JOURNAL OF SPORTS SCIENCE & MEDICINE

VOL.4 SUPPLEMENTUM 8 2005

BALANCE ABILITIES OF WORKERS IN PHYSICALLY DEMANDING JOBS: WITH SPECIAL REFERENCE TO FIREFIGHTERS OF DIFFERENT AGES*

Anne Punakallio

Department of Physiology, University of Kuopio, Department of Physiology, Finnish Institute of Occupational Health, Kuopio, Finland

* Doctoral dissertation presented on the 5th November 2004 at the Large Lecture Hall of the Haartman Institute, Helsinki, Finland by permission of Faculty of Medicine of the University of Kuopio, Finland.

PREFACE AND ACKNOWLEDGEMENTS

This study was carried out at the Finnish Institute of Occupational Health in the Department of Physiology. I wish to thank Professor Juhani Ilmarinen, the Director of the Department of Physiology, for placing the facilities of the Institute at my disposal.

I would like to express my deepest gratitude to my supervisor, Professor Veikko Louhevaara from the Finnish Institute of Occupational Health and the University of Kuopio, for his valuable comments and support throughout this study. Especially his encouragement during the writing process and the last stages of this work has been invaluable to me.

My most sincere thanks are also due to my supervisor, docent Pertti Era of Metitur Ltd, for his time and professional insight into the area of studying balance abilities. Despite the many other demands on him, he found time to constructively criticize my manuscripts and participate in long stimulating discussions, both of which crucially contributed to my work.

Professor Rolf Moe-Nilssen of the University of Bergen in Norway and Professor George Stelmach from the Motor Control Laboratory of the Arizona State University in the United States acted as the official reviewers of my dissertation, and I gratefully acknowledge their significant comments on the final manuscript.

My special thanks go to my co-author Sirpa Lusa, who I want to single out for our profound discussions, friendship and her encouraging support. Warm thanks go also to my co-author, Ritva Luukkonen, for her valuable advice and assistance with the statistical analyses and also for her support. I am grateful to Raoul Grönqvist and Mikko Hirvonen for their collaboration during the measurement and writing process of study III. They introduced me to slip and fall research. I also owe many thanks to Risto Toivonen for his kind help and advice on the technical aspects of balance measurements.

I am especially indebted to Arja Töyry, Tuija Toikka and Marja-Riitta Suikki for their expert work with the balance measurements, and also to the entire staff of the functional capacity laboratories in the Unit of Work Physiology in the Finnish Institute of Occupational Health and the Kuopio Regional Institute of Occupational Health for their help in performing the other laboratory measurements. I particularly wish to thank Olli Korhonen, Kaarina Eklöf and Harri Lindholm. My thanks also go to all the staff members of the Department of Physiology. I owe Georgianna Oja special thanks for her detailed and flexible advice in correcting the English language of the original articles and the summary of the thesis. Maija Jokinen, Hanna Koskinen and Seija Reponen added their experience in drawing the figures, and Hannele Törni in editing the first article.

Tiina Pohjonen deserves my thanks for her supporting friendship and enlightening discussions, which particularly directed me to define the topic of my thesis. I am grateful also to Maritta Österberg for her help with the references and to all my other friends and relatives for their long-suffering support.

The approving attitude of the heads of the fire brigades, as well as the flexible arrangements they provided, ensured the success and high quality of the measurements. Special thanks go to all the firefighters from Southern and Middle-Finland, as well as to the construction, home care and nursing workers who participated in this study. They made this thesis possible. I appreciate the intellectual support of the executive committee of the Association of Occupational Health Physicians in Rescue Services. Especially, I wish to thank Saila Lindqvist-Virkamäki for her friendship and trust in my work.

This study was financed by the Fire Protection Fund of Finland, the Finnish Work Environment Fund and the Finnish Institute of Occupational Health. A personal grant was obtained from the Finnish Work Environment Fund for the writing process. The Association of Occupational Health Physicians in Rescue Services also financially supported the preparation of the summary of the thesis. I thank these organizations for providing the resources necessary for this work.

Finally, dear Jarmo, thank you for your loving support and patience during these years. Your optimism and the smiles of our daughters have ensured my motivation and showed me what is really meaningful in life. My nearest and dearest Jarmo, Iina and Elli, you are the most precious to me.

Helsinki, September 2004

Anne Punakallio

ABBREVIATIONS

A/D	Analogue-to-digital
APA	Anticipatory postural adjustment
BOS	Base of support
CI	Confidence interval
CNS	Central nervous system
COG	Center of gravity
COM	Center of mass
COP	Center of pressure
EMG	Electromyographic
FPE	Fire-protective equipment
ICC	Intraclass correlation coefficient
LoA	Limits of agreement
LOS	Limits of stability
OR	Odds ratio
PWA	Physical work ability
RCOF	Required coefficient of friction
SCBA	Self contained breathing apparatus
SD	Standard deviation
SEM	Standard error of the measurement
WAI	Work ability index

This review is based on the following original publications, which will be referred to in the text as Studies 1-5:

1. Punakallio, A. (2003) Balance abilities of different-aged workers in physically demanding Jobs. *Journal of Occupational Rehabilitation* **13**, 33-43.

2. Punakallio, A., Lusa, S. and Luukkonen, R. (2003) Protective equipment affects balance abilities differently in younger and older firefighters. *Aviation, Space, and Environmental Medicine* **74**, 1151-1156.

3. Punakallio, A., Hirvonen, M. and Grönqvist, R. Slip and fall risk among firefighters in relation to balance, muscular capacities and age. *Safety Science* (submitted).

4. Punakallio, A., Lusa, S. and Luukkonen, R. (2004) Functional, postural and perceived balance for predicting the work ability of firefighters. *International Archives of Occupational and Environmental Health* **77**, 482-490 (in press).

5. Punakallio, A. (2004) Trial-to-trial reproducibility and test-retest stability of two dynamic balance tests among male firefighters. *International Journal of Sports Medicine* **25**, 163-169.

CONTENTS

Punakallio, A. (2005) Balance abilities of workers in physically demanding jobs. With special reference to firefighters of different ages. *Journal of Sports Science and Medicine* **4, Suppl. 8,** 1-47.

ABSTRACT

The objectives of the present study were to investigate the associations between balance abilities and age, occupation and the use of fire-protective equipment (FPE) in different visual conditions, and the associations of slip and fall risk with balance abilities among workers in physically demanding jobs, especially among workers in fire and rescue work. The reliability and predictive values of balance tests in respect to perceived work ability were also studied. The professional firefighters aged 30 to 56-years (n = 29-135), construction workers (n = 52), home care workers (n = 66) and nursing workers (n = 51) aged 23 to 61 years participated in this study. The data were obtained with balance tests with the use of a force platform, functional balance tests, slipping tests and questionnaires. In one study the balance tests were carried out with and without FPE. The slipping tests with FPE were carried out on a straight 8-m long path that had one area covered by water and detergent or glycerol. Perceived work ability at baseline and after a 3-year follow-up was determined with the use of the work ability index (WAI). In the reliability study, the dynamic balance tests were repeated six times in two testing periods at an interval of 2 months. The results indicated that the balance abilities of firefighters over 49 years of age were significantly poorer than those of firefighters in the age groups of <40 and 40-49 years. The decline of balance abilities among construction, home care and nursing workers was not as consistent. Postural balance was also more harmfully affected among the older firefighters (43-56 years) than among the younger ones (33-38 years) by the use of FPE without visual input. Self-contained breathing apparatus was the most significant single piece of FPE to impair balance in both groups. Furthermore, fast and controlled performance in the dynamic stability test based on visual feedback was related to smaller slip and fall risk with FPE in both age groups. The older firefighters tended to have longer and more serious slips than the younger ones. In addition, the construction workers were significantly faster and made fewer errors than the firefighters in the functional balance test. Among the firefighters, poor performance on the balance tests significantly predicted a reduced WAI after a follow-up of 3 years. The dynamic stability and functional balance tests showed reasonable reliability, especially when the reliability was estimated from the best of at least three repeated trials. The present results suggest that balance abilities should be taken into account in follow-ups of the work ability of firefighters, as well as in the organization of work tasks and the development of the characteristics of FPE. It is also essential to provide ample balance training opportunities for firefighters with and without FPE. The balance assessments of the present study can be included when prerequisites of work ability are evaluated and followed-up for firefighters.

KEY WORDS: Musculoskeletal equilibrium, posture, aging, occupations, rescue work, protective devices, risk factors, occupational exposure, comparative study, cross-sectional studies, follow-up studies, reproducibility of results.

1. INTRODUCTION

The ability to balance is a basic element of daily activity. Due to the high balance demands, sufficient balance abilities are especially important in physically demanding jobs, such as firefighting. Roof work, smoke-diving or the handling of patients and heavy tools are examples of typical tasks carried out in fire and rescue work, in which good individual balance ability can be critical for safe and efficient work performance. Temporary and difficult work conditions and the use of protective equipment further increase the challenges placed on the balance control system. Balance abilities play an important role also in other dynamic physical occupations that include the handling of heavy objects and locomotion in complex environments. High balance demands of a particular type of work may also develop balance abilities, but only a couple of studies have compared the balance abilities of people in different jobs. For instance, construction workers working on high buildings have been shown to sway less than people not engaged in physical work (Gantchev and Dunev, 1978).

The workforce is aging globally. For example, the mean age of Finnish fire and rescue, construction, home care and nursing workers is 39, 41, 45 and 41 years, respectively (Tilastokeskus, 2003). Most studies of age-related differences in balance have shown that older people are less stable than younger ones. In physically demanding jobs, balance demands are, however, equally high for workers of different ages. Moreover, age-related problems in balance control may increase accident risk (Gauchard et al., 2001). The risk increases when visual or proprioceptive inputs are disturbed due to challenging work conditions. Fall victims have been shown to have poor balance control, particularly with their eyes closed (Vouriot et al., 2004). Limited data are available about the age and balance abilities of workers in specific physically demanding jobs. Thus far, only one study, that of Pohjonen (2001a), has reported the age-related declines in functional balance among home care workers.

Furthermore, accidents requiring three or more days of sick leave as a result of lose of balance because of slips, trips and falls on level surfaces or falls and jumps from upper to lower levels have been reported to account for considerable proportions of work-related accidents among certain groups of workers in Finland, for example, for 30% and 6% among firefighters, for 22% and 12% among construction workers and for 25% and 3% among workers in health and social services, respectively (Tilastokeskus, 1996-2001; Tilastokeskus, 2002). The corresponding proportions for Finnish workers in general are clearly lower (20% and 8%) among men and higher (33% and 4%) among women (Tilastokeskus, 2002). Slips, trips and falls account for 20% to 40% of disabling occupational injuries in Sweden, the United Kingdom, and the United States (Courtney et al., 2001). Moreover, compared with younger workers, workers over 45 years of age have a greater number of slip-, trip- and fall-related accidents (Kemmlert and Lundholm 2001, Tilastokeskus, 2002).

Good balance control in relation to a specific task may also promote health and work ability. Pohjonen (2001a) showed that poor balance is a strong predictor of reduced work ability among home care workers and suggested that, in addition to tests of muscular capacities, balance tests should be included in evaluations of the work-related fitness of home care personnel. Several field and laboratory methods are available for evaluating balance abilities, but their relevance and validity to evaluate balance among active working populations with high balance demands have not been established, and, in most cases, their reliability has not been studied according to current recommendations.

This study aimed at investigating associations between balance abilities and age, aspects of work demands and workers' safety in physically demanding jobs, and it especially focused on firefighters. The reliability and predictive value of balance tests in respect to perceived work ability were studied also.

2. REVIEW OF THE LITERATURE

2.1. Concept of balance control and the measurement of balance

Balance is a complex motor skill that describes the dynamics of body posture in preventing falling. Balance control can be examined from neurophysiological, biomechanical, and functional perspectives depending on the goals of the study. There is, however, no solid consensus regarding the definition of balance control or globally approved "gold standards" for measuring it (Berg, 1989; Ekdahl et al., 1989; Pollock et al., 2000). Definitions of balance vary according to the scientific background of the research team using them, and measurements depend on what information is needed and why. The terms “equilibrium”, “postural stability” and “postural control” are used as synonyms for balance control (Horak, 1987; Karlsson and Frykberg, 2000; Shumway-Cook and Woollacott, 1995).

From a neurophysiological perspective, balance studies involve the interaction of different levels of balance control mechanisms, whereas, biomechanically, balance can be defined as the ability (balance ability) to maintain or return the body's center of gravity (COG) within the limits of stability (LOS), as determined by the base of support (BOS) (i.e., the area of the feet) (Horak, 1987; Nashner, 1997). Balance is related to the inertial forces acting on the body and the inertial characteristics of body segments. Furthermore, the LOS are the boundaries of an area of space in which the body can maintain its position without changing the BOS (Nashner, 1997).

The ability to maintain COG within BOS is a typically used definition of "static balance". The term “static” is, however, imperfect, as it ignores the minor automatic adjustments that occur continuously when a body maintains a stable position (Berg, 1989). Furthermore, it is the same organ system that is involved in regulating posture in static and dynamic conditions. Mechanisms and strategies for balance control can act differently, however, in static and dynamic tasks. For example, during quiet standing, balance is usually controlled by the ankle strategy, whereas ankle muscle activity alone is insufficient to maintain balance during walking (Winter, 1995; Woollacott and Tang, 1997). This is one reason for the low correlations between static and dynamic balance tests (Patla et al., 1990; Shimada et al., 2003; Tsigilis et al., 2001). Definitions of static and dynamic balance may, however, be useful when the character and goal of the tool measuring individual balance ability is described.

In static balance tests, the aim is to keep the center of pressure (COP) of the body as immobile as possible within the BOS during standing or sitting (Woollacott and Tang, 1997). COP can be calculated from the forces needed when maintaining balance applied to the surface of a force platform (Hirvonen et al., 2002). According to Hasan et al., (1996a) COP is the position of applied force vector that is influenced by the shear forces produced by body segment accelerations. Its displacement is a reaction to body dynamics representing all the vertical forces acting on the BOS (Winter, 1995). When two feet are in contact with a surface, COP is situated between the feet and depends on the relative weight taken by each foot (Winter, 1995). Whereas COP itself is easily quantified and directly measured, body COG is not directly accessible (Hasan et al., 1996a). COG (also referred as center of mass=COM) is the point at which the vector of total body weight passes. It depends only on the displacements of the body segments, but it is not influenced by the dynamics. Although COG and COP occupy different roles in the balance control system, according to Hasan et al., (1996b), their amplitude and frequency measures are highly correlated. This correlation supports the use of COP-based measures in quantifying standing balance. In the present study, static standing balance tests using a force platform are called postural balance tests.

As opposed to the goal of static tests, that of dynamic balance tests is to actively move the COP while standing, walking or different tasks of daily activities are performed. In this study, the term “dynamic stability” refers to a person’s ability to move the COP in a given direction within the LOS in force platform tests. The feet of the testee are not allowed to move. In general, LOS are not fixed boundaries. They change according to the task, the person's biomechanics, and environmental aspects (Nashner, 1997; Shumway-Cook and Woollacott, 1995). For example, in walking, the COG is kept within the BOS only during short double-limb support periods (Woollacott and Tang, 1997). In all dynamic movements, COG can move outside the LOS for a moment, but BOS has to be changed to bring COG back within BOS; otherwise a fall results. Some researchers have defined static and dynamic balance measurements according to whether the support surface is stable or movable. In dynamic posturography, the support surface can move in a horizontal plane or pitch the person either forward or backward, but the person tries to stand in place (Monsell et al., 1997).

Functionally directed balance tests are typically dynamic tests that measure a person’s ability to maintain balance as he or she walks or performs tasks as fast as possible or reaches as far as possible (Hertel et al., 2000; Podsiadlo and Richardson, 1991; Rinne et al., 2001). Ideally, the aim of functionally oriented balance tests is to simulate the tasks and actions of daily activities and work, because balance is one of the baseline requirements necessary for these tasks.

Balance is an integral component of almost all daily actions. Stability and orientation demands of balance changes with each task, and they are higher for activities of greater force, velocity, or magnitude (Berg, 1989). Postural orientation is the ability to maintain an appropriate relationship between the body segments and between the body and the environment during a task (Shumway-Cook and Woollacott, 1995). In addition to individual and task-related factors, environmental factors and their interaction affect balance control (Figure 1) (Shumway-Cook and Woollacott, 1995).

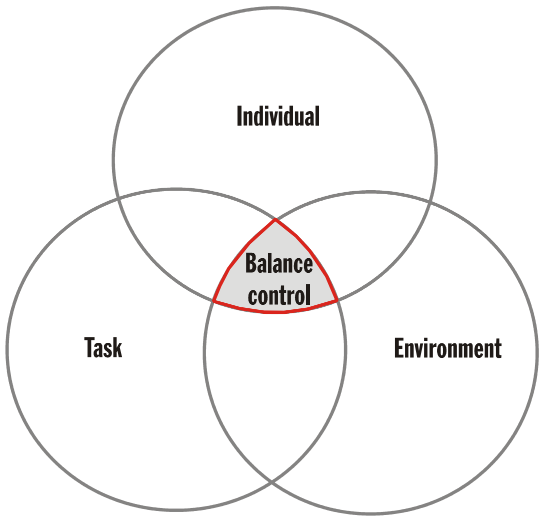

Figure 1. A conceptual model (Shumway-Cook and Woollacott, 1995) showing the relationship between the individual, the task demands and the environment with balance control.

2.2. Individual aspects of balance control

2.2.1. Sensory components

The ability to control balance is dependent on sensory inputs from somatosensory, visual and vestibular systems (Table 1). Information concerning the position and movement of body segments with reference to each other and the support surface and the distension of the respective muscles is provided through the somatosensory system, the proprioceptors and the mechanical sensitivity of cutaneous and subcutaneous tissue (Nashner, 1997). Proprioceptors are located in muscles, tendons and joints, and they include the following receptor systems: primary endings of muscle spindles (type I), secondary endings of muscle spindles (type II), the Golgi tendon organ and joint receptors (McComas, 1996). Muscle stretching activates primary (type I) and secondary

Table 1. Use of sensory inputs for balance control (Adopted from Nashner, 1997).

Sensory input	Reference	Conditions favorable to use	Conditions unfavorable to use
Somatosensory	Support surface	Fixed support surface	Irregular or moving support surface
Visual	Surrounding objects	Fixed visible surroundings Irregular or moving support surface	Moving surroundings Darkness
Vestibular	Gravity Inertial space	Irregular or moving support surface Moving surroundings Darkness	Unusual motion environments

(type II) endings of muscle spindles and releases a stretch reflex that monosynaptically facilitates the agonistic muscles and inhibits the activity of the antagonistic muscles (Noback and Demarest, 1981).

Muscle spindle type II (secondary endings) mediates the information on the length of the muscles to the central nervous system (CNS) as well. Increasing of the tension of the muscles also activates Golgi tendon organs (Noback and Demarest, 1981). The Golgi tendon reflex effect in respective muscles is opposite of the muscle spindle reflex, namely the activation of Golgi tendon organs causes the facilitation of antagonist muscles, whereas agonistic muscles are inhibited (Prochazka and Wand, 1980). These three receptor systems work in harmony by releasing segmental reflexes and mediating information on balance changes to the CNS (Prochazka and Hullinger, 1983). Information is also derived from receptors located in the cutaneous and subcutaneous tissue (Johansson and Vallbo, 1980) of the sole of the foot. These receptors adapt either slowly or quickly and they can detect changes in pressure, for example, postural sway, and can react to the acceleration and magnitude of skin stretching on the sole of the foot during standing and walking (Johansson and Vallbo, 1980; Magnusson et al., 1990; Toppila and Pyykkö, 2000).

