)

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7. Residual attentional capacity amongst young and elderly during dual and triple task walking

(Paper IV)

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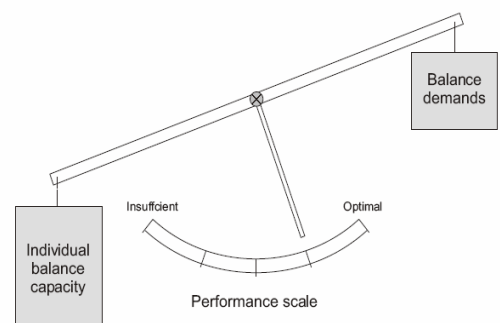
8. General Discussion

This Ph.D. project originated from a wish to contribute to the identification of elderly in risk of falling. The consequences of falls in the elderly population are often considerable including bone fractures and reduced quality of living (Bloem, Steijns, & Smits-Engelsman 2003). Fall risk can be reduced by targeted intervention, but it is difficult to identify the individuals prone to falling to whom this training should be offered (Gillespie, Gillespie, Robertson, Lamb, Cumming, & Rowe 2001). Much work has been done within this field with respect to the description of fall risk factors and to the construction of tests identifying fallers (AGS Panel on Falls Prevention 2001).

The fall risk evaluation of the individual is often initiated after the first fall accident, but it remains a challenge to pre-empt this accident (Tinetti 2003). Focus has not been directed towards the population of relatively healthy and active community-dwelling elderly who are normally not regarded as fragile. We believed that we could contribute to the fall risk prediction in this population by suggesting a test-battery which incorporated tests targeting the characteristics of this group. We selected relatively challenging tests including tests on feed-forward strategies and dynamic balance components as seen in specific tests on gait performance.

The test battery was validated with little success in relation to fall prediction in a population of 96 community-dwelling elderly. It was possible to discriminate between elderly with and without a history of falling (paper I), but the test battery had no predictive capability (paper II). The findings indicate that an assessment of physiological characteristics alone cannot provide sufficient information in order to

identify individuals in risk of falling. It may be possible to characterize groups of people as having a physiological profile related to increased fall risk, but when it comes to identification of specific individuals as prone fallers, it is necessary also to evaluate the postural demands of their lifestyle. A certain safety margin is necessary, which can be expressed as the magnitude of the complementary postural control capacity in relation to the postural demands. We presented a simple model to illustrate



this conception (figure 1.9). Future studies may find a fraction between capacity and demands which can characterize people in fall risk. However, it still remains a challenge to assess these parameters.

During the evaluation of the test battery we were encouraged to investigate the influence of motor planning on postural control. Our hypothesis was that a good postural control during activities like walking requires feed-forward strategies. Motor planning is exercised through motor learning to an automated level at which cognitive resources become available for concurrent activities.

When a person wishes to cross the street, he must be able to walk relatively fast, to cope with the curb on each side of the street, and to look out for the traffic. At the same time he might try to keep up a conversation and handle some groceries. If his postural planning is less automated there may not be sufficient residual attentional capacities for all tasks and increased fall risk can be the result. We found that this could be a relevant aspect to consider when addressing the fall risk amongst this group of elderly.

Dual task assessment can be used to evaluate automation of the postural control (Mulder, Zijlstra, & Geurts 2002). We used this approach to evaluate age characteristics in the feed-forward strategies in two protocols. One protocol focused on proactive postural control during predictable perturbations in standing position, and the other protocol focused on complementary postural control capacity during walking.

It was observed that proactive postural control strategies are used by young and elderly to adjust for predictable perturbations (paper III). An increased proactive strategy was chosen in both groups when challenged by a dual task. This could be seen as a safety strategy based on an implicit knowledge that vulnerability to disturbances is increased, when full attention cannot be given to the postural control. The findings indicate that it is relevant to include the aspect of feed-forward strategies in the assessment of postural control.

When the postural control capacity was challenged in a dual task approach during walking, the gait pattern was more affected by the concurrent task for the elderly than for the young (paper IV). The results from the latter study indicate that there are in fact characteristics in the postural control capacity, which can be ascribed to age.