Furthermore, the visual system provides information about the body's position and motion in relation to the environment. Vision has an important role in balance control, but it is not essential because it can also be compensated by other sensory inputs (Brandt et al., 1986). According to Brandt et al., (1986) visual signals, which start postural corrections, seem to react to motion as a relative image shift on the retina when visual surroundings are stationary. Visual input is needed not only for the continuous evaluation of head sway, but it also seems to trigger required muscle activation in controlling postural perturbations (Brandt et al., 1986). In general, the central area of the visual field, when compared with that of the peripheral retina, is more important for balance control, and the foveal region contributes powerfully, especially to lateral postural sway (Paulus et al., 1984). When the direction of movement is rapidly changed, it would be impossible to maintain a stable image on the retina without some automatic control mechanism to stabilize the direction of the gaze of the eyes. Therefore, the purpose of the vestibulo-ocular reflex is to stabilize vision by producing eye movements in opposite directions during the turning of the head (Baloh et al., 1993; Noback and Demarest, 1981). Through this phenomenon the vestibulo-spinal reflex stabilizes the whole body.

Input concerning the position of the head in relation to gravity, as well as to motion through the linear and angular acceleration of the head, is provided by the vestibular system (Noback and Demarest, 1981). Vertical and horizontal semicircular canals sense rotational movement of the head in the sagittal and frontal, as well as horizontal, planes, respectively. Canals are the most sensitive to fast movements, for example, those occurring during sudden slips and trips, and they detect movement with a large dynamic range (frequencies 0.5-10 Hz) (Horak and Schubert, 1994; Toppila and Pyykkö, 2000). Furthermore, the otoliths sense position relative to the earth's gravitation axis and linear and slow (range 0.2-0.5 Hz) acceleration of the head (Toppila and Pyykkö, 2000). Saccular otoliths sense vertical linear accelerations of the head (e.g., gravity), for example, head translations generated during deep knee bends, whereas utricular otoliths sense horizontal linear accelerations like head movements generated during forward walking (Horak and Schubert, 1994). The input of otoliths and semicircular canals converges in the vestibular nuclei in the same neuron, which also receives visual and proprioceptive input (Toppila and Pyykkö, 2000).

Sensory strategies

Sensory strategies, which refer to the relative weight given to a sense by the CNS, vary as a function of such individual aspects as age, task and environment

(Table 1). It has been suggested that, under normal conditions, the nervous system weights the importance of somatosensory information for postural control among healthy adults (aged 20-70 years) more heavily than vision does, but, when reliable proprioceptive information is removed, vision becomes more important to the maintenance of balance (Colledge et al., 1994). It has also been suggested that there may be a systematic change in the multisensorial process, which controls balance throughout life (Straube et al., 1988). Young children (2-8 years) rely more on visual inputs (Straube et al., 1988), whereas pressoreceptor and proprioceptor systems are important for balance control among children aged 6 to 16 years (Hytönen et al., 1993). Furthermore, the importance of vision in balance control increases again among people over 60 years of age (Hytönen et al., 1993; Straube et al., 1988), and persons over 85 years of age become especially dependent on vision (Pyykkö et al., 1990).

Vision, together with vestibular input, becomes especially important with respect to compensation for continuously applied low-frequency balance disturbances, for example, when the support surface is unstable (Diener et al., 1986). Furthermore, vestibular input is critical for balance control when somatosensory and visual inputs are unavailable, as well as under sensory conflict conditions (Allum et al., 1989) (Table 1). According to Colledge et al., (1994), the vestibular system alone can only partially compensate, however, for proprioceptive loss. Several studies concern the importance of vestibular inputs in different aspects of balance control; for example, Runge et al. (1998) suggested that vestibular information is not critical as regards selecting and triggering hip strategy, although it may be meaningful in controlling hip strategy in some environments. Because the environment is constantly changing, the CNS also has to adapt according to information for multiple sensory modalities in order for balance to be maintained. Therefore, the most appropriate inputs have to be selected according to the requirements of the task and environment (Shumway-Cook and Woollacott, 1995).

2.2.2. Integration of motor responses according to sensory input

According to sensory systems and demands of the situation, sensory information is organized, and motor responses are chosen in the CNS to stabilize posture or prevent a harmful change in it (Table 2). The ability to control balance emerges from a reciprocal action of biomechanical, musculoskeletal and sensory systems and the CNS (Nashner, 1997). The CNS consists of the spinal cord and the brain. Several parts of the CNS take part in posture control, and there are three motor systems involved in balance control. The first and fastest response to a change in posture is triggered by the *myotatic stretch reflex* (spinal cord), which regulates contractile muscle forces (Noback and Demarest, 1981). Reflexes are activated by an external stimulus and are highly stereotyped (Nashner, 1997).

The earliest functionally effective responses to balance perturbations are called *automatic postural responses* also referred to as the long-loop reflex or the functional stretch reflex. Their postural latencies (mean 94 ms and 120 ms for medium and long latencies, respectively) are much longer than the spinal stretch reflex latencies (35-40 ms), but they

Table 2. Components of balance control.

Sensory system	CNS	Motor system
Afferent input	Organization of sensory input and choice and triggering of motor responses	Efferent output
Somatosensory system: - proprioceptors: muscle spindle type I and II, Golgi tendon organ, joint receptors - cutaneous and subcutaneous receptors Vision: - retina Vestibular system: - semicircular canals and otholiths in the inner ear	Myotatic stretch reflex Long-loop reflexes Internal representations Learned skills Synergistic action Sensory strategies Adaptive mechanisms Anticipatory mechanisms	Reflexes Automatic movements Voluntary movements Muscles of the upper and lower extremities Trunk and neck muscles Neuromuscular synergies: - ankle strategy - hip strategy - stepping strategy - mixed strategy

are shorter than voluntary reaction times (≥150 ms) (Diener and Dichgans, 1986; Nashner, 1997). Automatic postural responses, which are mediated in the brain stem and subcortical area, coordinate movements across joints (Nashner, 1997). They are stereotyped, but adaptable. Like reflexes, automatic responses are activated by external stimuli. Their responses can be thought of as overlearned, "long-loop" reflexes that rapidly respond by resisting disturbances (Diener and Dichgans, 1986). Automatic responses depend on movement strategy, which in turn is dependent on the experience of the person and on surface conditions (Nashner, 1997). Automatic reactions are also adaptable to specific balance demands.

Contrary to reflexes and automatic responses, *voluntary postural movements*, mediated by the brainstem and cortical area, can be initiated in response to an external stimulus, or they can be self-initiated and generate purposeful movements and behavior (Nashner, 1997). Postural adjustments associated with voluntary movements are organized on the basis of internal representation (Massion, 1994). In order to know when and how to apply restoring forces to keep the COG within the BOS, the CNS must have an accurate picture of where the body is in space and whether it is stationary or in motion (Shumway-Cook and Woollacott, 1995). Therefore, internal representations (provided by the postural body scheme) of body geometry, body dynamics (support conditions) and body orientation through sensory inputs are essential for the mapping of sensation to action (Massion, 1994) (Table 2).

2.2.3. Motor components

Balance control requires an ability to produce adequate muscle contractions according to task demands. In simplifying the control demands for the CNS, independent, although related, muscles are combined into muscle synergies by the nervous system (Shumway-Cook and Woollacott, 1995). Because the muscles act around the joints when balancing the body, the role of ankle and hip strategies and their related muscle synergies are especially important. The ankle strategy produces shifts in the COG by rotating the body about the ankle joints. It elicits a distal-to-proximal muscle activation of ankle, hip and trunk musculature (Horak and Nashner, 1986). The ankle strategy uses compensatory ankle torques that are believed to correct for small postural perturbations on firm support surfaces (Nashner, 1997). Therefore efficient use of the ankle strategy depends on accurate sensations from somatosensory inputs (Horak et al., 1990).

The hip strategy controls movement of the COG primarily by flexing and extending the hips, and it uses early proximal hip and trunk muscle activation (Horak and Nashner, 1986). Hip strategy occurs when the ankle is unable to exert the appropriate torque necessary to regain balance, for example, when the support surface is smaller than the feet or is compliant or narrow when perturbations are large and fast or when the body COG is near the limits of stability, as it is during walking (Nashner, 1997; Horak and Nashner, 1986). The third strategy used to achieve balance is the stepping strategy, which is used when the COG is displaced outside the BOS. The stepping strategy uses early activation of hip abductors and ankle co-contraction (Horak and Nashner, 1986). The muscle strategies are not as stereotyped as reflexes are. They can also be learned with experience in new environmental contexts (Horak and Nashner, 1986). When conditions are intermediate, between favoring the use of the ankle or hip strategy, and when a person must adapt to a new surface condition, for example, to control balance on a flat support as the magnitude of postural perturbations increases, the use of combinations of these strategies (mixed strategies) is common (Runge et al., 1999).

2.2.4. Effects of age and sex on balance control

2.2.4.1. Decrease of balance abilities with aging

An age-related decline in balance abilities has been shown in several cross-sectional studies of postural sway and functional balance among working-aged populations and the elderly (Colledge et al., 1994; Du Pasquier et al., 2003; Ekdahl et al., 1989; Era and Heikkinen, 1985; Gill et al., 2001; Matheson et al., 1999; Pohjonen 2001a; Røgind et al., 2003; Straube et al., 1988). Children below 10 years of age and elderly people over 60 years of age have the most pronounced postural sway (Hytönen et al., 1993; Pyykkö et al., 1988; Sihvonen et al., 1998). Some investigations have shown that differences in postural balance abilities in a normal standing position are minor between the ages of 17 and 54 years (Sihvonen et al., 1998) or that no correlation exists at all between age and postural sway (Juntunen et al., 1987) or that body sway is the most stable among 46-to-60-year-old people (Hytönen et al., 1993). When the balance demands of a test are increased (i.e., the BOS is smaller or balance is tested on a compliant surface), when the eyes are closed, or, especially, when the eyes are closed on a compliant surface when two sensory cues are affected, some studies have shown detected balance declines to be greater between younger people and the elderly (>60 years) and between different age groups of the working population (comparisons made for people below and over 40 years of age), and others report that, among working-aged subjects, declines can only be detected (Colledge et al., 1994; Era and Heikkinen, 1985; Gill et al., 2001; Matheson et al., 1999; Straube et al., 1988).

It should, however, be remembered that comparisons of the age-related results reported in different studies are complicated due to differences in the methods, the selection of the subjects, the different age ranges of the subjects and the study design. Moreover, most studies on the relationship between balance and age are cross-sectional in design (Colledge et al., 1994; Ekdahl et al., 1989; Era and Heikkinen, 1985; Gill et al., 2001; Hytönen et al., 1993; Kollegger et al., 1992; Matheson et al., 1999; Pohjonen, 2001a; Røgind et al., 2003; Sihvonen et al., 1998; Straube et al., 1988), and a cross-sectional design is not ideal for obtaining an understanding of the aging phenomenon. In longitudinal studies findings of age-related changes have, however, confirmed the results of cross-sectional studies, and balance deterioration in people over 75 years of age has been shown to be even more pronounced (Baloh et al., 1998; Du Pasquier et al., 2003; Era et al., 2002). Despite the considerable amount of research available on age-related differences in balance, very little is known about age-related differences in the balance of workers in specific physical jobs.

2.2.4.2. Age-related changes in senses, reflexes and automatic muscle responses

Changes in balance control mechanisms due aging take place at different levels of the balance control system (Woollacott et al., 1986). There is, however, no solid consensus concerning mechanisms contributing to these changes (Colledge et al., 1994; Laughton et al., 2003). In addition, most of the studies of mechanisms contributing to age-related balance changes have dealt with elderly subjects (mean age about 70 years) and young controls of about 20 years of age. Age-related deficits in peripheral sensory systems are important factors, as an elderly person's balance is more altered than that of younger adults when visual and proprioceptive or both inputs are eliminated or reduced (Matheson et al., 1999; Shumway-Cook and Woollacott, 2000; Straube et al., 1988; Woollacott et al., 1986).

For example, the following changes take place in the senses as a result of aging: older people have higher proprioceptive thresholds (Stelmach and Sirica, 1987) and anatomical changes take place in the semicircular canals, the saccule and the utricule of the inner ear (Johnson and Hawkins, 1972). Furthermore, visual acuity declines with age, depth perception and contrast sensitivity are poorer among the elderly, and older people progressively lose their peripheral vision (Cohn and Lasley, 1985; Gittings and Fozard, 1986). Age-related changes in the aforementioned sensory inputs could decrease the redundancy of sensory information that is normally available and can, therefore, make a shift in the relative weighting of inputs less effective, depending on the environmental demands (Woollacott et al., 1986). Colledge et al. (1994) studied 20-to-70-year-old healthy adults and suggested that the relative contributions of sensory inputs to balance do not, however, alter with advancing age.

Age-related changes in the long latency automatic postural response systems characterize reduced muscle coordination (e.g., temporal breakdown of distal and proximal muscle activation) and increase the absolute latency of distal muscles within a muscle response synergy (Woollacott et al., 1986). The variability of the relative constancy of the contraction amplitude of distal and proximal synergies also increases with aging (Woollacott et al., 1986). The latency of the monosynaptic stretch reflex, which is the lowest level of the balance control hierarchy, increases in the achilles tendon with age (Carel et al., 1979), whereas in the patellar tendon no significant differences have been found between 20- and 60-year-old men (Clarkson, 1978). Furthermore, Woollacott et al. (1986) found impaired integration of sensory inputs among older subjects.

2.2.4.3. Changes in higher integrative mechanisms

In their study Stelmach et al. (1989) found that elderly subjects adapt more poorly to repeated small-slow balance perturbations, which activate integrative mechanisms through sensory inputs, than young controls did, although the two groups responded similarly to large-fast rotations (elicit reflexive postural responses). The continuous control of balance is, however, highly dependent upon the quality of the proprioceptive information, and its integration with visual and vestibular information, and it is not based upon reflex mechanisms (Woollacott et al., 1986; Stelmach et al., 1989). Therefore, older people are at some disadvantage when balance is under the control of slower, higher level sensory integrative mechanisms (Stelmach et al., 1989).

More recent studies have also provided additional evidence that higher integrative levels dominate in the decline of postural control (Colledge et al., 1994; Rankin et al., 2000; Shumway-Cook and Woollacott, 2000). For example, an enriched sensory context is not necessarily related to more stable behavior among elderly people because the reintegration of ankle proprioceptive input causes faster postural sway both with the eyes open and with them closed (Teasdale and Simoneau, 2001). Therefore, in addition to decreased peripheral acuity among older people, their sensory reweighting process is limited by the capacity of the central integrative mechanisms that reorganize the hierarchy among the sensory inputs (Teasdale and Simoneau, 2001). Colledge et al. (1994) also suggested that the increase in body sway demonstrated with normal aging is more likely to be due to the slowing of central integrative processes than to altered peripheral sensibility.

Furthermore, people have shown poorer balance when they perform a simultaneous cognitive task than when they do a balance task only (Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000). Balance during a simultaneous cognitive task is more affected among the elderly than among younger persons when the accuracy of visual and somatosensory inputs is reduced (Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000). A recent experiment of Rankin et al. (2000) demonstrated that, especially among older people, muscle activity declines significantly in the gastrocnemius and tibialis anterior muscles if balance is measured when a math task is performed concurrently. These findings suggest that the elderly have a lower attentional processing capacity for balance control during a dual-task paradigm.

2.2.4.4. Age-related changes in neuromuscular synergies and muscle function

With respect to output, the slowing of peripheral nerve conduction velocity and the decrease in the number of motor units may also be related to balance changes among the elderly (Leonard et al., 1997). Furthermore, elderly people have been found to have mixed hip-ankle activation when the BOS is narrowed during standing, whereas young subjects adapt to increased postural demands by using the ankle strategy only (Amiridis et al., 2003). Okada et al. (2001) also showed that older people rely more on hip movements to control balance while young controls rely on ankle movements. The greater hip muscle activation in the elderly may be caused by insufficient torque production of the ankle muscles, which is needed to counteract the great moment of inertia in the anteroposterior direction (Amiridis et al., 2003; Kuo and Zajac, 1993). According to Kuo and Zajac (1993) the hip strategy is the most effective in controlling the COM with minimal muscle activation.

The greater hip muscle activation in the elderly may also be caused by greater loss of motor units in the distal than the proximal muscles or an insufficient proprioceptive contribution (Amiridis et al., 2003; Stelmach and Sirica, 1987). The elderly have also been found to have a greater amount of muscle activity during postural sway in a quiet stance than younger persons do (Laughton et al., 2003). The authors concluded that it is, however, unclear if high muscle activity of the legs precedes greater postural instability or if increased muscle activity is a compensatory response to increases in postural sway (Laughton et al., 2003).

2.2.4.5. Effects of sex on balance control

In some studies, men have been reported to sway more than women (Ekdahl et al., 1989; Era et al., 1996; Juntunen et al., 1987; Kollegger et al., 1992; Maki et al., 1990; Matheson et al., 1999). Other studies have reported contradictory findings (Panzer et al., 1995) or no difference between the sexes (Colledge et al., 1994; Hageman et al., 1995; Røgind et al., 2003). Moreover, no results of functional balance tests (walking time, standing on one leg) have depended on sex (Ekdahl et al., 1989). It has been shown, however, that standardizing the balance results by the length of the base of support or body weight removes the difference between the sexes (Era et al., 1996; Maki et al., 1990).

2.2.5. Effects of vision on balance control

It is well known that, in the eyes-closed condition, the velocity and amplitude of postural sway is higher than in the eyes-open condition (Colledge et al., 1994; Matheson et al., 1999; Stelmach et al., 1989). For example, postural sway was shown to increase two- to threefold with the eyes closed in all age groups of men and women aged 15-25, 45-55 and 65-75 years and also among men aged 31-35, 51-55 and 71-75 years (Era and Heikkinen, 1985; Gill et al., 2001). The increase in sway in a normal standing position after the eyes are closed is clearer in the anteroposterior direction (Era and Heikkinen, 1985). Paulus et al. (1984) showed that especially anteroposterior sway increased gradually as visual acuity decreased. Slower speed and smaller amplitude of COP movement in postural balance tests are associated with better visual acuity among elderly men and women (Era et al., 1996).

2.3. Work task demands and balance control

2.3.1. Characteristics of task-related balance control demands in physical jobs

Physically demanding work includes several complicated tasks in which the perturbation of balance is expected. The expected threat to balance also causes anticipatory postural adjustment (APA) (Belen'kii et al., 1967; Cham et al., 2002; Commissaris and Toussaint, 1997a; Cordo and Nashner, 1982; Marigold and Patla, 2002). APA activates the postural muscles and actively initiates movements, which in advance counteract the possible disturbances of balance associated with a voluntary task and locomotion. For example, pushing a rigid handle while standing is associated with tibialis anterior activation, which precedes the onset of the handle force signal (Cordo and Nashner, 1982). This APA compensates for the body displacement induced by the voluntarily performed handle movement.

In physical jobs APA are needed in respect to work safety, but it is as important in respect to the fluency and efficiency of work (Belen'kii et al., 1967). The anticipatory activation of muscles before a voluntary task is associated with the need to maintain balance a the minimum expenditure of energy (Belen'kii et al., 1967). According to Zettel et al., (2002) the CNS is able to use exteroceptive visual input to alter balance control parameters in an anticipatory manner, even when the characteristics of the forthcoming perturbation cannot be predicted in advance. When the conditions in which a task is performed change, the preparation for the movement also changes in a way that ensures balance in the new situation (Belen'kii et al., 1967). Balance adjustments and the sequence in which postural muscles have been activated are also task-specific (Belen'kii et al., 1967; Commissaris and Toussaint, 1997a; Toussaint et al., 1997).

The work tasks that challenge balance control the most among firefighters are associated with work with ladders, on roofs and when smoke-diving (Gledhill and Jamnik, 1992a; Lusa et al., 1994). Tasks demanding good balance abilities are involved in work on scaffoldings and roofs among construction workers (Hsiao and Simeonov, 2001). Furthermore, in nursing and home care work, as well as in construction, firefighting and rescue work, manual lifting of clients or construction material and the handling of heavy tools are essential parts of the work. For example, the clients of municipal home care workers in Finland are frail and elderly, and they need help with daily living activities several times a day (Pohjonen, 2001b).

Lifting a load in front of the body creates a risk of falling forward because adding the extra mass causes the COP to shift forward in relation to the BOS (Commissaris and Toussaint, 1997b). Pan et al. (2003) examined postural stability in association with four lifting methods commonly used by drywall installers and carpenters. They found that vertical lifting of drywall sheet placed greater demands on their subjects' balance control (i.e., higher COM accelerations and greater postural sway) than horizontal lifting of drywall. To minimize the effects of balance-threatening events during lifting, preparatory actions immediately before a load, placed in front of the toes in lifting is grasped, are characterized by a lower forward rotational velocity, a clear increase in the backward-directed horizontal momentum of the body COP and a backward-directed horizontal force vector, as well as forward displacement of the COP (Commissaris and Toussaint, 1997b; Toussaint et al., 1997). During lifting the electromyographic (EMG) activity of ankle plantar flexors increases considerably before contact with the load (Commissaris and Toussaint, 1997b).

In one study, if the weight of the lifted load was reduced unexpectedly (16 kg to 6 kg), balance was disturbed in most of the trials (Commissaris and Toussaint, 1997a). In general, the APA scales the amplitude of adjustment according to the size or amplitude of the expected perturbation (Shumway-Cook and Woollacott, 1995). When a worker overestimates the weight of a load to be lifted, an unnecessarily high linear and angular momentum of the body occurs. This momentum can lead to disturbed balance and possibly to a fall (Commissaris and Toussaint, 1997a; Toussaint et al., 1997a). Moreover, Aruin et al. (1998) suggested that higher instability during task performance can also be expected to lead to smaller APA because the CNS makes a logical and deliberate choice to help decrease the probability that the APA itself will produce postural instability.

2.3.2. Effects of protective equipment on balance control

The use of both bulky tools and protective equipment increases the demand for highly developed and flexible balance skills (Hsiao and Simeonov, 2001). A worker's balance control can be affected by specific items of protective equipment, such as footwear, clothing, eyeglasses and respirators (Hsiao and Simeonov, 2001). For example, shoes act as a sensory interface between the foot and the BOS. The properties of the shoes affect the functional limit and the slip resistance of the BOS and the sensitivity of the foot according to extent, friction, firmness and incline of the surface (Hsiao and Simeonov, 2001). The soles of a person's shoes considerably affect the frictional properties of the shoes (Grönqvist, 1995). It has been shown that shoes with thin hard soles provided good walking stability, whereas shoes with thick, soft soles reduced foot position awareness and destabilized the walking stability of men of different ages (Robbins et al., 1997; Waked et al., 1997).

Protective eyeglasses, masks and other face or head protectors can form a sensory interface to the visual system. They restrict the peripheral visual field, and therefore protective eyewear may have harmful effects on balance (Samo et al., 2003). Respirators and protective clothing can also influence balance control. Firefighters have to carry out tasks with fire-protective equipment (FPE), consisting of specialized clothing and a self-contained breathing apparatus (SCBA), at least a few times each year (Lusa et al., 1994). Furthermore, firefighters need to be able to work safely with FPE, while still maintaining sufficient physical capacity for the most demanding tasks. However, the use of FPE also has negative effects on performance. For example, for submaximal work in a thermoneutral environment, the use of standard European FPE (Committee of Standardization 1995) with SCBA weighing 15 kg increases cardiorespiratory strain by 20% (Louhevaara et al., 1984), and it also significantly increases thermal strain (Ilmarinen and Mäkinen, 1992). The strain caused by SCBA is partly due to the weight of the equipment (Louhevaara et al., 1984), which, together with increased heat stress, may also affect postural stability (Kincl et al., 2002).

Kincl et al. (2002) showed that standard United States FPE impaired postural stability in terms of sway length and sway area, especially after physical loading (sustained squatting). These findings indicate that wearing a heavy respirator during demanding physical work may disturb balance (Kincl et al., 2002; Seliga et al., 1991). Previous studies on postural sway and FPE have, however, used subjects in a narrow age range (24-34 years) (Seliga et al., 1991) or failed to examine age-related effects (Kincl et al., 2002). Although the effects of European FPE (Committee of Standardization, 1995) on the cardiorespiratory system have been well quantified (Ilmarinen and Mäkinen, 1992; Louhevaara et al., 1984), no data are available on balance control.

2.3.3. Differences in the balance abilities of workers in various occupations

In general, only a few studies have dealt with balance control in different occupations. According to Kohen-Ratz et al., (1994) fighter pilots demonstrate superior and more-mature postural control than candidates for flight training, whereas helicopter pilots show intermediate balance values. Although helicopter pilots are also highly selected, they represent a group not chosen as fighter pilots (Kohen-Ratz et al., 1994). Diard et al. (1997) also reported that pilots on active duty had significantly better performance in dynamic posturography than former fighter pilots, firefighters and a control group of the general working population. Nurses showed better performance in a Flamingo balance test than a reference group of adults with various occupations, whereas public servants scored better than nurses (Zinzen et al., 1996) and construction workers had better stability than workers not engaged in physically demanding work (Gantchev and Dunev, 1978). Reported differences in balance abilities could be caused either by an innate ability or by training and learning (Kohen-Ratz et al., 1994).

Furthermore, dancers are found to be able to minimize COG displacement towards the supporting side when raising one leg laterally to an angle of 45 degrees in response to a light (Mouchnino et al., 1992). Compared with naive subjects, dancers reach the new COG position faster and require only a short adjustment period. Especially under sensory challenged conditions professional dancers were better than controls in maintaining their balance in a one-legged stance (Crotts et al., 1996). These differences may be due to the better internal representation of the biomechanical limits of the stability of dancers (Mouchnino et al., 1992). Era and Heikkinen (1985) reported that differences in postural sway are minor between manual and office workers.

2.4. Environmental factors involved in balance control

2.4.1. Effects of the visual and physical environmental factors on balance control

Workers maintain their balance by means of visual and physical interaction with the work environment, such as their interaction with the surface on which they stand (Hsiao and Simeonov, 2001). The work environment can also consist of such aspects as exposure to noise, lead and organic solvents, which have detrimental effects on balance (Juntunen et al., 1987; Ratzon et al., 2000; Kuo et al., 1996). For example, men with long-term exposure to impulse noise in the military service had poorer postural balance than controls (Juntunen et al., 1987).

Visual input from the work environment is used in a feedback mode (reactive) to control balance during walking and standing or in a feed-forward (anticipatory) mode to help guide locomotion on different surfaces and avoid obstacles (Patla, 1997). Several factors in a visual environment, such as the distance between the eyes and the closest object in the visual field and between the eyes and the visual target, as well as the visual target size and contrast, affect balance control (Paulus et al., 1984). Furthermore, elevation (3 m and 9 m) increases postural sway, and this effect is correlated with the absence of close visual references and fear of falling (Hsiao and Simeonov, 2001; Simeonov and Hsiao, 2001). For example, during construction work at an elevation, when workers direct their eyes to a distant target (i.e., to the ground, a tree or a house) their visual field may not include close visual references (Simeonov and Hsiao, 2001). The recent report of Simeonov et al. (2003) also showed that the destabilizing effect at heights without close visual references is similar to that of the eyes being closed at ground level. Furthermore, height vertigo is associated with postural instability in conditions in which visual references are farther away than 2.5 m (Brandt et al., 1980; Paulus et al., 1984). The effect of height with the absence of close visual contrasts was found to be substantially more pronounced on uneven surfaces than on normal surfaces (Simeonov and Hsiao, 2001).

Moving visual scenes can affect postural stability harmfully; for example, while on a roof, a worker may look at a tree moving in the wind or at swinging objects such as materials moved by a crane (Hsiao and Simeonov, 2001). Fall incidents can also occur as a result of a worker miscalculating distance and depth (Clark et al., 1996; Hsiao and Simeonov, 2001). The detection of obstacles and changes in the properties of surfaces are critical for the anticipatory control of balance (Hsiao and Simeonov, 2001). Successful anticipatory detection of potential hazards in the visual environment depends on how distinguishable they are from their surroundings, on subject visual attention and on the prior experience and knowledge of the worker (Hsiao and Simeonov, 2001; Patla, 1997). Poor lighting detrimentally influences postural balance, especially in more demanding reach and bending tasks, compared with the stationary postural task (Bhattacharya et al., 2003). Firefighters, for instance, work frequently in heavily smoky or totally dark environments where visual input is poor. In these conditions balance is maintained through proprioceptive and vestibular systems (Nashner, 1997).

In firefighting and rescue work, as in other physical jobs, the surfaces are frequently compliant, narrow, inclined or slippery, of all which challenge the balance control system by involving different strategies to maintain postural stability (Cham and Redfern, 2002; Leroux et al., 2002; Marigold and Patla, 2002). Increase in the slope and height of a surface have been shown to increase postural sway synergistically (Simeonov et al., 2003; Bhattacharya et al., 2003). Furthermore, during locomotion, a more cautious walking strategy seems to be adopted when a potential risk of slipping exists (Cham and Redfern, 2002; Marigold and Patla, 2002); the foot is placed more flatly, and therefore the foot contact area increases, and the COM is kept closer to the contralateral limb, which is in contact with the stable surface (Marigold and Patla, 2002). The stance duration and loading speed of the supporting foot are smaller, and the stride length is shorter; Thus the strength requirements of walking are decreased. According to Cham and Redfern (2002), anticipation of slipping trials produced peak values for the required coefficient of friction (RCOF) (shear forces divided by normal forces) that were 16-33% lower than the corresponding values in the baseline trials. The RCOF is believed to best reflect aspects of the ground reaction forces in the contribution of the shoe-floor interface to slip and fall potential.

Working on inclined surfaces also produces an increased risk for slipping due large shear forces at the shoe-floor interface (Hsiao and Simeonov, 2001). The RCOF increases linearly with increasing inclination (Redfern et al., 2001). An inclined surface affects balance control by altering sensory input from the foot and ankle as a result of a reduced effective BOS and modified position (Hsiao and Simeonov, 2001, Simeonov et al., 2003). Furthermore, anticipation during walking down an inclined surface results in a reduced stride length and stance duration (Cham and Redfern, 2002). According to Leroux et al., (2002), the main strategy in standing on a slope is to maintain the COG within the BOS by orienting the trunk and pelvis in relation to the earth's vertical across slopes. During standing on a slope, to provide postural stability, the ankle joints become plantar- or dorsiflexed, and a stretching or contraction of the muscles occurs that controls the movement of the ankle joints (Simeonov et al., 2003). The increase in muscle activity and stiffness at the ankle joints probably cause an increase in sway velocity (Simeonov et al., 2003).

2.4.2. Balance control during slipping

The activity of the bilateral leg and thigh muscles, as well as the coordination between the lower extremities, has been shown to be important with respect to reactive balance control in slips occurring at heel strike (Tang et al., 1998). During a slipping event, ankle moment has been shown to decrease with the severity of the slip, and knee flexor and hip extensor moments are primarily responsible for any corrective balance reactions (Cham and Redfern, 2001). Key factors that distinguish between subjects who fall due to a slip and those who maintain their balance are an increased slip distance of the foot (Brady et al., 2000) and a shorter double support phase on a slippery surface (You et al., 2001). According to different studies, the critical slip distance between an avoidable and unavoidable fall is 5-22 cm (Brady et al., 2000; Grönqvist et al., 1999; Strandberg and Lanshammar, 1981).

Reactive recovery responses to unexpected slipping (first trial) consist of a rapid onset of flexor synergy, range 150-200 ms, and this synergy suggests that polysynaptic reflexes contribute to the regain in balance and that proprioceptive cues are responsible for triggering the response (Marigold and Patla, 2002). Furthermore, a large arm elevation strategy, which helps stabilize COM by shifting it more anteriorly, and a modified swing limb trajectory are used as balance recovering strategies (Marigold and Patla, 2002). In addition, grasping, arm swinging and compensatory stepping are efficient means of restoring balance (Redfern et al., 2001). The reweighting of the different cues controlling balance has been found to be less efficient among fall victims than among controls (Vouriot et al., 2004).

When a subject is exposed repeatedly to slip perturbation, the knowledge of the slip results in a shift in the medial-lateral COM closer to the support limb at foot contact, as well as in a flatter foot landing. Muscle response magnitude and braking impulse are also diminished (Marigold and Patla, 2002). The reactive strategies to help maintain balance during slipping are influenced by knowledge of the surface characteristics and prior experience, and therefore the recovery strategies are modifiable (Cham and Redfern, 2001; Marigold and Patla, 2002).

2.5. Balance assessment of workers in physical jobs

2.5.1. Work-related validity

Although the importance of balance abilities in physically demanding jobs has already been recognized (Hsiao and Simeonov, 2001; Lusa, 1994), there is limited knowledge of the validity of the balance tests in use. Valid work-related balance tests are, however, needed for purposes of screening in occupational health care and for rehabilitation so that the effects of balance training can be evaluated. When the work-related validity of a physical test is evaluated, it is necessary to examine how a test result is associated with and predicts performance in an actual work situation (*criterion-related validity*). The problem in practice is the lack of quantification for gold standards (King et al., 1998). In general, the definition of work- or performance-related fitness is complex, and the main problem is the lack of a conception of the optimal level of balance tests or other fitness tests, in respect to work (Pohjonen, 2001b).

Test drills that simulate physically demanding work tasks have been developed and validated for evaluating firefighters' physical work capacity, mainly in terms of aerobic capacity (Louhevaara et al., 1994; Williford et al., 1999). Although some of the drills also include tasks that demand, among other capacities, balance and agility, the outcome variable is either performance time or heart rate without any measurement of balance abilities specifically (Gledhill and Jamnik, 1992b; Louhevaara et al., 1994; Misner et al., 1989). Performance-related balance tests that simulate important daily activities for the elderly, such as walking, rising from a chair and turning, have also been developed and validated (e.g., Berg, 1992; Podsiadlo and Richardson, 1991). Furthermore, widely used posturography tests of standing balance have been shown to differentiate between workers with various balance abilities (Gantchev and Dunev, 1978; Kohen-Ratz et al., 1994). "Standing still" tests on a force platform have, however, been criticized for their inability to predict changes in functional balance and gait (O'Neill et al., 1998).

Another method of validating a work-related balance test is to measure its ability to predict future work capacity or disability (*predictive validity*). Predictive validity studies of balance tests have mainly focused on the association between balance and low-back pain among working populations (Takala and Viikari-Juntura, 2000), between balance and health-related fitness (Suni, 2000) and between balance and risk of falling among the elderly (Brauer et al., 2000; Lord and Clark, 1996). Other than those of a study on functional balance among home care workers (Pohjonen, 2001a), no data are available on the predictive values of balance tests in respect to work ability. The study of Pohjonen (2001a) showed that the perceived work ability of home care workers with poor performance in the functional balance test was 6.5 times more likely to decrease during a 5-year follow-up than that of workers with a good result.

Furthermore, *the content validity* of a test is based on theoretical arguments in relation to a job analysis of the degree to which the test measures the physical demands of the job (King et al., 1998). Content validity should, however, not be used as the only basis for determining the validity of a test. With respect to aspects of content validity, most tasks in physically demanding jobs require balance control during movement in difficult conditions. Therefore the work-related balance tests used should also be dynamic or otherwise related to task and environmental demands for balance, such as the demands of different surfaces, the BOS and visual conditions.

2.5.2. Reliability

In addition to validity, reliability is an essential characteristic of a measure, but it is not so complicated to establish (King et al., 1998). In fact, to be valid, a test must also be reliable, because a test that measures what it is supposed to measure must consistently provide the same results day after day (Baumgartner, 1989). It is necessary to establish reliability between test and retests (*test-retest reliability*), as well as between testers (*interrater reliability*). According to Atkinson and Nevill (1998) some amount of error is always present in physical tests. Systematic bias is a general trend for test results to differ in a particular direction between several tests. Usually systematic bias is associated with the effects of learning, training or fatigue. Random error is the other type of error related to physical test results. It is usually larger than systematic bias. Inherent biological or mechanical variation or inconsistencies in the test protocol can be the reasons for large random error (Atkinson and Nevill, 1998).

Suitable and multiplex statistical analyses of reliability have also been called for (Atkinson and Nevill, 1998). Different kinds of correlation coefficients are useful for measuring the relative reliability of showing the degree to which subjects maintain their position within a sample (Baumgartner, 1989), but, according to Atkinson and Nevill (1998) and Lamb (1998), they should not be employed on their own as an assessment of reliability. Therefore, it has been recommended that both an appropriate correlation coefficient and a method for absolute reliability (i.e., coefficient of variation, limits of agreement (LoA) or standard error of measurement (SEM) be used (Atkinson and Nevill, 1998; Baumgartner, 1989). Absolute reliability focuses on the amount of error to expect in a person's score, and it makes it possible to consider the practical significance of the reliability result as well (Atkinson and Nevill, 1998; Baumgartner, 1989). Since some amount of error is always present in physical test results, absolute reliability can show the amount of error that could be acceptable in the practical use of a test (Atkinson and Nevill, 1998). Furthermore, in order to evaluate the effects of learning and training, more than two test sessions are recommended (Atkinson and Nevill, 1998). The process of the reliability evaluation should also show whether or not a test needs more familiarization trials or more time between repeated trials. The following sections present examples of reliability studies of methods assessing postural balance, dynamic stability and functional balance abilities mainly among working-aged people.

Postural balance

Using the Good Balance measurement system (Metitur, 2001), Mustalampi et al. (2003) showed intraclass correlation coefficient (ICC) values of 0.56-0.90 for postural balance tests (anteroposterior and mediolateral sway velocity) in a normal and a single-leg standing position with the eyes open. Tests were performed at a 3-day interval among 35 volunteers aged 26.6 (SD 8.9) years. The coefficient of variation of the tests ranged from 5.4% to 8.7%. Two (normal standing) or three (single-leg standing) trials were performed per session, and the best result was used as an outcome variable.

Takala et al. (1997) reported that, with the use of a custom-made force platform, sway velocity had the best day-to-day reproducibility and stability over time (9 months) among working people aged 38.7 years (n=9), the standard deviation (SD) being 10.9. The other sway parameters studied were maximum lateral and anterior-posterior displacement, mean amplitude, mean sway frequency and sway area. For most of the items the mean differences in the parameters over time were less than 5-10% of the measured values. Day-to-day values of the ICC for sway velocity in a two-foot stance with the eyes open were 0.56 (mediolateral sway) and 0.50 (anteroposterior sway), the corresponding values for the eyes-closed condition being 0.46 and 0.54, respectively (Takala et al., 1997). Single leg standing gave the following ICC values: 0.64 (lateral sway) and 0.72 (anteroposterior sway) for the right foot and 0.50 and 0.46, respectively, for the left foot. The ICC values for long-term stability were at about the same level or a little higher for some parameters. During the one-foot tests, the subjects were allowed to repeat the test three times if they failed the test; otherwise one repetition was performed.

Corriveau et al. (2000) concluded that at least four trials of the COP minus COM variable are required to provide reliable results for postural balance among healthy people over the age of 60 years (n=7). Their outcome variable was the average of four trials. It has also been shown that, among healthy navy recruits and hospital staff (20-54 years, n=60), a longer time (≥17 days) between 10 repeated postural balance tests was less likely to produce a learning effect (Nordahl et al., 2000). The other time intervals studied averaged 11, 31 and 115 days.

According to Le Clair and Riach (1996), the best test-retest reliability is obtained for postural sway parameters at 20- and 30-s trial durations (subjects aged 19-32 years, n=25). They studied the reliability of five different test durations (i.e., 10, 20, 30, 45 and 60 s) and 10 s proved to be the least reliable.

Dynamic stability

High ICC values (0.88-0.93) were reported for a dynamic stability test (balance master) that involved weight shifting to eight targets positioned in an ellipse (Brouwer et al., 1998). Young volunteers aged 24 (SD 3.2) years (n=33) performed tests on three occasions at 1-week intervals. For a sample of voluntary subjects aged 17-55 years, the results of a dynamic stability test (Good Balance) (to move the COP actively to follow a circle shown on a screen) improved systematically (paired T-test) in the second trial (Hofmann, 1988). In this case, the possible effects of learning needed to be determined by quantifying actual baseline levels and the stability of the test over a longer period of time. Furthermore, Hirvonen et al. (2002) found ICC values of 0.93-0.96 for a dynamic stability test (to the move COG marker from the central target to the eight peripheral targets) with a custom-made force platform. Healthy subjects (aged 16-54 years, n=23) repeated the tests five times (4 practice trials and 1 test trial at each session) at different time intervals (1-12 days). The length of the time interval between the test occasions did not have a significant effect on test reliability, whereas two to four parameters showed learning effects between the first and fourth and first and fifth test sessions (Hirvonen et al., 2002).