The task of fig.8-walking challenges the feed-forward strategies of the postural control, and findings of age-related differences in the vulnerability to a secondary task must indicate that the elderly perform this task in a less automated way. The reason for this may be ascribed to deterioration in the mechanisms

making basis for the postural control (e.g. loss of sensory integration, delayed processing, altered muscle mass leading to re-organization of the neuromuscular control, etc.).

These findings support the view that impaired postural control capacity is one factor which could be related to the increased fall risk amongst elderly. This factor is therefore relevant to assess when trying to identify individuals in increased fall risk.

As described earlier, the "Stop Walking While Talking" test has proved useful in assessment of fall risk in institutionalized elderly (Lundin-Olsson, Nyberg, & Gustafson 1997). Similarly, a "Walking and Counting" test which used 20% speed reduction as a cut-off value showed some success in identifying fallers amongst elderly attending a medical clinic (Gulich & Zeitler 2000). The elderly population included in our studies comprised of active community-dwelling elderly, and these elderly were included without using their relation to the health care system as a mean of contact. The physical activity level of this population was therefore taken into consideration, and a more challenging approach was chosen for assessment of the postural control.

The results from paper IV suggest that a dual task test is a clinical feasible way of assessing postural control capacity also amongst active and healthy elderly. This approach seems to reveal early deficits in the postural control as would be expected with age. An approach should be set up according to the following guidelines:

A sufficiently challenging basic motor task should serve as a "pre-load" on the postural control system. This pre-load should be supplemented by one or more concurrent tasks in order to see response in performance outcome measures. Relevant performance measures must be selected. The residual attentional capacity for postural control will be reflected in either the motor performance measures in relation to a given concurrent task or by the amount of additional load, which can be handled, before a collapse of the postural control.

Conclusions

In the following the findings of the presented studies are listed point by point.

In relation to fall prediction we have seen:

- Inclusion of dynamic balance measures in a test battery did not provide discriminative power in relation to fall prediction in an active population of community-dwelling elderly

- A test battery consisting of tests on physiological characteristics related to postural control can to some extent discriminate between community-dwelling elderly with and without a fall history (paper I)
- The same test battery cannot be used as the sole instrument for evaluating fall risk and predicting future fall events in this population (paper II)
- When assessing fall risk in a community-dwelling population of active elderly, we believe it is necessary to estimate the risk level of individual lifestyle as well as the individual physical capacity related to fall risk (paper II)
- The different conclusions, which could be made in paper I and II regarding the value of the test battery, illustrate the importance of using a prospective study design in the evaluation of tests meant for fall risk prediction in order to obtain correct estimates on nosography and predictive values

In relation to postural control we have seen:

- The postural control during predictive rhythmic perturbations improves with repetitions (paper III)
- Pro-active (feed-forward) postural strategies are present in predictable rhythmic perturbations (paper III)
- These proactive postural strategies are affected by a concurrent cognitive task (paper III).
- We believe that the anticipatory adjustments are used as a compensatory safety strategy which is relevant for keeping balance

As in rhythmic perturbations a feed-forward strategy can be assumed to exist also in the voluntary rhythmic movements of gait. Gait is most often believed to be an automated function which is robust to dual task challenges, but walking in a figure-of-eight may be less automated. When using this task as a basic motor task in a dual task approach, we have seen:

- The gait speed of both young and elderly is affected by a concurrent manipulation task (paper IV)
- The gait speed and variability of elderly are affected by a concurrent cognitive task (paper IV)
- Elderly are more affected by a cognitive task than young people. We believe this observation reveals a poorer automation of the gait function amongst the elderly in this motor task (paper IV)

As parallel observations we ascertain that:

- A dual task approach is relevant to reveal minor postural deficits as seen in normal ageing (paper IV)
- A sufficiently challenging basic motor task is necessary when trying to reveal minor deficits in generally healthy individuals by using a dual task approach (i.e., the summarized load of the motor performance task and the concurrent task must be sufficient in order to challenge the postural control and reveal a possible lack of residual attentional capacity) (paper III and IV)

Perspectives

Assessment of Postural Control in Gait

The challenge of assessing postural control during walking has led to many solutions. One of the more promising assessment methods is the evaluation of gait variability.