Functional balance

Rinne et al. (2001) studied the ICC values and LoA of tandem walking forwards, tandem walking backwards and standing on a bar among 25 healthy volunteers aged 36-72 years. The test-retest and interrater reliabilities were 0.91 and 0.88, 0.85 and 0.96, and 0.92 and 0.96, respectively. The tests were performed in three different sessions at 1-week intervals. All the balance tests showed some learning effect; however, the authors considered the LoA for tandem walking forwards and tandem walking backwards to be reasonable, 2 and 3 s, respectively. Furthermore, for a stratified sample of firefighters (aged 34-54 years, n=50) the test-retest reliability between two functional balance tests (walking as quickly and controlledly as possible on a wooden plank) repeated at 1-week intervals was 0.77 ($p< 0.001$) according to Pearson's correlation coefficient (Punakallio et al., 1997a). Furthermore, the reliability of a dynamic balance test (walking on a 5-m long track while stepping only on two pads and standing on one foot, the empty pad being retrieved from behind and placed ahead so that the subject could proceed) at 1-week intervals was 0.90 (performance time) and 0.71 (loss of balance) for 57 healthy male volunteers aged 38-57 years (Räty et al., 2002).

In most cases the star excursion balance test (a grid on the floor with eight lines extending at 45 degree increments from the center of the grid in which the subject maintains a single-leg stance while reaching with the other leg to touch as far as possible along a line) showed high intratester (ICC 0.78-0.96, SEM 1.8-3.4 cm) and intertester (ICC 0.35-0.93, SEM 2.3-5.0 cm) reliability among 16 recreationally active volunteers aged 21.3 (SD 1.3) years (Hertel et al., 2000). At two testing sessions with a 1-week interval the subjects performed three trials (one practice trial) for both legs in each direction. There were significant learning effects, however, for the repetitive trials of four of the eight excursion directions, and trials 7-9 had the longest excursions in all directions.

3. THEORETICAL FRAMEWORK OF THE STUDY

The theoretical framework of this study is based on, and has been modified from, the systems approach of Shumway-Cook and Woollacott (1995). In the present framework balance control is considered to be an interaction between the individual capacities of a worker, the work task with its inherent balance demands, and the demands of the work environment on balance (Figure 2).

The high balance demands of the work and unpredictable and rapidly changing work conditions make balance control and maintenance challenging for a worker in physically demanding jobs. Adequate balance control in relation to task and environmental demands may prevent accidents and injuries, and may also support and promote health, safety and work ability. Therefore, in addition to the worker's individual capacities, the aspects of the work task and the environment should be characterized when balance abilities are studied with various tests.

4. AIMS OF THE STUDY AND STUDY DESIGN

4.1. Aims of the study

The purpose of this study was to investigate the associations between balance abilities and aspects of

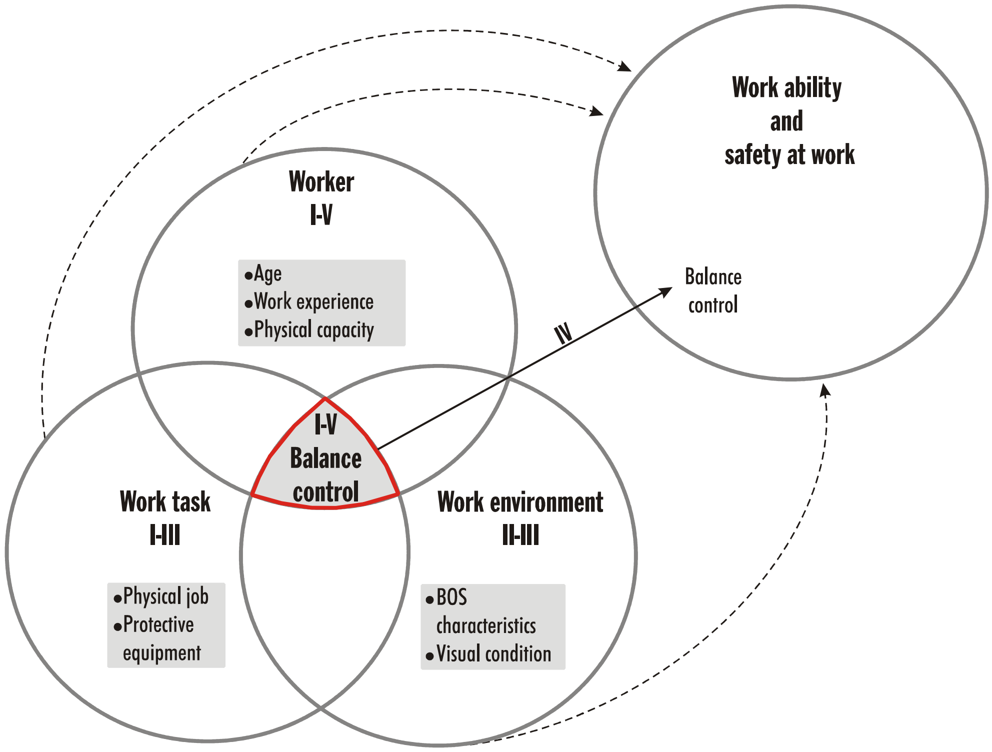

Figure 2. The framework of the study (modified from Shumway-Cook and Woollacott, 1995). The Roman numerals represent the present studies, as based on the framework. The dotted lines indicate relations not measured in this study (BOS = base of support).

job demands, work ability and safety among different aged workers in physically demanding jobs, and, particularly, those in fire and rescue work. The associations between individual characteristics, such as age and occupation, with balance abilities were studied. The task-related and environmental factors, such as the effects of FPE, visual conditions and slippery surfaces, were also studied in association with the balance abilities of firefighters. The methodological aim was to evaluate the reliability of the balance tests and their predictive value in respect to perceived work ability.

The aims of the study can be specified in the form of the following questions:

1. Do postural and functional balance abilities differ among different aged workers from different physical occupations, and do balance abilities differ between workers in different occupations? (Study 1)

2. Does fire-protective equipment affect functional and postural balance abilities, and do the influences differ in two visual conditions and between younger and older firefighters? (Study 2).

3. Are balance abilities, muscular capacities and age associated with slip and fall risk in walking experiments with firefighters wearing fire-protective equipment? (Study 3).

4. Do postural, functional and perceived balance abilities predict perceived work ability and physical work ability? (Study 4).

5. What is the reproducibility of the dynamic stability test and functional balance test, and what is their test-retest stability after 2 months? (Study 5).

4.2. Study design

The study design varied depending on the specific objectives of Studies 1-5. Cross-sectional measurements were applied in Studies 1-3, and longitudinal designs were used in Studies 4 and 5 (Table 3).

5. METHODS

5.1. Subjects

The subjects of the overall study comprised firefighters (Study 1-4), construction workers (Study 1), home care workers (Study 1) and nursing staff (Study 1) (Table 3). The data on firefighters are based on a 3-year follow-up of the health and

Table 3. Number of subjects (n), age and occupation of the subjects, the participation rate of the eligible subjects, the sampling method, and the design for Studies 1-5.

Study	N	Age (years), mean (SD) range	Occupation	Participation rate, %	Entrance to the study	Study design
1	69	41.7 (7.7) 33-56	Firefighter	87	Stratified sampling	Cross-sectional
	52	39.9 (8.7) 23-56	Construction worker	84	All from one occupational health care unit	Cross-sectional
	51	41.9 (10.5) 26-61	Nursing staff	85	Stratified sampling	Cross-sectional
	66	46.2 (8.5) 28-61	Home care worker	88	All from 10 work units	Cross-sectional
2, 3, 5	29	42.3 (7.7) 33-56	Firefighter	97	Volunteers	Cross-sectional (2, 3) Longitudinal (5)
4	135	40.7 (7.5) 30-54	Firefighter	82	Stratified sampling	Longitudinal

physical and mental capacity of Finnish professional firefighters (3-year study) (Punakallio et al., 1999). Most of the data in this study are from the second cross-section in 1999 (Figure 3).

At baseline in 1996, 210 professional male firefighters were selected from central and southern Finland by stratified sampling. Samples were obtained from all professional, operational firefighters in the age groups of 30-34 (n = 254), 40-44 (n = 208) and 50-54 (n = 120) years in 1996 and were from 28 fire departments situated within 100 km of Helsinki (southern Finland) or 150 km of Kuopio (central Finland). About 9 out of 10 of the selected firefighters (89%) participated in the balance tests and responded to the questionnaire.

5.1.1 Study of balance abilities among different aged workers in physically demanding jobs (Study 1)

In addition to firefighters, Study 1 included

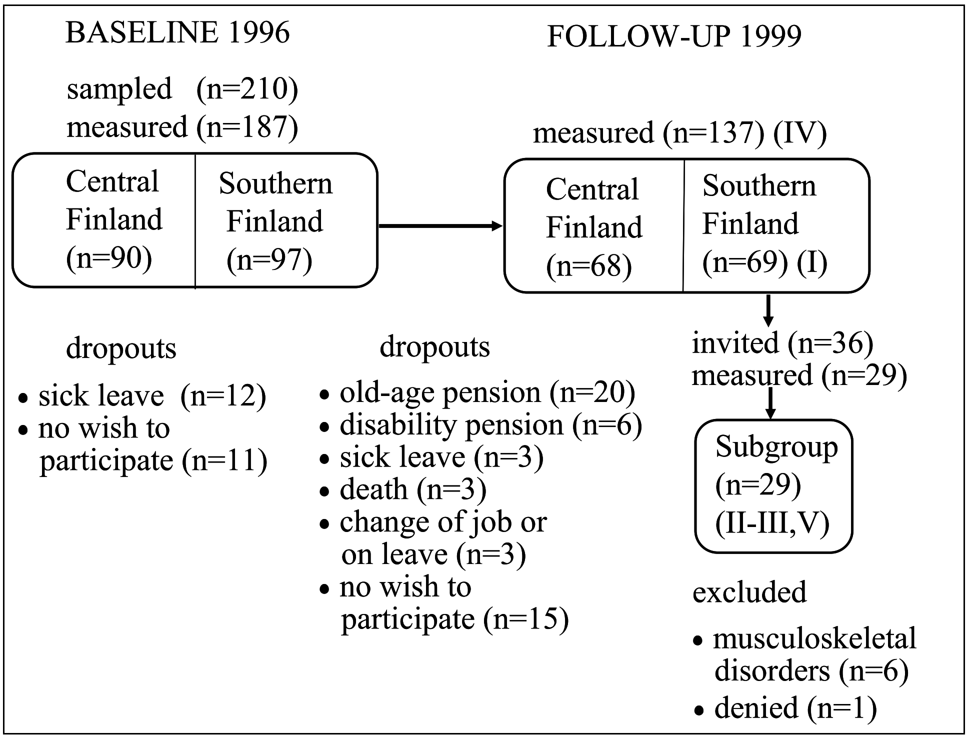

Figure 3. Sampling, number of subjects (n) and dropouts in different phases and parts of the 3-year study of firefighters.

construction workers, nursing staff and home care workers (Table 3). The construction workers came from both private companies and the municipal sector of the city of Lappeenranta. Their balance was measured when they took part in their periodic health check-ups in an occupational health care unit. Municipal home care workers, who cared for elderly people in private or institutional homes, from 10 entire work units in the city of Helsinki formed the initial sample of home care workers (Pohjonen, 2001a). Their balance tests were carried out at the time of their 5-year follow-up tests for physical fitness. Altogether 60 municipal nursing workers were selected by stratified sampling from 216 nursing workers from an old people's home in the city of Helsinki (Pohjonen et al., 2003). The data on firefighters came from those in southern Finland who participated in the follow-up tests (in 1999) in the 3-year study (Figure 3, Table 3).

5.1.2. Studies of balance and slip risk with fire-protective equipment and the reliability of the balance tests (Study 2, 3, 5)

In Studies 2, 3 and 5, the subjects were a subgroup (n = 29) of the 69 firefighters from southern Finland who participated in the follow-up tests of the 3-year study (Figure 3, Table 3). A total of 36 male firefighters in two age groups (33-38 and 43-56 years) were asked to volunteer for the studies. Six of the firefighters over 50 years of age were excluded because they had had low-back pain during the preceding year, had acute low-back or other musculoskeletal pain or had disorders that might have been exacerbated by the activities in the studies. After the selection process, one young firefighter refused to participate, and the final sample included 29 firefighters.

5.1.3. Study of the predictive value of the balance tests (Study 4)

In study 4 the subjects were firefighters who participated in balance tests in 1996 and responded to the questionnaires in 1996 and 1999 in the 3-year study (Figure 3). The study sample also included six firefighters who retired on a disability pension during the 3-year follow-up. They were included in the category of poor work ability in 1999. Furthermore, eight firefighters who participated in the laboratory tests did not respond to the questionnaire. Therefore, the final number of subjects was 135 (Table 3).

5.2. Balance measurements (Study 1-5)

5.2.1. Functional balance

The balance tests and variables, from Studies 1-5, are shown in Table 4. Functional balance was measured by a test in which a subject walked forwards, backwards and turned 180 degrees in the middle on a 2.5-m long, 9-cm wide and 5-cm thick wooden plank (Figure 2, Study 5) (Punakallio et al., 1997a). He or she was instructed to walk as quickly as possible without falling off the plank or touching the floor, as these movements were considered errors. It was also an error if the subject turned around before or after the mid-area of the plank or if the subject did not step on the footprints at the ends of the plank. The performance time and the number of errors were recorded. The sum variable was also calculated by summing the time and the number of errors, where one error was assigned a value of 1 s.

5.2.2. Postural balance

In Studies 1-3 postural balance was measured using the Good Balance measurement device of Metitur Ltd (Metitur, 2001), and in study 4 postural balance tests were carried out on a custom-made force platform (Starck et al., 1993; Takala et al., 1997). The outputs of the instruments were voltage signals from force transducers that registered vertical forces and anteroposterior and mediolateral moments in relation to the central axis of force platform. The force transducers were situated in each corner of the platforms. The Good Balance measurement system consisted of an equilateral triangular force platform, with a side length of 800 mm, connected to a computer through an electronic unit, which included a 3-channel amplifier and a 12-bit analogue-to-digital (A/D) converter. The analogue signals were amplified and then digitized with a sampling frequency of 50 Hz and passed to the computer through a serial (com) port. Then the data were filtered and processed in digital form by the software. The data of each channel were filtered separately using two different filters: a 7-point median filter and lowpass infinite impulse response filter with a cut-off frequency of 20 Hz. The median filter removed or effectively reduced impulse noise, whereas high-frequency noise, caused by the measurement system and A/D conversion, was reduced by lowpass filtering (Aalto, 1997).

The custom-made force platform consisted of two square metal plates, with a side length of 400 mm, placed horizontally and separated by force measuring elements (Starck et al., 1993; Takala et al., 1997). After amplification, 12-bit A/D conversion of the force signals was carried out, the signals being digitized with a sampling frequency of 40 Hz. Measurement noise was decreased by filtering signals digitally with a three-point median

Table 4. Variables measured in Studies 1-5.

Variables	Study	Reference
Balance tests		
Functional balance		Punakallio et al., 1997a
Performance time (s)	1-5	
Performance time (s) + errors	1-5	
Errors (number)	1-5	
Dynamic stability		Metitur, 2001
Performance time (s)	3, 5	
Distance traveled by COP (mm)	3, 5	
Postural balance		
Normal standing (EO, EC) 40 s		Era et al., 1996; Metitur, 2001
Mediolateral velocity ($mm·s^{-1}$)	1 (EO), 2	
Anteroposterior velocity ($mm·s^{-1}$)	1 (EO), 2	
Velocity moment ($mm^2·s^{-1}$)	1 (EO), 2, 3	
Tandem standing (EO) 20 s		Era et al., 1996; Metitur, 2001
Mediolateral velocity ($mm·s^{-1}$)	1	
Anteroposterior velocity ($mm·s^{-1}$)	1	
Velocity moment ($mm^2·s^{-1}$)	1	
Normal standing (EO, EC) 30 s		Starck et al., 1993; Takala et al., 1997
Mean sway velocity ($mm·s^{-1}$)	4	
Mean sway amplitude (mm)	4	
Perceived balance (1-5)	4	Lusa-Moser et al., (unpublished data), Punakallio et al., 1997a
Risk of slipping and falling		
Sliding distance of the foot (cm)	3	Grönqvist, 1995
Work ability		
Work ability index (7-49)	4	Tuomi et al., 1991, 1998
Perceived physical work ability (1-5)	4	Tuomi et al., 1991, 1998
Work experience (years)	1-5	
Physical activity		
Frequency (not at all-≥3 times/week)	1-5	Aromaa et al., 1989
Muscular capacities		
Sit and reach (cm)	3	Pollock and Willmore, 1990
Squatting (repetitions/60s)	1, 3	Lusa, 1994
Squatting (repetitions/30s)	1	Aura, 1994
Sit-up (repetitions/60s)	3	Lusa, 1994
Trunk extension strength (N)	3	Viitasalo et al., 1977
Knee extension strength (N)	3	Viitasalo et al., 1985
Aerobic capacity		
VO_{2max} ($ml·min^{-1}·kg^{-1}$, $l·min^{-1}$)	2	
Anthropometrics		
Body height (cm)	1-5	
Body weight (kg)	1-5	
Body mass index ($kg·m^{-2}$)	1-5	

Abbreviations: EO = eyes open, EC = eyes closed, VO_{2max} = maximal oxygen consumption.

filter and thereafter with a 16-order finite impulse response filter with a cut-off frequency of 10 Hz.

From the filtered data the x- and y-coordinates of the COP displacements during the measurement time were then calculated following the procedures reported by Hoffmann (1998) (Good Balance) and Takala et al. (1997) (custom-made platform). In the Good Balance system on the basis of the COP coordinates three postural balance outcome variables were finally calculated: anteroposterior sway velocity ($mm·s^{-1}$), mediolateral sway velocity and velocity moment ($mm^2·s^{-1}$) (Table 4). Sway velocities were calculated by dividing the total COP displacements in each direction by the measurement time (s). The velocity moment refers to first moment of velocity calculated as the mean area covered by the movement of the COP during each second of the test (Era et al., 1996). The calculation of the velocity moment took into account both the distances from the geometric midpoint of the whole test and the speed of movement during the same period (Era et al., 1996). All analyses involving the Good Balance force platform, were carried out by centralizing the data of each test with respect to its own midpoint. The sway parameters of the custom-made force platform were related to the arithmetic mean point, which was calculated by averaging the mediolateral and anteroposterior displacement of the COP over the whole measurement period. The parameters calculated, when the custom-made platform was used, were the mean sway velocity ($mm \cdot s^{-1}$) and the mean sway amplitude (mm) (the anteroposterior and mediolateral components of sway were analyzed together) with eyes open and closed. The mean amplitude was the mean distance between the sampling points and the arithmetic mean point.

The following measurements were carried out while the subject was standing on the force platform: 1) normal standing for 40 s (Good Balance) or 30 s (custom-made platform) with the the eyes open, the hands placed on hips and the gaze fixed on a cross on the opposite wall at eye level, 2) normal standing as before, but with the eyes closed, 3) tandem standing for 20 s (Good Balance) with the eyes open and the feet positioned heel-to-toe along the midline of platform, the subject being instructed to stand as immobile as possible. Table 4 shows the variables measured with each force platform technique in Studies 1-5.

5.2.3. Dynamic stability

Dynamic stability was also assessed using the Good Balance measurement system (Metitur, 2001). In the test, the monitor for visual feedback was on the table in front of the subject. Eight targets were shown in a circle on the computer monitor (Figure 1, Study 5). The idea of the measurement was to move the COP through the targets. The subject was instructed to reach the targets as quickly and as accurately as possible and to avoid unnecessary and uneconomic movements. The performance time (s) (time used to complete the test) and the distance (mm) (the extent of the path traveled by the COP during the test) were measured. Dynamic stability and postural balance and parameters were scaled according to body height in Studies 1-3 and 5 (Metitur, 2001).

5.2.4. Perceived balance abilities

Perceived balance abilities in relation to the balance demands of work was inquired about in a questionnaire (Lusa-Moser et al., unpublished data; Punakallio et al., 1997a) using the following question: "Balance is needed especially in work in high and narrow places. How do you rate your current balance abilities with respect to the balance demands of your work?" The scale of the question ranged from 1 to 5: 1 = very poor, 2 = rather poor, 3 = moderate, 4 = rather good, 5 = very good. Categories 1 through 2 (poor) were combined for further analysis, as were categories 4 and 5 (good). The results were also presented with categories 1 through 3 (poor-to-moderate) merged.

Anthropometrics, muscle capacities and cardiorespiratory capacity (Table 4) were also measured, and they were considered to be individual background factors for balance. A detailed description of the measurements of balance and the other physical capacities are given in the original studies.

5.3. Balance and slipping tests with fire-protective equipment (Study 2-3)

5.3.1. Fire-protective equipment

The FPE included a two-piece multilayer fire-protective suit that fulfilled the European standard (EN 469: 1995) (Committee for Standardization, 1995). The subjects also wore Nordic-type middle and under clothing, rubber safety boots, a helmet and a tool belt, and they carried Dräger SCBA (Germany) with one steel air bottle worn on the back and a full-face mask. The mass of the FPE was 25.9 kg, of which the SCBA accounted for 15.5 kg.

5.3.2. Balance tests with and without the fire-protective equipment

After demonstrations of the balance tests, the subjects were allowed to practice once before the measurement. Each test and equipment combination was measured once. First, the subjects performed the baseline postural balance test with their eyes open and in sportswear (t-shirt, shorts and barefoot). The test was immediately repeated with the eyes closed. Second, the baseline functional balance test was carried out. Third, the functional balance test was performed 1) with the full-face mask of the SCBA, 2) with the rubber safety boots, and 3) with the SCBA. Finally, the functional and postural balance tests were carried out with the FPE.

5.3.3. Slipping tests with the fire-protective equipment

Slipping tests were carried out on a straight 8-m long path. In one area (400 × 600 mm), covered by stainless steel, water and detergent (0.5 % by weight sodium lauryl sulfate solution) or glycerol (85 % by weight) were spread on the path. The first half of the track was covered with a rubber carpet. The subject wore a safety harness fastened into a rail above the track.

The length of each slip (i.e., horizontal sliding distance of the foot in the walking direction in centimeters) was assessed with one high-speed camera system. Video-recordings were used to estimate the seriousness of the slipping incidents. The slips were classified into the following four categories according to the efforts of the walkers to restore their balance by corrective movements (Hirvonen et al., 1994): 1) no observable slipping (the length of the slip was less than 5 cm or the subject made no corrective movement), 2) controlled slip (the subject swayed and made controlled corrective movements and would probably have regained his balance even without the safety harness), 3) vigorous slip (the subject slipped and staggered significantly; the corrective movements were vigorous; without the harness a loss of balance would have been possible), and 4) extremely vigorous slip (the subject lost his balance and was suspended by the safety harness).

Each subject performed four slipping tests under the following conditions: 1) dry path, walking speed 100 steps·min^{-1}, 2) path spread with water and detergent, walking speed 100 steps·min^{-1}, 3) path spread with glycerol, walking speed 100 steps·min^{-1}, and 4) path spread with glycerol, walking speed 120 steps·min^{-1}. The walking speeds were defined by a metronome. The tests were performed in the same order with every subject, but none of them were aware of the slipperiness of the path in advance. The subjects were asked to walk at the given walking speed as naturally as possible throughout the tests.

5.4. Questionnaires (Study 1-5)

5.4.1. Perceived work ability

Perceived work ability was inquired about with the work ability index (WAI) using a questionnaire (Tuomi et al., 1991, 1998). The WAI is a sum variable based on the subjective estimations of work ability in relation to physical work ability (PWA) and mental job demands. It also includes questions on current diseases, estimated work impairment due to diseases, sick-leave days during the past 12 months, prognosis of work ability after 2 years and mental resources. The WAI score ranges from 7 to 49 and is divided into four categories of work ability as follows: poor (7 to 27 points), moderate (28 to 36 points), good (37 to 43 points), and excellent (44 to 49 points). The cut points for poor and excellent work ability were chosen from the 15th percentile of the index distribution of the total studied population, and the moderate and good classifications were the number of points dividing the distribution of the WAI in half (Tuomi et al., 1985; Tuomi et al., 1998). Furthermore work experience and physical activity were inquired about with the use of questionnaires in (Table 4).

5.5. Assessment of the predictive value of the balance tests (Study 4)

Work-related validity was assessed by examining the predictive value of the results of the balance tests and the perceived balance abilities in respect to the WAI and PWA. There were no classifications available for the functional and postural balance tests. Therefore with the continuous predictive variables, the subjects were divided into the categories of "good", "average" and "poor" using tertiles of the variables as the cut points. In the functional balance test, no errors were categorized as "good", one error was "average" and more than one error was "poor" (Table 10).

5.6. Assessment of reliability (Study 5)

In the evaluation of the trial-to-trial reproducibility, the functional balance and dynamic stability tests were repeated six consecutive times in one test period with a break of a few seconds between the trials. The test-retest stability was studied over a longer period by carrying out the balance tests again about 2 months later. Stability between the test sessions was calculated using both the last trial in each trial combination and the best values of the first to second, first to third, first to fourth, first to fifth, first to sixth and third to sixth consecutive trials as the outcome variables. From these two, the outcome variable with the highest test-retest stability was chosen as the final outcome variable.

5.7. Statistical analysis

In Study 1, one- and two-way general linear models were used to analyze the effects of age and occupation on the balance tests. Furthermore, in each occupational group, multiple comparisons with Tukey's method were made to determine the significant differences between the age groups. If differences were found between occupations, they were further evaluated separately among the "male-specific" occupations and the "female-specific" occupations. These models were adjusted for the muscular endurance of the legs, physical activity and work experience.

In Study 2, linear mixed models (analysis of variance with repeated measurements) were used to

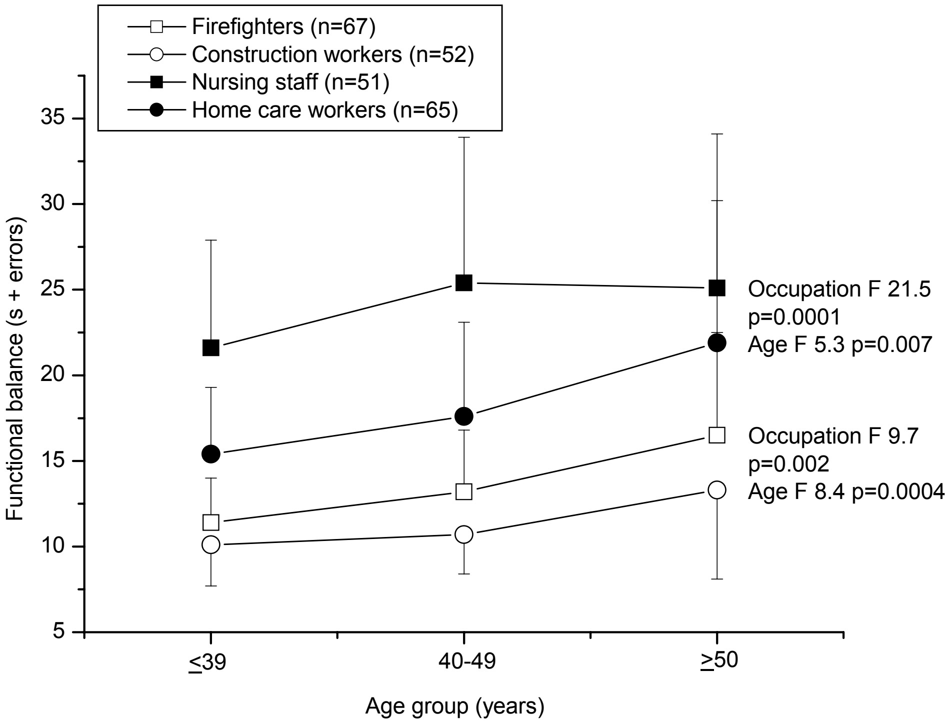

Figure 4. Functional balance (means and SD) of the three age groups of subjects from different occupations and the significance between balance and age and balance and occupation.

study the effect of FPE, age, and eye closure on the results of balance abilities. The interaction of FPE and age, eye closure and age, as well as the interaction of FPE, age, and eye closure, was added to the models. The models were fitted using the PROC MIXED procedure in the Statistical Analysis System, SAS Version 8.2 (SAS Institute, 1999).

In Study 3 Student's t-tests were applied to determine the statistical significance for age, balance and muscle capacities between the subjects as classified by sliding distance (< 5 cm versus ≥ 5 cm).

In Study 4, logistic regression analysis with proportional odds assumption (Peterson and Harrell, 1990) was used when the associations between the outcome (WAI and PWA determined in 1996 and 1999) and predictive variables (functional and postural balance and perceived balance in 1996) were examined. The final models (outcome in 1999) were estimated by adding the previous outcome in 1996 to the models (i.e., transition models) (Diggle et al., 1994). In addition, the models were adjusted for age. Odds ratios (OR) and 95% confidence intervals (CI) were calculated.

In Study 5, two-way general linear mixed models (analysis of variance with repeated measurements) were used to assess the systematic error between six consecutive trials and between the test sessions with an interval of 2 months. Stability between the test sessions was calculated using both the last trial in each trial combination and the best values of the first to second, first to third, first to fourth, first to fifth, first to sixth and third to sixth consecutive trials as outcome variables.

The absolute reliability between trial-to-trial and between test-retests in Study 5 was expressed using Bland and Altman's 95% LoA (Bland and Altman, 1986; Atkinson and Nevill, 1998). The LoA was calculated as follows. First, the differences (=bias) and the standard deviation between the tests were calculated, and then the standard deviation of the differences was multiplied by 1.96 to obtain the 95% random error component. The reproducibility between trial-to-trial and stability between test-retests over time was estimated by the ICC with 95% CI. The ICC values were classified according to Fleiss (1986), with the exception that the excellent category (> 0.75) was divided into two categories, as follows: > 0.90 excellent, > 0.75-0.90 good, 0.40-0.75 modest and < 0.40 poor reproducibility.

Statistical analyses were performed using the Statistical Analysis System, SAS Version 8.2 or 6.2 (SAS Institute, 1989 and 1999) and SPSS 11.5 (SPSS Inc, 1997). The statistical significance was defined as $p < 0.05$.

Table 5. Postural balance of the different occupational groups in the normal standing position by age and the significant differences between the age groups.

	Age group (years)			
	≤39 (1)	40-49 (2)	≥50 (3)	
Variable / occupation	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p < 0.05**
Mediolateral velocity (mm·s^{-1})				
Firefighters	3.2 (.9)	2.9 (.8)	4.6 (2.5)	1-3, 2-3
Nursing staff	4.5 (2.4)	3.9 (1.2)	4.9 (1.5)	
Home care workers	4.6 (1.4)	4.6 (1.6)	3.7 (1.1)	
Anteroposterior velocity (mm·s^{-1})				
Firefighters	5.0 (.9)	5.5 (1.3)	6.6 (1.6)	1-3, 2-3
Nursing staff	5.6 (2.7)	5.6 (1.8)	7.1 (2.6)	
Home care workers	5.4 (2.0)	5.6 (2.5)	5.6 (2.0)	
Velocity moment (mm^2·s^{-1})				
Firefighters	7.7 (3.4)	8.4 (4.6)	14.7 (9.1)	1-3, 2-3
Nursing staff	8.0 (5.0)	10.2 (6.4)	15.7 (8.0)	1-3
Home care workers	10.3 (4.0)	11.5 (6.5)	9.0 (3.6)	

6. RESULTS

6.1. Relationship between balance abilities and the age and occupation of workers in physically demanding jobs (Study 1)

In general, age and occupation had a significant effect on functional balance (F = 15.0, p = 0.0001 and F = 69.2, p = 0.0001, respectively). Among the firefighters, construction workers and home care workers, the younger and middle-aged subjects were significantly (p = 0.028-0.001) faster, and they made fewer errors than the older ones (Table 3, Study 3). About one-third of the male subjects (25% of the construction workers, 36% of the firefighters) and 54-57% of the female subjects made one error or more in the test. Furthermore, the construction workers had significantly better functional balance than the firefighters. The home care workers also performed faster in the test than the nursing workers (Figure 4). These differences remained significant when the muscular endurance of the legs, the intensity of physical exercise and work experience were used as covariates.

Significant effects due to age were observed for the mean mediolateral and anteroposterior sway velocity in normal (F = 4.5, p = 0.010, and F = 3.9, p = 0.020, respectively) and tandem (F = 13.8, p = 0.0001, and F = 3.8, p = 0.021, respectively) standing positions. The older subjects in each occupation tended to sway the most. The differences in the mean velocity between the occupational groups in the mediolateral direction in the normal standing position were also significant (F = 5.4, p = 0.006) (Tables 5 and 6).

The differences between the different aged

Table 6. Postural balance of the different occupational groups in the tandem standing position by age and the significant differences between the age groups.

	Age group (years)			
	≤39 (1)	40-49 (2)	≥50 (3)	
Variable / occupation	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p < 0.05**
Mediolateral velocity (mm·s^{-1})				
Firefighters	16.1 (3.6)	17.2 (3.3)	21.8 (6.6)	1-3, 2-3
Nursing staff	15.9 (4.1)	22.5 (2.9)	24.3 (8.5)	1-2, 1-3
Home care workers	14.7 (2.6)	22.1 (2.2)	19.2 (4.1)	1-2, 1-3
Anteroposterior velocity (mm·s^{-1})				
Firefighters	13.8 (3.5)	13.5 (3.0)	17.7 (4.0)	1-3, 2-3
Nursing staff	13.4 (3.1)	16.3 (4.4)	17.4 (8.6)	
Home care workers	12.1 (3.1)	13.5 (3.7)	13.6 (3.0)	
Velocity moment (mm^2·s^{-1})				
Firefighters	59.4 (31.4)	55.2 (25.7)	85.9 (36.9)	1-3, 2-3
Nursing staff	57.5 (30.1)	79.9 (34.3)	88.3 (59.1)	
Home care workers	38.9 (18.7)	55.2 (23.2)	62.5 (26.3)	1-2, 1-3

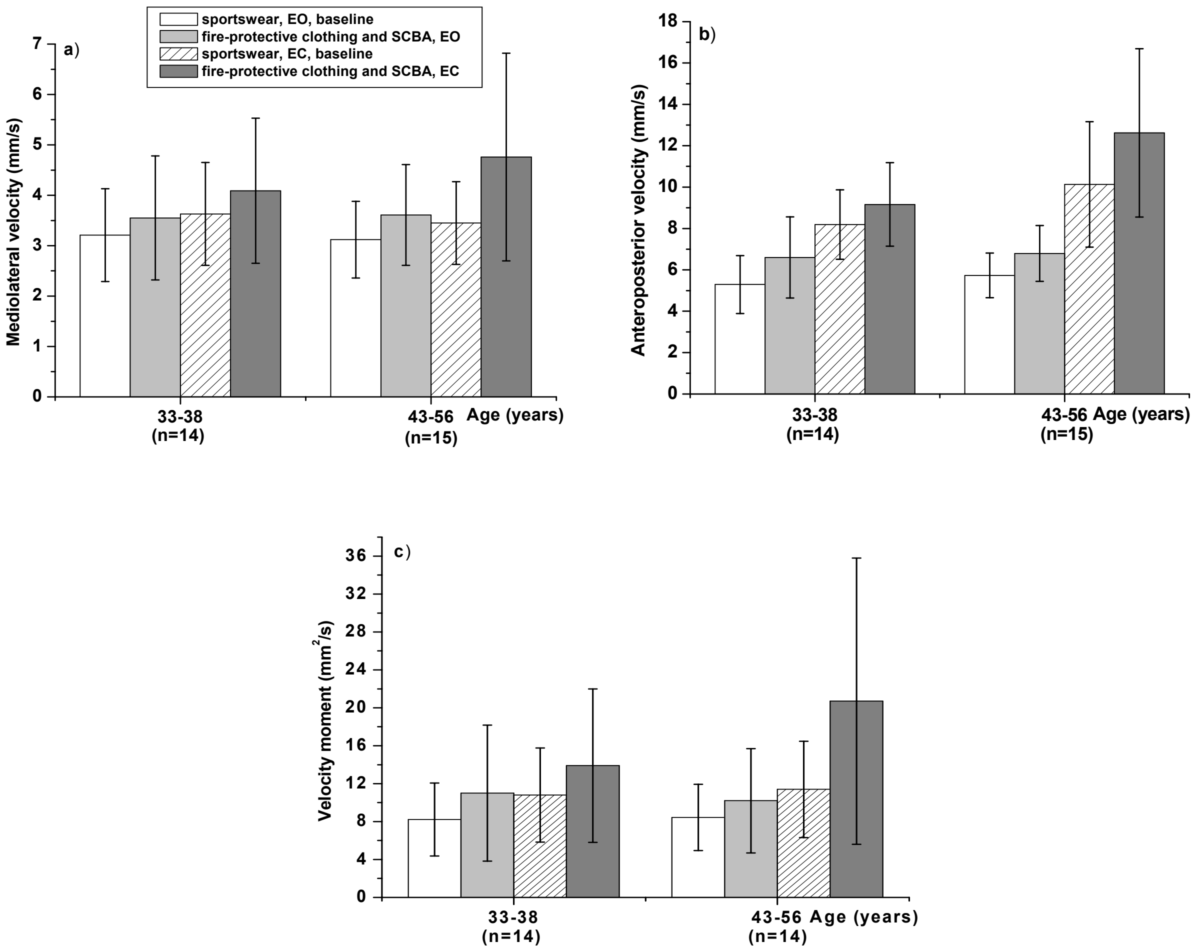

Figure 5a-c. Postural balance (mean and SD) of two age groups with fire-protective clothing and SCBA (self-contained breathing apparatus) and in the baseline tests with the sportswear (EO=eyes open, EC=eyes closed).

subjects were significant for velocity moment as well (F = 3.8, p = 0.020, for normal standing; F = 8.2, p = 0.0004, for tandem standing). The older subjects tended to sway the most (Table 5 and 6). During tandem standing, the home care workers tended to have lower values than the other occupational groups. The difference was significant in a comparison with the velocity moment of the nursing workers (p = 0.040), but the difference disappeared when the model was adjusted for muscular endurance of the legs.

6.2. Effects of fire-protective equipment on the balance abilities of younger and older firefighters (Study 2)

The postural balance was significantly poorer in the tests with the FPE than in the baseline tests with the sportswear (Figure 5a-c, Table 7). Age had a significant effect on the anteroposterior velocity, whereas eye closure increased postural sway significantly for all the variables. The interaction of FPE, age and eye closure was significant for the velocity moment, and it was nearly significant for the mediolateral velocity of postural sway (Table 7). The harmful effect of the equipment on postural balance with the eyes closed was greater for the older firefighters (p = 0.033 for mediolateral velocity and p=0.005 for velocity moment) than for the younger firefighters (p = 0.737 for mediolateral velocity and p = 0.893 for velocity moment.)

The use of the FPE impaired functional balance significantly (F = 5.5, p = 0.0002) as well. With the exception of the safety boots, the different combinations of equipment had a significant effect on functional balance (Figure 6). The interaction of the FPE and age was, however, not statistically significant (Figure 6). The age-related differences in functional balance with and without equipment were close to statistical significance (p = 0.065).

Table 7. Effects of fire-protective clothing (FPC) with SCBA (self-contained breathing apparatus), age, eyes closed (EC) and their interaction on postural balance (n=29). F and p-values were determined in an analysis of variance with repeated measurements.

	Mediolateral velocity		Anteroposterior velocity		Velocity moment	
Variable	**F**	**P**	**F**	**P**	**F**	**P**
FPC+SCBA	11.3	.002	31.2	<.0001	12.1	.0001
Age	.12	.736	5.47	.027	0.74	.396
EC	22.0	<.0001	101.2	<.0001	20.7	.001
FPC+SCBA·age	1.59	.218	.94	.340	.90	.352
EC·age	1.02	.322	10.2	.004	3.85	.060
FPC+SCBA·age·EC	2.56	.096	1.33	.281	4.48	.021

6.3. Balance, muscular capacities and age in association with slip and fall risk (Study 3)

When the path was spread with water and detergent, altogether two subjects in the older age group slipped 4 cm, and the sliding movement and balance was well controlled. Every subject slipped in the tests with glycerol at both walking speeds. The average values of the sliding distances were 9.7 (SD 9.1) cm (100 steps·min^{-1}) and 15.6 (SD 18.2) cm (120 steps·min^{-1}) in the 33-to-38-year age group. The corresponding values were 10.8 (SD 15.3) cm and 18.0 (SD 18.6) cm in the 43-to-56-year age group.