The organisation of a steady gait requires a fine-tuned feed-forward system, which again relies on a well-functioning feedback system. During gait a loss of steadiness could be regarded as a kind of stepping response which becomes necessary when the motor control or motor planning in some of the previous steps has been insufficient. It is understood that a smooth and steady gait is the result of a successful postural planning and execution. A successful gait depends on many factors:

- Adjustment of the swing phase as to clear the foot off the ground and adjust the forces for the heel contact situation
- Adjustment of the medio-lateral load onto the supporting leg in the stands phase
- Adjustment of vertical and anterior-posterior forces in the stands phase
- Adjustment of push-off forces before the toe-off period
- Control and minimization of the forces in the body as a whole
- Adjustment of movements in relation to optimizing cost-benefit of the locomotion

Any deviation in the gait control will somehow be reflected in the gait rhythm. Therefore, a gait pattern, which needs to be corrected from step to step or from stride to stride, reveals a less successful postural control and motor planning.

Elderly have been described to use shorter step length (Menz, Lord, & Fitzpatrick 2003a; Winter et al. 1990). However, this must be seen in the perspective of the studies on elderly fallers and non-fallers which have found that stride variability is associated with fall risk while gait speed, stride length, and stride time are not (Hausdorff, Edelberg, Mitchell, Goldberger, & Wei 1997; Hausdorff, Rios, & Edelberg 2001; Maki 1997). It has been observed that gait speed and stride length were significantly related to fear of falling, but not to fall risk (Maki 1997). In contrast, stride length variability is associated with fall risk, but not with fear of falling.

It is likely that a person in fear of falling wishes to reduce the postural control demands by reducing stride length and gait speed. He will therefore be less prone to falling, and there will be no relation between these parameters and fall risk. When addressing fall risk the gait variability has therefore been the more interesting aspect to study.

Gait Variability

Gait variability can be expressed as temporal or spatial variability, and these characteristics can be measured in many different ways. A wide gait pattern would not necessarily be shown in the temporal measures, but when it comes to variability there is a close connection between the temporal and spatial parameters. A spatial variability will also be seen in the temporal variability and vice versa.

The spatial gait parameters are the mere obvious phenomena to measure when assessing gait instability, and they have been the subjects for studies for many years. The information on the spatial parameters used to be difficult to retrieve, but the development in technology has removed some barriers within this research area. Footprint recordings used to be carried out by letting subjects walk on paper while having ink under soles of their feet, but these methods have now been replaced by electronic walking mats, etc. Simple measures of foot placement include relevant information on the disturbed spatial steadiness in two dimensions. More advanced recordings can be carried out by gait analysis using 3-D video recordings of reference markers on the body, and also these data are nowadays more easily collected and computed.

Gait variability has, so far, not been the main focus of interest within this field, but this may change with the feasibility of the technology. As an example, one spatial variability study on elderly adults showed that step-length variability was greatest and step-width variability was smallest in those who walked the slowest (Brach et al. 2001).

Many measuring methods for spatial parameters include parallel measuring of time, but also measures of temporal factors alone are relevant. The assessment of temporal steadiness alone seems to be an informative approach to the early signs of deteriorated postural control (Hausdorff 2005).

The temporal parameters seem easily assessed and can be measured quite precisely. Force sensitive foot contacts have provided sufficient information for evaluating temporal gait characteristics, but also more sophisticated methods can be used.

Accelerometers have been used to characterize speed change for different reference points of the body. Placed on the shank an accelerometer will indicate heel contact from one foot as a temporal measure. Placed on the trunk or head it will indicate the speed changes derived from the ground contact and the movement of trunk and extremities during the gait cycles (Auvinet et al. 2002; Zijlstra & Hof 2003). In this way these methods will contain a conglomerate of the kinetics and kinematics of the body. It is therefore likely to be a very informative measure, but the signal is difficult to interpret in all its aspects.

The temporal stride to stride variability shows characteristics linked to maturation and deterioration of postural control. A decrease in temporal variability in relation to age can be seen when comparing the gait of children in the age of 3-4, 6-7, and 11-14 years (Hausdorff, Zeman, Peng, & Goldberger 1999). In addition, an increased variability is seen in the gait of elderly subjects (Buzzi et al. 2003; Hausdorff, Edelberg, Mitchell, Goldberger, & Wei 1997; Menz, Lord, & Fitzpatrick 2003a).

One major reason that temporal variability has gained so much interest is probably, that it has proven a close relation to fall risk (Hausdorff 2005; Hausdorff, Rios, & Edelberg 2001; Menz, Lord, & Fitzpatrick 2003b).

Alternative Methods for Evaluation of Gait Variability/Stability

A common way of analysing the variability of a signal from a gait measurement is to use mean and standard deviation of specific signal characteristics (e.g., first peak at heel contact) in the expression of a variance coefficient (SD/mean %). This measure has proven valid in many of the studies on elderly (Hausdorff et al. 2001; Mbourou, Lajoie, & Teasdale 2003). Some information on the fluctuation of the signal can, however, be lost by using this method.

A way of analysing the variability of an accelerometry signal is to perform an autocorrelation in which a certain number of steps are evaluated by phase shift (Moe-Nilssen & Helbostad 2004). This method

reveals some aspects in the fluctuation of the signal, but it is vulnerable to variation in the number of gait cycles included in the analysis.

The two analysis methods mentioned above have both been used in many studies including the present studies, but alternative methods might also be considered for future studies.

Slifkin et al. have illustrated that three different ways of analysing signals (frequency distribution; x_1 -to- x_{t+1} plots depicting lag-1 autocorrelation; and autocorrelation) reveal different information about the same signal (Slifkin & Newell 1998). In the same paper it was also suggested that examination of “approximate entropy” might be a relevant way to characterize the structure of a biological signal. The use of approximate entropy has also been suggested for analysing gait data (Buzzi & Ulrich 2004). Approximate entropy estimates the degree of predictability (order) of future values in a time series from previous values. A high degree of predictability, i.e. less noisiness, will be reflected by low entropy values. In this way the entropy will be a measure of disorder.

A normal walking pattern has a certain rhythm and order. If the gait is disturbed, then the increased disorder will be characterised by an increase in entropy. Very low entropy does, however, not necessarily reflect a positive condition. Studies on heart rhythm variability have shown that patients with congestive heart failure have a heartbeat pattern with low entropy (Costa, Goldberger, & Peng 2005). A normal biological signal is seldom very stereotypic, and a natural variation in the gait pattern must be expected. It is therefore not trivial to interpret an entropy estimate in order to evaluate whether a gait should be accepted as normal.

An interesting view has evolved in relation to the use of dynamic gait variability analysis. It can be seen that patients with gait disabilities as well as healthy people walking on ice will slow down their walking speed to improve stability. However, it is also seen that slower walking speed leads to increased gait variability. This is a schism, and Dingwell et al. have questioned whether static variability analysis reveals the stability of the gait (Dingwell & Marin 2006). They argue that measures of gait variability may be a clinically valid predictor of future falls, but that these measures do not quantify how the neuromuscular control system responds to perturbations, and they can therefore not provide direct measures of stability itself. It is suggested that nonlinear time series analysis is better at revealing aspects of gait stability. Dingwell et al. are operating with the term “local dynamic stability” which indicates the resilience of the locomotor system to the infinitesimally small (i.e. “local”) perturbations occurring naturally during walking. It must be noted that they are not addressing the capacity of the system to respond to larger perturbations, such as tripping or slipping, which they call “global stability”.

In nonlinear time series analysis an attractor can be derived from a given signal with a time delay embedding in two, three or even more dimensions and with specified time lags. As an example, the values from three points of the signal can be used as coordinates for a geometric representation of the signal in three dimensions. The three points have a fixed interval (time delay), and they are moved stepwise from frame to frame through the entire time span of the signal. An example of an attractor representing an anterior-posterior trunk acceleration signal is presented in figure 8.1. By advanced mathematics this attractor can be characterized by a Lyapunov exponent (Dingwell & Marin 2006).