Half of the subjects slipped more than 5 cm in the test. About two-thirds (37/54) of the slip incidents were well controlled or needed no corrective movements (Table 8).

The subjects whose sliding distance with glycerol was ≥ 5 cm performed significantly poorer in the dynamic stability test than those who slipped < 5 cm when the walking speed was 100 steps·min^{-1} (Table 9).

6.4. Predictive value of balance with respect to the perceived work ability of firefighters (Study 4)

During the 3-year follow-up the proportion of the subjects whose WAI category decreased was 34% (n = 45), and the proportion of those whose WAI was poor increased from 6% to 16%. The WAI category was increased for 21 subjects (17%) (Table 2, Study 4). Correspondingly, PWA decreased for 30% of the subjects (n = 39) and increased for 5% (n = 7) (Table 3, Study 4).

At baseline in 1996, when the models were adjusted for age, the poor PWA category was associated with poor results in the majority the balance tests used (Table 10). In addition, poor results for performance time in the functional balance test (OR 2.2, CI 0.9-5.4) and time (s) + errors (OR 2.4, CI OR 0.9-5.4) and poor-to-moderate perceived balance (OR 9.8, CI 3.8-24.9) was associated with a lower WAI category at baseline (Table 10). The postural sway velocity and the sway amplitude with the eyes open were excluded both from Table 10 and from the further analyses because the OR values were not significant in any category.

The final predictive models were adjusted for age and also the baseline WAI category. Table 11 shows the predictors that were still statistically significant (i.e., poor categories in the functional balance test, sway amplitude with the eyes closed and perceived balance in 1996 indicated 3.6-, 2.3- and 9.5-fold risks, respectively, for a decline in the WAI during the 3-year follow-up). The results were also calculated so that the categories of poor and moderate were grouped together for perceived balance. Then poor-to-moderate perceived balance showed a 2.4-fold risk (OR 0.9-6.6) for a decline in the WAI in comparison with good perceived balance abilities. Age and the baseline WAI category were powerful predictors of the WAI in 1999. The final models for PWA did not produce valid results because the PWA in 1996 and 1999 were strongly related.

6.5. Reliability of the dynamic stability and functional balance tests (Study 5)

6.5.1.Trial-to-trial reproducibility

The performance time of the dynamic stability test and the functional balance test improved significantly (p < 0.001) after repeated trials in both test sessions. After the third trial the improvement between consecutive trials was no longer significant (Figure 7a-d, Table 2, Study 5), and the average difference between the individual means was <0.5 s between the third and fourth trials (Table 3, Study 5).

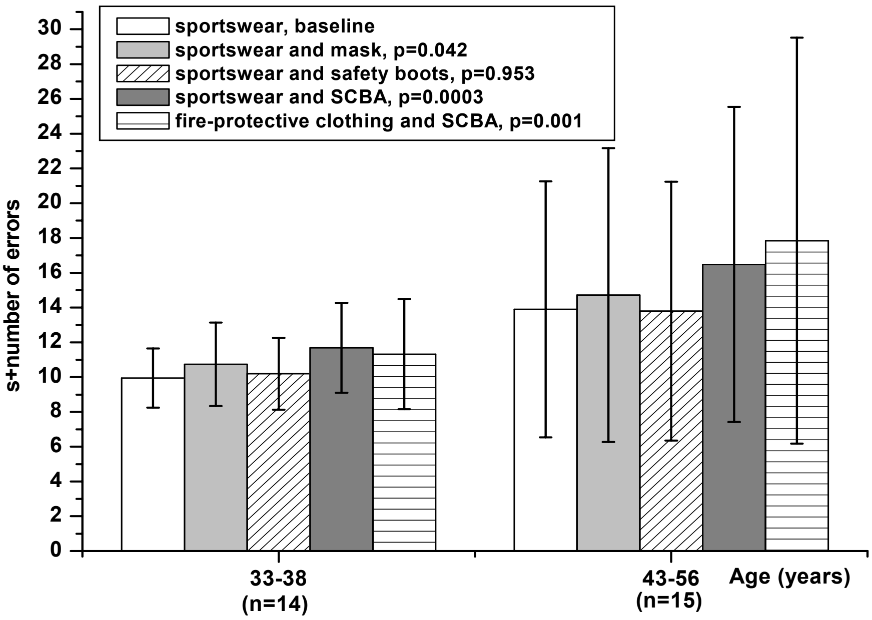

Figure 6. Functional balance (mean and SD) of two age groups of firefighters and the significance of the different equipment combinations in the comparison with the baseline test (sportswear only). (SCBA=self-contained breathing apparatus).

6.5. Reliability of the dynamic stability and functional balance tests (Study 5)

6.5.1.Trial-to-trial reproducibility

The performance time of the dynamic stability test and the functional balance test improved significantly ($p < 0.001$) after repeated trials in both test sessions. After the third trial the improvement between consecutive trials was no longer significant (Figure 7a-d, Table 2, Study 5), and the average difference between the individual means was <0.5 s between the third and fourth trials (Table 3, Study 5)

In both balance tests, the LoA values were larger and the ICC values were smaller almost without exception between the first and second consecutive trials when compared with the results of all the other consecutive trials (Table 12). The differences between the LoA and ICC values of trial combinations 2-3, 3-4, 4-5, 5-6 were minor. The very lowest LoA values, as well as the highest ICC values occurred either between the fifth and sixth (dynamic stability) or the fourth and fifth (functional balance) trials.

Table 8. Seriousness of the slipping incidents and the length of slips on glycerol in the age groups of firefighters at the walking speeds of 100 and 120 steps·min^{-1}. The values are the number of subjects in each category (n) with the ranges of the slip distances in parentheses.

	Walking speed (steps·min^{-1})			
	100	120	100	120
	Age group (years)			
	33-38		43-56	
Seriousness of the slips	n (slip distance range, cm)		n (slip distance range, cm)	
No corrective movement	1 (2)	1 (2)	2 (2)	1 (2)
Controlled slip [a]	8 (1-14)	7 (2-20)	9 (2-11)	7 (3-8)
Vigorous slip [b]	5 (13-20)	2 (20-50)	3 (40-50)	2 (15-40)
Extremely vigorous slip [c]	0	1 (50)	1 (25)	4 (30-50)
	n total 14	n total 11	n total 15	n total 14

[a] Balance could also be regained without the safety harness.
[b] Loss of balance is possible without the safety harness.
[c] Balance was lost and the subject was suspended by the safety harness.

Table 9. Age, body mass index, balance and muscular capacities as classified by sliding distance when the path was spread with glycerol and the walking speed was 100 steps·min^{-1}. (EO = eyes open, EC = eyes closed).

	Sliding distance		
	<5 cm (n = 14)	≥5 cm (n = 15)	
Characteristic	**Mean (SD)**	**Mean (SD)**	**P-value**
Age (years)	43.6 (8.5)	41.4 (6.9)	
Body mass index (kg·m^{-2})	27.0 (3.1)	26.2 (1.9)	
Balance			
Functional balance (s)	10.7 (2.2)	12.2 (7.7)	
Functional balance (s+errors)	11.0 (2.2)	12.9 (7.7)	
Functional balance (errors)	.4 (.6)	.7 (.7)	
Dynamic stability (mm)	1393 (379)	1902 (565)	.0094
Dynamic stability (s)	15.1 (2.3)	18.8 (4.3)	.0095
Postural balance (EO) (mm^2·s^{-1})	7.5 (3.1)	9.2 (4.0)	
Postural balance (EC) (mm^2·s^{-1})	10.4 (3.9)	11.8 (5.9)	
Perceived balance (1-5)	3.7 (.7)	3.4 (.9)	
Muscular capacities			
Sit and reach (cm)	32.9 (8.9)	29.9 (10.7)	
Squatting (repetitions/60s)	28.4 (5.8)	24.8 (8.9)	
Sit-up (repetitions/60s)	35.4 (7.7)	34.3 (6.7)	
Trunk extension strength (N)	795 (143)	866 (149)	
Knee extension strength (N)	532 (122)	494 (128)	

6.5.2. Test-retest stability

The performance time of the dynamic stability test in two test sessions with an interval of 2 months was significantly ($p < 0.001$) shorter in the retest. The distance was shorter as well, and it was close to statistical significance ($p = 0.06$) (Figure 7a-d).

The LoA and ICC values of the test-retest stability were reported using the best values as the outcome variable because they were smaller than the results obtained in the last trial of each trial combination as a final score. In the dynamic stability test, the LoA values were the smallest (Table 13), and the ICC values were the highest when the test-retest stability was calculated using the best value of five repeated trials as the outcome variable. In the functional balance test the most reliable LoA and ICC values were obtained using the best of three trials as the outcome (Table 13).

7. DISCUSSION

7.1. Main findings

The main findings of this study were that the balance abilities of the firefighters over 49 years of age were poorer than those of the age groups of <40 and 40-49 years. The decline of balance abilities among the construction, home care and nursing workers was not as consistent. Postural balance was also more detrimentally affected among the older firefighters than among the younger ones when they used fire-protective equipment (FPE) without visual input. Self-contained breathing apparatus (SCBA) was the most significant single piece of FPE to impair balance among both the younger and the older firefighters. Furthermore, fast and controlled performance in the dynamic stability test of the firefighters in all the age groups was related to less slip and fall risk with FPE. Older firefighters tended to slip longer and more seriously than the younger ones, but the difference was not significant.

It was also found that the construction workers were faster and made fewer errors than the firefighters in the functional balance test. Among the firefighters, poor performance in the balance tests was shown to be a risk factor for reduced work ability index (WAI) category after a follow-up of 3 years. Finally, the dynamic stability and functional balance tests showed reasonable reliability, especially, when the reliability was estimated from the best of at least three repeated trials.

7.2. Individual-, task- and environment-related aspects of balance control

The results of this study agreed with previous findings of age-related deterioration of postural and functional balance abilities among people of working age (Choy et al., 2003; Du Pasquier et al., 2003; Gill et al., 1991; Pohjonen, 2001a; Røgind et al., 2003) and of balance being the poorest among people over 50 years of age (Ekdahl et al., 1989; Era

Table 10. Age-adjusted odds ratios (OR) and 95% confidence intervals (CI) for balance abilities associated with the work ability categories at baseline in 1996 (n = 135). (EC = eyes closed).

	Work ability index 1996		Physical work ability 1996	
Predictor	**OR**	**CI**	**OR**	**CI**
Functional balance (s)				
Good ≤10.6	1.0		1.0	
Average >10.6≤13.1	2.3	1.0-5.4	5.2	2.0-13.4
Poor >13.1	2.2	0.9-5.4	3.2	1.2-8.5
Functional balance (errors)				
Good <1	1.0		1.0	
Average 1	0.7	0.3-1.5	1.5	0.7-3.2
Poor >1	1.0	0.3-2.9	2.3	0.8-7.0
Functional balance (s+errors)				
Good ≤11.1	1.0		1.0	
Average >11.1≤14.6	1.2	0.5-5.4	2.5	1.0-5.8
Poor >14.6	2.4	0.9-5.4	3.8	1.4-10.8
Sway velocity EC ($mm \cdot s^{-1}$)				
Good ≤19.2	1.0		1.0	
Average >19.2≤24.7	1.9	0.8-4.8	2.5	1.0-6.3
Poor >24.7	1.8	0.7-4.5	3.3	1.3-8.5
Sway amplitude EC (mm)				
Good ≤6.0	1.0		1.0	
Average >6.0≤7.5	1.8	0.7-4.3	2.4	0.9-6.0
Poor >7.5	1.3	0.5-3.2	2.6	1.0-6.5
Perceived balance [a]				
Good 4-5	1.0		1.0	
Moderate 3	8.3	3.2-21.4	4.4	1.7-11.4
Poor 1-2	57.7	9.9-336	34.4	6.1-193
Perceived balance [b]				
Good 4-5	1.0		1.0	
Poor-to-moderate 1-3	9.8	3.8-24.9	5.5	2.2-13.7

[a] The 95% CIs were very wide,
[b] therefore the results were also computed using two categories.

and Heikkinen, 1985). The present results do not agree with those of Hytönen et al., (1993) that postural balance was the most stable among healthy volunteers from different occupations aged 46-60 years or with those of Sihvonen et al. (1998), who detected only minor decreases in the balance of the working-age population. Although the same measurement tools and parameters would have been used, comparisons of the age-related results reported in different studies are difficult due to differences in the selection of the subjects, the varying age ranges of the subjects, and the differences in study design. As in the previous studies of Colledge et al. (1994), Matheson et al. (1999) and Straube et al. (1988), the age-related differences in the present study among home care and nursing workers were more often significant when the balance task was more challenging (i.e., the BOS was narrow as in tandem standing and beam walking in the functional test). One reason for the poorer balance among the older subjects in this study, when compared with the results of the younger ones, may be related to their lower muscular capacity. Colledge et al. (1994) suggested that the increase in body sway with aging is more likely to be due to the slowing of central integrative processes than to altered peripheral sensibility. Most of the studies of mechanisms contributing age-related balance changes deal with subjects over 60 years of age and young adults (Rankin et al., 2000; Teasdale and Simoneau, 2001), and they do not include working-age populations.

Furthermore, the present results parallel those of Kincl et al., (2002), who showed that the use of FPE also impairs balance performance. Moreover, age and visual condition affected the efficiency of the balance control system to compensate for the inconvenience caused by FPE. In the eyes-closed condition, FPE increased sway clearly more among the older firefighters than among the younger ones.

Table 11. Odds ratios (OR) and 95% confidence intervals (CI) for the significant predictors of the Work Ability Index (WAI) after the follow-up. The final models were adjusted for age and baseline WAI (1996) (n = 134), (EC = eyes closed).

	WAI 1999 Model 1		WAI 1999 Model 2		WAI 1999 Model 3	
Predictor	**OR**	**CI**	**OR**	**CI**	**OR**	**CI**
Functional balance (number of errors)						
Good <1	1.0					
Average 1	1.0	0.5-2.2				
Poor >1	3.6	1.0-12.7				
Sway amplitude (EC) (mm)						
Good ≤6.0						
Average >6.0≤7.5			1.0			
Poor >7.5			2.7	1.0-7.2		
			2.3	0.9-6.1		
Perceived balance						
Good 4-5					1.0	
Moderate 3					2.4	0.8-5.8
Poor 1-2					9.5	1.5-58.3
Age (years)						
30-34	1.0		1.0		1.0	
40-44	4.4	1.8-10.9	4.9	1.8-13.7	4.0	1.6-10.2
50-54	37.8	9.7-147	33.1	8.0-137	27.0	6.9-106
WAI 1996						
Excellent	1.0		1.0		1.0	
Good	3.3	1.3-8.2	3.9	1.4-11.0	2.7	1.0-6.7
Moderate	18.4	5.4-62.2	27.9	7.0-111	13.7	3.7-50.5
Poor	53.3	6.3-452	82.9	6.0->999	30.4	3.5-265

These findings also show that visual afferents are more important in balance control when FPE is used by firefighters over 43 years of age than when it is used by younger ones (33-38 years). The role of vision in balance control has been shown to increase at least after the age of 60 years (Du Pasquier et al., 2003; Perrin et al., 1997). Recently Choy et al. (2003) reported that reliance on vision for postural stability was clear among women aged 40-49 years in a single-limb stance, among 50-to-59 year-olds when they were standing on foam, and among 60-to-69-year-olds on a firm surface. The good balance abilities and physical capacity of younger firefighters, as well as their greater reliance on proprioceptive input rather than visual input in balance control, may help explain their greater ability to compensate for the harmful effects related to the use of FPE in eyes-closed conditions.

In the present study, SCBA was the most significant single piece of equipment to decrease balance performance. According to Egan et al., (2001) the United States Army's chemical protective ensemble, which includes a M40 protective mask, a chemical overgarment, gloves, and rubber overboots, but no respirator, does not affect postural balance, even after simulated field tasks of 18 minutes. SCBA affects balance control by shifting the place of body COG, and its weight (15.5 kg) also increases strain on the balance control system. Better balance control in firefighting and rescue operations may be achieved by replacing the currently-used steel air tanks with those made of composite materials, which are at least 6 kg lighter. According to this study, balance performance with the full-face mask of SCBA was also significantly poorer than that in the baseline test. The mask limits visual fields and thus may affect postural control because peripheral vision is important in locomotion and the detection of movement and changes of illumination (Paulus et al., 1984; Samo et al., 2003; Zelnick et al., 1994). This negative effect was not observed in the tests with and without the M40 protective mask (Egan et al., 2001). As in the results of Egan et al., (2001) the use of safety boots did not affect the balance of firefighters in this study. Therefore, safety boots do not contribute to a decline in balance performance due to decreased tactile cues from the feet. SCBA is usually used in difficult, unusual and rapidly changing work conditions, and it is

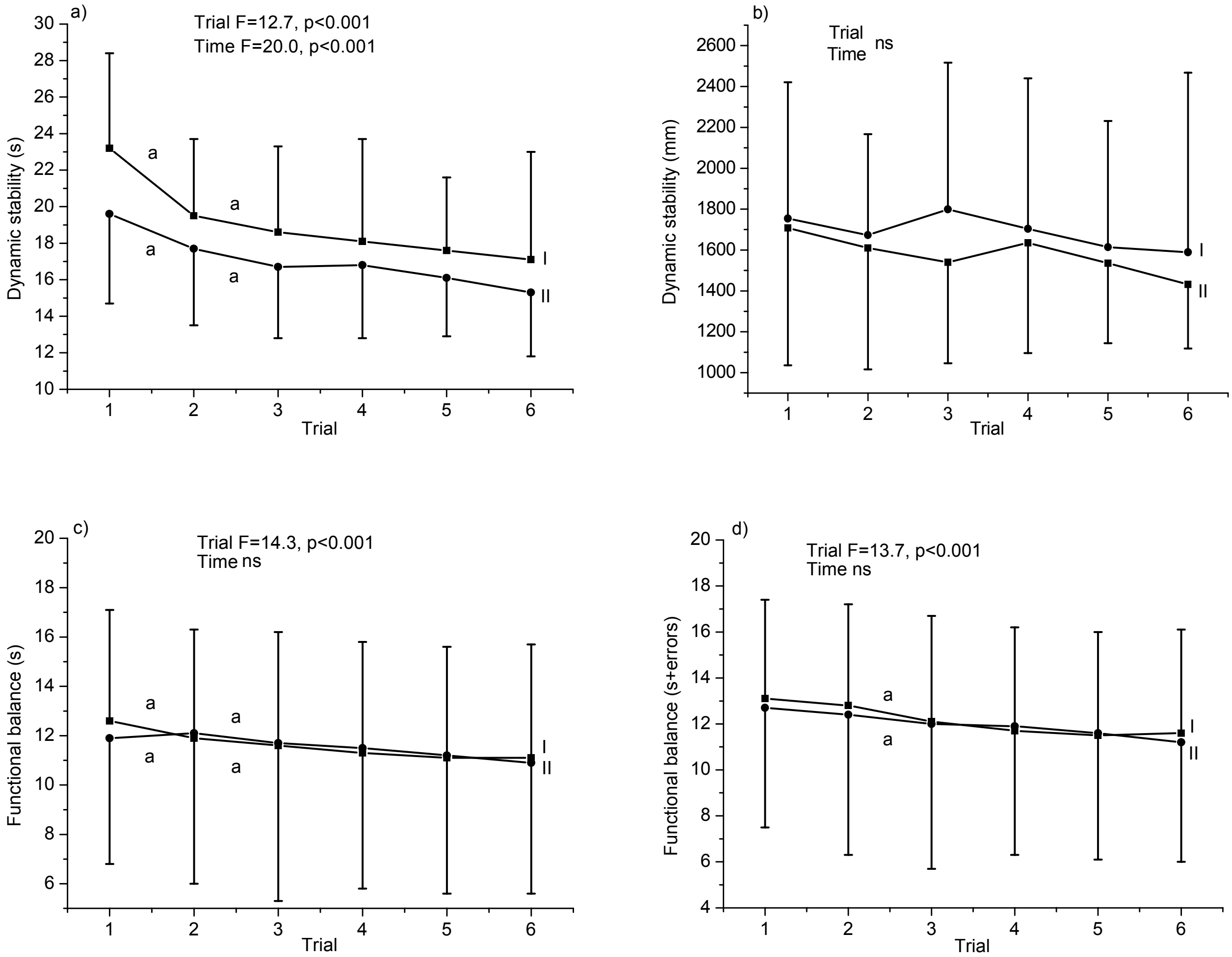

Figure 7a-d. Means and SD of the balance tests measured twice (I-II) with an interval of 2 months and the significant differences between six trials (trial) and between test sessions I and II (time) (n = 29), ([a] $p < 0.05$ for differences between two consecutive trials, ns = not statistically significant).

associated with high physical strain. This complex situation offers a greater challenge for a balance control system than basic balance tests in laboratory conditions do. According to Niinimaa and McAvoy (1983) postural sway is greater during the aiming of an air rifle after strenuous physical exercise than it is during the same procedure in rest. An increase in postural sway after a 2-mile run was also reported by Pendergrass et al. (2003). It is possible that the negative effect of FPE on balance control in the present study underestimated the effect in actual fire and rescue operations. Some evidence of underestimation has been reported by Kincl et al. (2002) and Seliga et al. (1991), who showed that postural sway increased more consistently after physical loading with respirators than without such physical loading. These findings may indicate that the use of respirators modifies the ability to maintain balance due to a combination of work-related muscular and general fatigue (Kincl et al., 2002; Seliga et al., 1991). Fatigue probably detrimentally affects the ability to compensate for the respirator. In conditions of fatigue due to physical exertion, the latency of a response to regulate balance may be increased and may, therefore, have a degrading effect, especially on the emergency reactive control of balance (Hsiao and Simeonov, 2001).

The present results showing an age-related decline in balance abilities and negative effects of FPE and eye closure on balance control, as well as the tendency of longer slip distances among older firefighters, are important to consider for safety reasons in actual work situations in physical jobs. Fire and rescue situations usually occur in heavily smoky or totally dark environments in which visual feedback is poor, although not absent as in the eyes-closed condition. In alarm situations, several complicated aspects of work and the environment have to be taken into account. Complex tasks that divide a worker's full attention can reduce his or her ability to execute proactive control of balance (Hsiao

Table 12. Limits of agreement (LoA) and the intraclass correlation coefficients (ICC) between the consecutive trials of the balance tests in the first test session (n = 29).

Trials	Dynamic stability (s)		Dynamic stability (mm)		Functional balance (s)		Functional balance (s+errors)	
	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC
1-2	3.7 (10.8)	.16	81.8 (1258)	.41	.7 (2.9)	.84	.4 (3.7)	.78
2-3	.9 (7.8)	.59	127 (1072)	.60	.4 (2.4)	.90	.7 (3.2)	.80
3-4	.4 (9.2)	.60	95.1 (1042)	.73	.2 (2.1)	.94	.4 (2.2)	.93
4-5	.6 (10.4)	.43	88.5 (1135)	.66	.2 (1.4)	.96	.2 (2.3)	.93
5-6	.6 (8.4)	.64	12.1 (919)	.81	.1 (1.7)	.93	.0 (2.4)	.89

and Simeonov, 2001). Especially among older subjects, less attentional processing capacity is available for balance control during a dual-task paradigm (Rankin et al., 2000). For example, balance control has been shown to be poorer when subjects perform a simultaneous cognitive task than when balance performance takes place alone (Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000). Furthermore, Hsiao and Simeonov (2001) and Parnianpour et al. (1989) have suggested that the decline in postural control due to age or inexperience may contribute to accidental falls at work. It can be hypothesized, however, that experienced older workers may be able to use their professional competence and efficient work techniques to compensate for their age-related decrease in balance control, for example, the disadvantage related to the use of FPE. This possibility is important because the mean age of Finnish firefighters is 39 years (Tilastokeskus, 2003), and it will increase in the future because firefighters' retirement age has been raised from 55 to 65 years. According to Lusa et al., (1994) every firefighter has to carry out tasks with FPE at least a few times a year regardless of age. Although work in the fire and rescue service has changed and diversified much during the past few decades, it will contain the regular use of FPE.

7.2.1. Occupation-related differences in balance

In this study balance abilities were better for the workers whose work also demanded high balance control. Compared with the construction workers, the firefighters performed more slowly and also made more errors in the functional balance test. Firefighters operate on roofs or use ladders, on the average, once in 3 months, depending on the number of alarms (Lusa et al., 1994), whereas construction workers almost daily climb and work for many hours on high scaffoldings. In general, the home care and nursing staff performed more poorly than the firefighters and construction workers did in the functional balance test, and more poorly than the firefighters in the postural balance test in a normal standing position. On the other hand, the home care workers were superior in the tandem standing position. The demands of the functional balance test may be closer to those of dynamic physical jobs, and the differences between the occupational groups were more consistent in the functional balance test than in the postural balance test. Moreover, the average results of postural balance in this study did not differ from the reference values of the force platform system that was used (Metitur, 2001).

The work environment may positively influence balance abilities by providing the opportunity for intensive and specific training and the learning of balance skills. According to Pajala et al. (2004), individual environmental factors accounted for up to half of the variance in postural

Table 13. Limits of agreement (LoA) and the intraclass correlation coefficients (ICC) for the repeated tests (best values of the trial combinations) after an interval of 2 months (n = 29).

Best value of trials	Dynamic stability (s)		Dynamic stability (mm)		Functional balance (s)		Functional balance (s+errors)	
	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC
1-2	2.3 (7.8)	.25	149 (933)	.54	.4 (3.1)	.89	.6 (3.7)	.85
1-3	2.0 (6.7)	.40	173 (687)	.68	.2 (2.7)	.88	.2 (2.5)	.90
1-4	1.6 (6.6)	.56	144 (745)	.62	.2 (2.6)	.92	.2 (2.7)	.92
1-5	1.3 (4.2)	.60	87.4 (572)	.72	.3 (2.9)	.83	.2 (2.8)	.86
1-6	1.2 (4.6)	.50	166 (762)	.52	.3 (2.8)	.88	.3 (2.5)	.92
3-6	1.1 (5.0)	.57	173 (898)	.72	.2 (2.8)	.84	.2 (2.6)	.86

balance among older women. For example, fighter pilots had better balance control than candidates for flight training (Kohen-Ratz, 1994), and construction workers showed lower body sway than workers not engaged in manual work (Gantchev and Dunev, 1978). Unfortunately the present study did not collect postural balance data for the included construction workers. Diard et al. (1997) suggested that the better performance of fighter pilots on active duty in comparison with that of retired pilots is an acquired skill, that requires continuous training. In addition to learning and training in respect to environment- and task-related balance demands of work, differences in balance abilities between occupations may be explained by genetic effects (Kohen-Ratz et al., 1994; Pajala et al., 2004), as well as by worker selection to a specific job. Genetic effects accounted for one-third of the variance of the balance factor, which consisted of data from postural sway measurements in normal and semi-tandem positions (Pajala et al., 2004).

The aforementioned findings of occupation-related differences in balance between male- and female-specific occupations are preliminary, and they need further clarification because of the possible differences between the sexes. Some studies have shown balance differences between men and women, but the findings are conflicting or the standardization of anthropometrics removed the difference (Era et al., 1996; Juntunen et al., 1987; Maki et al., 1990; Matheson et al., 1999; Panzer et al., 1995). The differences in functional and postural balance between home care and nursing staff in the present study cannot be explained by different balance demands of the work. In the tandem standing test, the difference between home care and nursing staff disappeared when muscle strength and endurance of the legs were used as covariates, but it remained significant in the functional balance test. In this study no results were available on the maximal rate of force development, which may be a more important factor in balance control than maximal strength (Izquierdo et al., 1999) or muscle endurance. Among people aged 40 and 70 years, a decreased ability to develop force rapidly seems to be associated with a lower capacity for neuromuscular response in controlling postural sway (Izquierdo et al., 1999).

7.3. Slip and fall risk in association with age, balance and muscular capacity

Although the younger and older firefighters experienced as many slips in walking trials, there was a trend towards higher age negatively affecting slip distances and the seriousness of the slips, especially in the tests with a faster walking speed. The age range of the older firefighters was also larger (33-38 and 43-56 years) and therefore produced a high standard deviation and reduced the differences between the age groups. Slip distances of 2-50 cm were detected. Most of the slips were, however, well controlled, even if their length was about 20 cm, and, in some cases, balance could be regained without the safety harness. The recommended maximum tolerable criterion for a slip distance ranges from 5 to 22 cm (Brady et al., 2000; Grönqvist et al., 1999; Strandberg and Lanshammar, 1981). According to Leamon and Li (1991), an additional load increases slip distance as well. Therefore, the use of FPE may have produced long slip distances in the present study. Furthermore, the muscular endurance of the lower extremities of the firefighters in the present study could be classified as at least good (Lusa, 1994). It is possible that the good muscular capacity of the firefighters allowed long controlled slips. Postural activity from bilateral leg and thigh muscles and coordination between the two lower extremities have also been shown to be key factors in reactive balance control in slips occurring at heel strike (Tang et al., 1998).

The firefighters whose sliding distance with glycerol was critical (i.e., ≥5 cm) tended to have poorer results in the balance and muscular capacity tests than those who slipped less than 5 cm at a walking speed of 100 steps·min^{-1}. The difference was significant only for the dynamic stability test. The same tendency was seen with the speed of 120 steps·min^{-1}, but no differences were significant due to the smaller number of studied firefighters (because of technical reasons four firefighters' results were not available).

The dynamic stability test is based on visual feedback on the movement of the COP through the targets shown a computer screen. Therefore, the efficient utilization of visual input in balance control may be an important protective factor with respect to slip and fall risk. Although the balance task is to move the COP actively in the dynamic stability test, it cannot go over the BOS in a successful test. For a forward slip during walking, a smaller movement and faster velocity of the body's COM over the BOS plays a significant role in slip recovery and fall termination from heel strike to contralateral toe off (You et al., 2001). Furthermore, the dynamic stability test primarily demands the use of ankle strategy, which is one of the protective responses after the onset of a slip as well. The ankle moment has been shown to decrease with the severity of the slip, and knee flexor and hip extensor moments have been found to be primarily responsible for corrective balance reactions (Cham and Redfern, 2001).

Therefore, in actual work situations, ankle strategy may be insufficient to prevent falling during a slip event.

7.4. Predictive value of balance for work ability and the reliability of the dynamic balance tests

Poor perceived balance abilities, many errors in the functional balance test, and a high amplitude of postural sway with the eyes closed were the most significant predictors of decreased WAI after the 3 years of follow-up in this study. The errors in the functional balance test showed almost 4-fold risk for decreased WAI when compared with an accurate performance in the test. At baseline, good performance time in the functional balance test was also associated with good WAI and PWA. Performance time in the functional balance test has been shown to be a strong predictor for WAI among home care workers (Pohjonen, 2001a) as well. In difficult environments of actual fire and rescue work, both accurate and rapid balance adjustments are challenged and needed. Findings of occupation-related differences in this study also suggested that performance in the functional balance test may be related to the balance demands of physical work. According to the results difficulties to control balance without visual input in the postural balance test may also reflect problems with work ability.

The question of perceived balance may include specific aspects of balance needed in fire and rescue work. It can be hypothesized that the studied firefighters considered extrinsic factors, such as difficult work environments and challenging work tasks, when they evaluated their ability to balance in respect to the demands of fire and rescue work. Furthermore, like perceived balance, both WAI and PWA are based on subjective opinion, which probably also affected the close association between perceived balance abilities and WAI and between perceived balance abilities and PWA. Previously, Chiou et al. (1998) showed promising results for the Perceived Sense of Postural Sway and Instability Scale among industrial workers in evaluating the possible loss of balance at work. The ability to perceive balance demands correctly was critical if the necessary postural stabilization processes were to be triggered during work. It was concluded that workers were able to perceive their postural sway due to changes in peripheral vision, environmental lighting, workload and surface firmness. In the present study the used perceived balance abilities and the functional balance test are simple, easy and unequivocal to perform and interpret in occupational health services. The method using a force platform for measuring postural sway is more complicated, but it offers a reliable means of studying the basic balance function with different sensory conditions.

Furthermore, six repeated trials showed improving results in both of the dynamic balance tests. This learning effect may be related to a person's ability to change postural strategy to a more efficient one (Hertel et al., 2000; Hirvonen et al., 2002). According to Hansen et al. (2000) the learning process is more pronounced for dynamic balance tests than for static ones. In the present study, a baseline level was attained for performance time in the dynamic stability and functional balance tests after three repeated trials. The results supported the concept of using more than one trial to obtain reliable balance results (Hertel et al., 2000; Hirvonen et al., 2002). The performance time in the dynamic stability test of the present study was also shorter in the test-retests done after an interval of 2 months, whereas there was no significant difference for the functional balance test. The major learning effects associated with the dynamic stability test, when compared with those of the functional balance test, can partly be explained by the different balance tasks evaluated. Walking belongs to habitual activities of daily living, which alleviates the learning effect, whereas the firefighters moved their COP through the targets on the computer monitor for the first time. Kinzey and Armstrong (1998) hypothesized that reliable balance tests should possibly involve tasks that simulate daily activities.

Almost all of the ICC and best LoA values of the repeated trials in the functional balance test showed good trial-to-trial reproducibility. Although most of the ICC values of the dynamic stability test were moderate between six repeated trials, the LoA values between repeated trials were broad and indicated low absolute trial-to-trial consistency and wide individual variation. Large individual variation was also previously reported to be a typical problem in the evaluation of balance control within a normal population (Birmingham, 2000; Hansen et al., 2000; Takala et al., 1997). Large variation may hamper, for example, a reliable evaluation of the changes in balance control. In general, the individual variation in the balance results of the present study was high. That observation and previous results strengthen the need to use the best or average value for repeated trials as an outcome variable for reliability, as shown previously to improve the reliability of balance tests (Corriveau et al., 2000; Mustalampi et al., 2003). In addition, the sample size was small, and large changes in the results of one studied individual made the LoA values significantly broader. The sample size of previous reliability studies of dynamic balance tests range from 16 to 57 (Brouwer et al., 1998; Hertel et al., 2000; Hirvonen et al., 2002; Punakallio et al., 1997a; Räty et al., 2002; Rinne et al., 2001), and some reliability studies of postural balance have been carried out with less than 10 subjects (Corriveau et al., 2000; Takala et al., 1997).

In the present study, the highest test-retest reliability (moderate level, LoA±4 s and ±572 mm) was attained in the dynamic stability test when the best results of the five first consecutive trials were used as the outcome variables. With the exception of the first trial combination (best of trials 1 and 2) as an outcome variable for the functional balance test, the reliability of different trial combinations was very similar and showed good stability. LoA values of ±2.5 s (best of three trials) were also reasonable. The ICC values of the functional balance test were at the same level as previously reported for functional tests (Hertel et al., 2000; Räty et al., 2002; Rinne et al., 2001) and lower for the dynamic stability test when compared with the findings of previous studies (Brouwer et al., 1998; Hirvonen et al., 2002). The tasks in the dynamic stability tests differed, and, therefore, the reliability of these tests is specific for each method.

7.5. Methodology

7.5.1. Subjects

The present data were based on a stratified sample, and not only healthy volunteers were invited to participate. Therefore, the dropout rate of 27% during the 3-year follow-up is reasonable and describes a normal phenomenon in worklife. The reasons for the dropout were also obvious. For example, over half of the dropouts retired on an old-age or disability pension or were on long-lasting sick leaves, and 15 subjects were unwilling to participate in the follow-up tests for personal reasons. Generalization of the results to the entire study group is supported in that the balance test results, the WAI and the PWA did not differ significantly at the baseline between the study sample and the dropouts in Study 4. Furthermore, the characteristics of the southern Finland firefighters in Study I did not differ with respect to the entire sample measured in 1999.

Although, the studied firefighters in Studies 2, 3 and 5 were volunteers, and six of them were excluded from the study because of their musculoskeletal disorders, their results at baseline were similar with respect to balance, muscle and cardiorespiratory endurance and the frequency of physical exercise of the entire sample of firefighters at baseline and also when compared with the sample of firefighters from southern Finland in 1999. The mean age of the firefighters (41-42 years) in Studies 1-5 was at the same level as the mean age of all professional firefighters in Finland (i.e., 39 years) (Tilastokeskus, 2003). All the studied firefighters were men since, at the time, there was only one female professional firefighter in Finland.

In addition to firefighters, Study 1 included construction workers, home care workers and nursing staff. These subjects represented ordinary workers of different ages in four occupational groups without any specific background of motor skill training. The subjects were either randomly chosen or all the workers from certain work units were selected for the study, and not only volunteers were invited. In some cases, the group sizes were small, in most cases below 25 and in four cases below 15. Although the studied occupational groups were small, the participation rates of the eligible subjects were high (84-88%).

7.5.2. Methods and study design

7.5.2.1. Balance measurements

Two physiotherapists performed the balance measurements in Study 4 and those on firefighters and home care workers in Study 1. Two different physiotherapists tested the nursing staff and construction workers. In Studies 2, 3 and 5 the same physiotherapist conducted the measurements and, in study 5, also on both occasions. All the physiotherapists were well-trained and experienced professionals. In addition, the reliability between two well-trained physiotherapists was shown to be high with respect to the functional balance test ($r = 0.95$, $p < 0.001$, $n = 12$) (Punakallio, unpublished data). The present dynamic stability and functional balance tests have previously shown some learning effects between repeated trials, and their reliability was not defined according to current recommendations in exercise sciences (Atkinson and Nevill, 1998; Hoffman, 1998; Punakallio et al., 1997a). Therefore the test-retest reliability of these two dynamic balance tests was investigated in Study 5 (See section 7.4.).

In the functional balance test, in addition to short performance time, no or few errors can be considered to show good control of performance. When a sum variable (performance time + number of errors) was used, a time measurement of 1 s was chosen as one error. Then the proportion of errors (range 0-6 for the subjects in this study) increased the mean performance time (range 10-23 s) of the sum score, but the errors were not emphasized in the sum score.

The postural balance tests performed in this study are widely used, and the reliability of the used parameters was acceptable (Mustalampi et al., 2003;

Takala et al., 1997). The reliability of perceived balance abilities needs to be established.

In Study 2, of balance abilities and FPE, the firefighters first performed the baseline postural balance tests in two visual conditions and the baseline functional balance test. Thereafter, two postural balance tests and four functional balance tests were performed with different equipment combinations. Furthermore, in Study 5, on trial-to-trial reproducibility, the balance tests were repeated six times. The firefighters included in both studies were highly motivated to perform all the repeated tests well. The tests were brief and physically undemanding, and fatigue hardly affected performance. If there was a learning effect from the four and five repeated trials in Study 2, it would probably have only reduced the differences between the baseline balance tests and the tests with FPE.

7.5.2.2. Slipping tests

So that the unexpected and surprising nature of slipping in the tests would be preserved, the number of trials were limited as much as possible. The firefighters received no information on the number of trials they would perform or on the slipperiness and slip-resistance of the path. Anticipation of slipping could not completely be avoided, and it may have affected the slipping responses and, therefore, possibly diminished the differences between the firefighters. Previously, it has been shown that a more cautious walking strategy seems to be adopted when a potential slip risk exists (Cham and Redfern, 2002; Marigold and Patla, 2002). Because of the anticipation and test method, the present slipping responses obtained in the laboratory may also differ from those in actual firefighting situations, which often include disturbing factors such as noise, poor lighting and psychological stress. A track with curves, uphills, and downhills, and different kinds of obstacles would be closer to actual work situations than the straight path used in Study 2. In addition only one foot stepped on the slippery surface. A larger slippery area would be nearer actual environmental conditions.