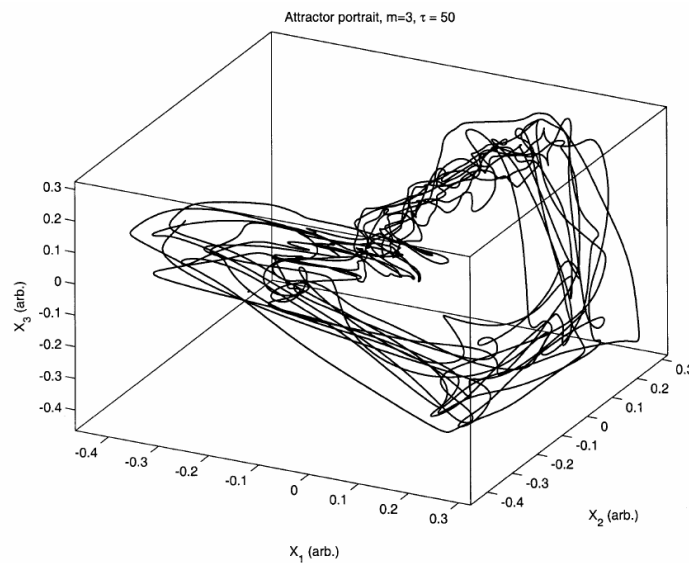


Figure 8.1. An anterior-posterior trunk acceleration signal illustrated by its attractor with a time delay of 50 ms ($\tau=50$) embedded in three dimensions ($m=3$).

The choices of embedding dimensions and time lags are not trivial, however, and the choices will influence the results of the analysis. These choices can therefore be guided by different methods: “global false nearest neighbors” can be used to evaluate the relevant embedding dimension, which depend on the complexity of the signal; and “mutual information” can be used to evaluate the relevant time lag, which depends on the fluctuation speed of the signal (Cellucci, Albano, & Rapp 2003).

Dingwell et al. studied the gait, characterized by three-dimensional movements of a marker placed over the first thoracic vertebra, for eleven young subjects walking on a treadmill at different speed (Dingwell & Marin 2006). In relation to gait speed they found a U-shaped trend for mean standard deviations, but a linear trend for the derived Lyapunov exponents. Stability expressed by this exponent suits the intuitive

understanding that the purpose of decreasing the gait speed is higher stability. Variability and stability may therefore be two different aspects of the gait.

Future studies may further validate this approach to the analysis of gait signals and improve the understanding of the outcome measure.

As emphasized in the introduction to this thesis, we have used quite simple outcome measures reflecting a complex interaction of many elements. When trying to understand the postural control, we must evaluate and interpret these outcome measures in a way which reveals relevant aspects of the underlying factors. The new initiatives regarding signal analysis in relation to gait data therefore become highly relevant.

Clinical Directions

In the introduction it was described how the problem presented by a given patient in the clinic often must be handled as a “black box”. We have operated with this template in relation to the assessment of the postural control capacity. We have seen differences in “output” according to different “input”, and we have seen some differences between “the black box” of young and elderly people. We found that the dual task approach was promising in this respect. The combination of concurrent tasks provides a “load” on the system, and the capacity of the system will be reflected in the “output”.

The presented studies have therefore the following clinical aspects:

- The approach to fall risk prediction among community-dwelling elderly should include an evaluation of both the postural control capacity and the postural control demands (i.e. risky lifestyle)
- A dual task approach is relevant for assessing postural control, but the motor task must be adjusted in complexity in relation to the functional level of the target group

The future will probably provide new technological methods for measuring, and more advanced analyzing techniques may refine the interpretation of the outcome measures. Interaction between different branches of science will most likely provide a deeper insight into the human motor control and lead to new approaches to the assessment of postural control. The ultimate goal for all these efforts must be to let the results benefit the patients and other people with postural problems.

The practical experiences and the knowledge we have gained through this Ph.D. project, and especially the work with the protocol leading to paper IV, have inspired us to suggest ideas for a new clinical test. We would therefore like to end this thesis by presenting the following concrete outline for a clinical test for this population.

The test might show similarities to tests like the “Timed Up and Go test with cognitive task”, which has not contributed to fall prediction (Shumway-Cook, Brauer, & Woollacott 2000). However, we do believe that the presented test suits the more active population in a better way.

Test suggestion:

Procedure:

- A figure-of-eight track with the dimensions 5 x 2 meter is marked on a flat floor
- The patient walks the track 3 x 5 times at self-selected comfortable speed
- After ten rounds a concurrent cognitive task is introduced. The cognitive task consists of fast subtractions of seven from a three digit number spelled out loud.
- The first five rounds are used to allow familiarizing with the task (automation); following five rounds are representing single task condition, and the last five rounds are representing dual task condition

Outcome measures:

- Time to complete five full round are measure by a stopwatch (gait speed)

Analysis:

- Gait speed is compared for single and dual task performance and expressed as relative speed reduction

We find that this test would be clinically applicable. However, much work needs to be done before a new test can be utilized. The reliability and validity must be evaluated, and cut-off values in relation to a norm material need to be estimated.

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Summary

The overall purpose of this Ph.D. project was to identify clinically relevant quantitative parameters as to predict fall risk in an elderly population. The specific aim of the studies was to find methods to identify balance and gait characteristics for the assessment of postural control. The target population was community-dwelling elderly who were not regarded as fragile.

The first approach implied the development of a test battery consisting of existing tests covering fall related aspects of postural control. The test battery was validated with little success in relation to fall prediction in a population of 96 community-dwelling elderly.

It was concluded that assessment of physiological factors alone cannot identify fall risk in this relatively active and healthy population. The postural control capacity must be evaluated in relation to the individual level of risky lifestyle.

The second approach implied an investigation of age characteristics in specific aspects of postural control. Dual task assessment was used to evaluate automation of the postural control in two protocols. One protocol focused on proactive postural control during predictable perturbations in standing position, and the other protocol focused on residual attentional capacity during walking.

It was concluded that feed-forward strategies seem to play an important role in the postural control. The automation of postural control during walking is affected by age, and early deficits can be revealed by dual task testing. These findings indicate that it is relevant to develop clinical tests based on a dual task approach for assessing early signs of deterioration in postural control.

Fall risk assessment in this population should therefore include an assessment of the individual postural control based on challenging test including dual task tests evaluated in relation to an estimate of the postural demands of the individual lifestyle

Danish summary / Dansk sammendrag

Det overordnede mål med dette Ph.D.-projekt var at identificere klinisk relevante kvantitative parameter, der kunne bidrage til at vurdere faldrisiko blandt ældre. Mere specifikt var målet at finde metoder til at identificere balance- og gangkarakteristika som udtryk for postural kontrol. Målgruppen var friske hjemmeboende ældre.

Første del af studiet omfattede udvikling af et testbatteri bestående af allerede eksisterende test af faldrelaterede aspekter af den posturale kontrol. Testbatteriet blev vurderet i forhold til dets evne til at forudsige fald blandt 96 hjemmeboende ældre, og det viste sig ikke at være brugbart hertil. Det blev konkluderet at faldrisiko i denne gruppe af relativt aktive og raske ældre ikke kan bestemmes alene gennem en vurdering af fysiologiske faktorer. Evnen til posturale kontrol bør vurderes i relation til individuelle risici i den enkeltes livsstil.

Anden del af studiet omfattede en undersøgelse af alderskarakteristika indenfor bestemte områder af den posturale kontrol. Graden af automatisering af den postural kontrol blev vurderet ved anvendelse af en ”dual task” tilgang i to forsøgsprotokoller. En protokol fokuserede på proaktiv postural kontrol under forudsigelige forstyrrelser af den stående stilling. En anden protokol fokuserede på den overskydende kapacitet til ekstra udfordringer under gang.

Det kunne konkluderes, at feed-forward strategier synes at spille en rolle i forbindelse med postural kontrol. Alder har indflydelse på automatisering af den posturale kontrol under gang, hvilket kommer til udtryk i ændrede gangkarakteristika i forbindelse med ”dual task”. Disse fund indikerer, at det er relevant at udvikle kliniske tests baseret på en dual task tilgang med henblik på at vurdere tidlige tegn på forringelser i den posturale kontrol.

Vurdering af faldrisiko i denne population bør således omfatte en vurdering af den enkeltes posturale kontrol baseret på udfordrende tests, der inkluderer dual task test, sat i forhold til en vurdering af de postural krav, som den enkeltes livsstil lægger op til.