7.5.2.3. Work ability index

Because the concepts of job performance, work capacity and work ability are rather confusing and therefore difficult to define, their operationalization is also problematic, and there is a lack of valid measures for them (Pohjonen, 2001b). Using the stress-strain concept (Rutenfrantz, 1981) Ilmarinen et al. (1991) have defined work ability as a worker's capability to manage his or her job demands. This group of Finnish researchers also constructed a questionnaire-based measure, the work ability index (WAI) (Tuomi et al., 1991; Tuomi et al., 1998), to operationalize the concept of work ability. The mean WAI score and its classification into WAI categories have been reported to be stable over a 4-week interval at the group level. Repeated assessments of WAI have also provided evidence of acceptable test-retest reliability at the individual level (De Zvart, 2002). In addition, the WAI is a sum variable, which also includes many other aspects of work ability than physical work capacity.

In cross-sectional studies, prerequisites of work ability for physical jobs (i.e., good performance in motor, musculoskeletal and cardiorespiratory capacity tests) are associated with a good WAI among firefighters (Pokorski et al., 2004; Punakallio et al., 1997b). Good performance on physical capacity tests (balance, muscle strength) was strongly associated with the physical demands and WAI of home care workers as well (Pohjonen, 2001b). Among firefighters, the higher categories of the WAI were also significantly associated with quicker performance through a labyrinth in a smoke chamber (Pokorski et al., 2004).

8. CONCLUSIONS

This study was carried out among workers in physically demanding occupations, mainly among firefighters. The demands for balance control have been characterized as high in fire and rescue tasks. Based on the results of this study, the following conclusions and recommendations are justified:

1. Balance abilities of firefighters aged 50 years and over are poorer than those of younger firefighters. The differences in balance abilities are not as consistent among different aged construction, home care and nursing workers. Furthermore, postural balance is more harmfully affected among older firefighters than among younger ones when they use FPE with their eyes closed. SCBA proved to be the most significant single piece of equipment to decrease balance performance.

   These aspects should be taken into consideration during the organization of work tasks in fire departments and in the development of the characteristics of FPE. It is also essential to provide ample balance training opportunities for firefighters with and without FPE. These findings also support the need for including balance assessments when the prerequisites of work ability are evaluated for firefighters.

2. The ability to exploit visual feedback efficiently in balance control seems to be associated with smaller slip risk, whereas associations between muscular capacity and the risk of slipping are not significant. Older firefighters also tend to slip longer and more seriously than younger ones.

   In respect to safety aspects on slippery surfaces, methods based on visual feedback may provide useful information of balance control, and, therefore, this kind of test may be useful in evaluations of balance ability among workers in physically demanding jobs.

3. Many errors in the functional balance test, a high mean sway amplitude with the eyes closed, and a poor estimate of one's own balance abilities predicted reduced WAI category after the follow-up.

   Balance abilities proved to be related to perceived work ability, and the aforementioned tests and parameters may therefore be useful when prerequisites of work ability are evaluated for firefighters.

4. The functional balance test showed high trial-to-trial reproducibility and stability over time, and for the dynamic stability test the result was moderate. The narrowest limits of agreement, about ±2 s in the functional balance test and about ±4 s in the dynamic stability test, would be acceptable for practical use as well.

   To improve the reliability of functional balance and dynamic stability tests, three and five trials, respectively, should be carried out after one pretest. Then the best trial value should be used as the final result.

5. On the whole, in respect to safety and work ability in fire and rescue work, the present results suggest that, when the work ability of firefighters is being followed-up the balance abilities should be taken into account. The balance assessments of the present study can be included when prerequisites of work ability are evaluated for firefighters. The approach of the present study, in which balance control is considered an interaction between a worker's individual characteristic and the demands of daily work tasks and the work environment, appeared to be relevant when the balance abilities of workers in physically demanding jobs were studied. It may be useful to adapt the frame of reference of the present study for studies on workers from other physically demanding occupations as well. Additional investigations of balance abilities utilizing the frame of reference of the present study can be recommended. These studies should include versatile individual-, task- and environment-related parameters in association with balance.

   It would also be useful to study the occupation- and age-related differences in balance and the associations between slip risk, age and balance with studies of larger numbers of subjects in various physical jobs. Methods are needed for studying balance demands of actual or simulated work tasks, and valid field and laboratory balance tests based on the actual work balance demands should be developed for workers from different kinds of physical jobs. In the laboratory balance abilities and the risk of slipping and falling during walking should be tested concurrently to provide more understanding of individual balance abilities in respect to slip-related accidents and to provide a validation of balance tests in respect to slip and fall risk. The effect of fatigue as well as exercise on slip and fall risk and balance control on slippery or other difficult surfaces and the environment should also be studied.

9. REFERENCES

Aalto, H. (1997) *Force platform posturography. Methodological aspects and practical applications*. Doctoral thesis, University of Helsinki, Helsinki.

Allum, J.H.J., Honegger, F. and Pfaltz, C.R. (1989) The role of stretch and vestibulo-spinal reflexes in the generation of human equilibriating reactions. *Progress in Brain Research* **80,** 399-409.

Amiridis, I.G., Hatzitaki, V. and Arabatzi, F. (2003) Age-induced modifications of static postural control in humans. *Neuroscience Letters* **350**, 137–140.

Aromaa, A., Heliövaara, M., Impivaara, O., Knekt, P., Maatela, J., Joukamaa, M., Klaukka, T., Lehtinen, V., Melkas, T., Mälkiä, E., Nyman, K., Paunio, I., Reunanen, A., Sievers, K., Kalimo, E. and Kallio, V. (1989) *Terveys, toimintakyky ja hoidontarve Suomessa*. Kansaneläkelaitos. Kansaneläkelaitoksen julkaisuja, Helsinki and Turku. AL 32.

Aruin, AS., Forrest, W.R. and Latash, M.L. (1998) Anticipatory postural adjustments in conditions of postural instability. *Electroencephalography and Clinical Neurophysiology* **109**, 350-359.

Atkinson, G. and Nevill, A.M. (1998) Statistical methods for assessing measurement error (reliability) in variables relevant to Sports medicine. *Sports Medicine* **26**, 217-238.

Aura, O. (1994) *Kuntotestauksen perusteet.* Liite r.y., Helsinki.

Baloh, R.W., Corona, S., Jacobson, K.M. Enrietto J.A. and Bell T. (1998) A prospective study of posturography in normal older people. *Journal of the American Geriatrics Society* **46,** 438-443.

Baloh, R.W., Jacobson, K.M. and Socotch, T.M. (1993) The effect of aging on visual-vestibuloocular responses. *Experimental Brain Research* **95**, 509-516.

Baumgartner, T.A. (1989) Norm-referenced measurement: reliability. In: *Measurement concepts in physical education and exercise science*. Eds: Safrit, M.J. and Wood T.E. Champaign IL: Human Kinetics Books. 45-72.

Belen'kii, V.Y., Gurfinkel', V.S. and Pal'tsev, Y.I. (1967) Elements of control of voluntary movements. *Biofizika* **12**, 154-161.

Berg, K. (1989) Balance and its measure in the elderly: a review. *Physiotherapy Canada* **41,** 240-246.

Berg, K.O., Wood-Dauphinee, S.L., Williams, J.T. and Maki, B. (1992) Measuring balance in the elderly: validation of an instrument. *Canadian Journal of Public Health* **83 (Suppl. 2),** S7-11.

Bhattacharya, A., Succop, P., Kincl, L. and Clark C.S. (2003) Postural stability during task performance on elevated and/or inclined surfaces. *International Journal of Occupational Safety and Ergonomics* **3**, 83-97.

Birmingham, T.B. (2000) Test-retest reliability of lower extremity functional instability measures. *Clinical Journal of Sport Medicine* **10**, 264-268.

Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1,** 307-310.

Brady, R.A., Pavol, M.J., Owings, T.M. and Grabiner, M.D. (2000) Foot displacement but not velocity predicts the outcome of a slip induced in young subjects while walking. *Journal of Biomechanics* **33**, 803-808.

Brandt, T., Arnold, F., Bles, W. and Kapteyn T.S. (1980) The mechanisms of physical height vertigo. I. Theoretical approach and psychophysics. *Acta Oto-Laryngologica* **89**, 513-523.

Brandt, T., Paulus, W. and Straube, A. (1986) Vision and posture. In: *Disorders of posture and gait*. Eds: Bless, W. and Brandt, T. Amsterdam: Elsevier Science Publishers B.V. 157-175.

Brauer, S.G., Burns, Y.R. and Galley, P. (2000) A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **55A:M**, 469-476.

Brouwer, B., Culham, EG., Liston, R.A.L. and Grant, T. (1998) Normal variability of postural measures: implications for the reliability of relative balance performance outcomes. *Scandinavian Journal of Rehabilitation Medicine* **30**, 131-137.

Carel, R.S., Korczyn, A.D. and Hochberg, Y. (1979) Age and sex dependency of the achilles tendon reflex. *The American Journal of the Medical Sciences* **278**, 57-63.

Cham, R., Redfern, M.S. (2001) Lower extremity corrective reactions to slip events. *Journal of Biomechanics* **34,** 1439-1445.

Cham, R. and Redfern, M.S. (2002) Changes in gait when anticipating slippery floors. *Gait Posture* **15**, 159-171.

Chiou, S., Bhattacharya, A., Lai, C-F. and Succop, P.A. (1998) Effects of environmental and task risk factors on workers´ perceived sense of postural sway and instability. *International Journal of Occupational Safety and Ergonomics* **1**, 81-93.

Choy, N.L., Brauer, S. and Nitz, J. (2003) Changes in postural stability in women aged 20 to 80 years. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **58 A,** 525-530.

Clark, M., Jackson, P.L. and Cohen, H.H. (1996) What you don't see can hurt you: understanding the role of depth perception in slip, trip and fall incidents. *Ergonomics in Design* **4(3)**, 16-21.

Clarkson, P.M. (1978) The relationship of age and level of physical activity with the fractionated components of patellar reflex time. *The Journals of Gerontology* **33,** 650-656.

Cohn, T.E. and Lasley, D.J. (1985) Visual depth illusion and falls in the elderly. *Clinics in Geriatric Medicine* **1**, 601-620.

Colledge, N.R., Cantley, P., Peaston, I., Brash H., Lewis S. and Wilson J.A. (1994) Ageing and balance: the measurement of spontaneous sway by posturography. *Gerontology* **40**, 273-278.

Commissaris, D.A. and Toussaint, H.M. (1997a) Load knowledge affects low-back loading and control of balance in lifting tasks. *Ergonomics* **40**, 559-575.

Commissaris, D.A. and Toussaint, H.M. (1997b) Anticipatory postural adjustments in a bimanual, whole body lifting task with an object of known weight. *Human Movement Science* **16,** 407-431.

Committee for Standardization (1995). *European standard EN 469: 1995: protective clothing for firefighters - requirements and test methods for protective clothing for firefighting*. European Committee for Standardization, Brussels.

Cordo, P.J. and Nashner, L.M. (1982) Properties of postural adjustments associated with rapid arm movements. *Journal of Neurophysiology* **47,** 287-302.

Corriveau, H., Hébert, R., Prince, F. and Raîche, M. (2000) Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. *Archives of Physical Medicine and Rehabilitation* **81,** 45-48.

Courtney, T.K., Sorock, G.S., Manning, D.P., Collins J.W. and Holbein-Jenny M.A. (2001) Occupational slip, trip, and fall-related injuries−can the contribution of slipperiness be isolated? *Ergonomics* **44**, 1118-1137.

Crotts, D., Thompson, B., Nahom, M., Ryan, S. and Newton R.A. (1996) Balance abilities of professional dancers on select balance tests. *The Journal of Orthopedics and Sports Physical Therapy* **23**, 12-17.

De Zwart, B.C.H., Frings-Dresen, M.H.W. and Van Duivenbooden, J.C. (2002) Test-retest reliability of the Work Ability Index questionnaire. *Journal of Occupational Medicine* **52**, 177-181.

Diard, J-P., Aubin, F., May, D., Michel, M. and Gouteyron, J.F. (1997) Equitest and high performance patients. *Revue de Laryngologie - Otologie – Rhinologie* **118**, 307-310.

Diener, H.C. and Dichgans, J. (1986) Long loop reflexes and posture. In: *Disorders of posture and gait*. Eds: Bles, W. and Brandt, T. Amsterdam: Elsevier. 41-67.

Diener, H.C., Dichgans, J., Guschlbauer, B. and Bacher, M. (1986) Role of visual and static vestibular influences on dynamic posture control. *Human Neurobiology* **5**, 105-113.

Diggle, P., Liang, K-Y., Zeger, S.L. (1994) *Analysis of longitudinal data*. Clarendon Press, Oxford.

Du Pasquier, R.A., Blanc, Y., Sinnreich, M., Landis, T., Burkhard, P. and Vingerhoets, F.J. (2003) The effect of aging on postural stability: a cross sectional and longitudinal study. *Clinical Neurophysiology* **33**, 213-218.

Egan, W.E., Fisher, D.P., Gerber, L.D., Hatler, B.S., Ernst, G.P., Hall, C. and Henderson, N. (2001) Postural sway of subjects wearing the U.S. Army chemical protective ensemble after functional activity. *Aviation, Space and Environmental Medicine* **72,** 831-835.

Ekdahl, C., Jarnlo, G.B. and Andersson, S.I. (1989) Standing balance in healthy subjects: evaluation of a quantitative test battery on a force platform. *Scandinavian Journal of Rehabilitation Medicine* **21**, 187-195.

Era, P., Heikkinen, E. (1985) Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. *Journal of Gerontology* **40,** 287-295.

Era, P., Heikkinen, E., Gause-Nilsson, I., Schroll, M. (2002) Postural balance in elderly people: changes over a five-year follow-up and its predictive value for survival. *Aging Clinical and Experimental Research* **14 (Suppl. 3)**, 37-46.

Era, P., Schroll, M., Ytting, H., Gause-Nilsson, I., Heikkinen, E. and Steen, B. (1996) Postural balance and its sensory-motor correlates in 75-year-old men and women: a cross-national comparative study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **51A:M** 53-63.

Fleiss, J.L. (1986) Reliability of measurement. In: *The design and analysis of clinical experiments*. Ed: Fleiss, J.L. New York, NY: John Wiley & Sons, Inc. 1-32.

Gantchev, G.N. and Dunev, S.T. (1978) Study of the body sway of workers at high buildings. *Agressologie*. **19B,** 67-68.

Gauchard, G., Chau, N., Mur, J.M., Perrin, P. (2001) Falls and working individuals: role of extrinsic and intrinsic factors. *Ergonomics* **44,** 1330-1339.

Gill, J., Allum, J.H.J., Carpenter, M.G., Held-Ziolkowska, M., Adkin, A.L., Honegger, F. and Pierchala, K. (2001) Trunk sway measures of postural stability during clinical balance tests: effects of age. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **56A:M**, 438-447.

Gittings, N.S. and Fozard, J.L. (1986) Age-related changes in visual acuity. *Experimental Gerontology* **21**, 423-433.

Gledhill, N. and Jamnik, V.K. (1992a) Characterization of the physical demands of firefighting. *Canadian Journal of Sport Sciences* **17**, 207-213.

Gledhill, N. and Jamnik, V.K. (1992b) Development and validation of fitness screening protocol for firefighter applicants. *Canadian Journal of Sport Sciences* **17**, 199-206

Grönqvist, R. (1995) *A dynamic method for assessing pedestrian slip resistance. People and Work. Research Reports 2.* Doctoral thesis, Finnish Institute of Occupational Health, Helsinki.

Grönqvist, R., Hirvonen, M. and Tohv, A. (1999) Evaluation of three portable floor slipperiness testers. *International Journal of Industrial Ergonomics* **25**, 85-95.

Hageman, P.A., Leibowitz, J.M. and Blanke, D. (1995) Age and sex effects on postural control measures. *Archives of Physical Medicine and Rehabilitation* **76**, 961-965.

Hansen, M.S., Dieckmann, B., Jensen, K. and Jakobsen, B.W. (2000) The reliability of balance tests performed on the kinesthetic ability trainer (KAT 2000). *Knee Surgery, Sports Traumatology, Arthroscopy* **8**, 180-185.

Hasan, S.S., Robin, D.W., Szurkus, D.C., Ashmed, D.H., Peterson, S.W. and Shiavi, R.G. (1996a) Simultaneous measurement of body center of pressure and center of gravity during upright stance. *Part I: Methods. Gait Posture* **4,** 1-10.

Hasan, S.S., Robin, D.W., Szurkus, D.C., Ashmed, D.H., Peterson, S.W. and Shiavi, R.G. (1996b) Simultaneous measurement of body center of pressure and center of gravity during upright stance. *Part II: Amplitude and Frequency Data. Gait Posture* **4,** 11-20.

Hertel, J., Miller, S.J. and Denegar, C.R. (2000) Intratester and intertester reliability during the star excursion balance tests. *Journal of Sport Rehabilitation* **9**, 104-116.

Hirvonen, M., Leskinen, T., Grönqvist, R. and Saario, J. (1994) Detection of near accidents by measurement of horizontal acceleration of the trunk. *International Journal of Industrial Ergonomics* **14**, 307-314.

Hirvonen, T.P., Hirvonen, M. and Aalto, H. (2002) Postural control measured by visual feedback posturography. *Journal for Oto-Rhino-Laryngology and its Related Specialties* **64**,186-190.

Hofmann, C. (1998) The implementation of normative data in a force patform based postural balance measurement system [Diplomarbeit]. *Zwickau: Westsächsische Hochschule Zwickau (FH), Fachbereich Physikalische Technik/Informatik*.

Horak, F.B. (1987) Clinical measurement of postural control in adults. *Physical Therapy* **67**, 1881-1885.

Horak, F.B. and Nashner, L.M. (1986) Central programming of postural movements: adaptation to altered support surgace configurations. *Journal of Neurophysiology* **55**, 1369-1381.

Horak, F.B., Nashner, L.M. and Diener, H. (1990) Postural strategies associated with somatosensory and vestibular loss. *Experimental Brain Research* **82**,167-177.

Horak, F.B. and Shubert, C. (1994) The role of the vestibular system in postural control. In: *Vestibular rehabilitation*. Ed: Herdman, S. New York: FA Davis. 22-46.

Hsiao, H. and Simeonov, P. (2001) Preventing falls from roofs: a critical review. *Ergonomics* **44**, 537-561.

Hufschmidt, J., Dichgans, J., Mauritz, K-H. and Hufschmidt, M. (1980) Some methods and parameters of body sway quantification and their neurological applications. *Archiv fur Psychiatrie und Nervenkrankheiten* **228**,135-150.

Hytönen, M., Pyykkö, I., Aalto, H. and Starck, J. (1993) Postural control and age. *Acta Oto-Laryngologica* **113**, 119-122.

Ilmarinen, R. and Mäkinen, H. (1992) Heat strain in fire-fighting drills. In: *Proceedings of the Fifth International Conference on Environmental Ergonomics*. Eds: Lotens, W.A. and Havenith, G. Maastricht: TNO-Institute. 90-91.

Ilmarinen, J., Tuomi, K., Eskelinen, L., Nygard, C.H., Huuhtanen, P. and Klockars, M. (1991) Background and objectives of the Finnish research project on aging workers in municipal occupations. *Scandinavian Journal of Work,Eenvironment & Health* **17(Suppl. 1),** 7-11.

Izquierdo, M., Aguado, X., Gonzalez, R., Lopez, J.L. and Häkkinen, K. (1999) Maximal and explosive force production capacity and balance performance in men of different ages. *European Journal of Applied Physiology* **79**, 260-267.

Johansson, R.S. and Vallbo, Å.B. (1980) Spatial properties of the population of mechanoreceptive units in the glabrous skin of the human hand. *Brain Research* **184**, 353-366.

Johnson, L-G. and Hawkins, J.E. (1972) Sensory and neural degereration with aging, as seen in microdissections of the inner ear. *The Annals of Otology, Rhinology, and Laryngology* **81**, 179-193.

Juntunen, J., Matikainen, E., Ylikoski, J., Ylikoski, M., Ojala, M. and Vaheri, E. (1987) Postural body sway exposure to high- energy impulse noise. *Lancet* **2**, 261-264.

Karlsson, A. and Frykberg, G. (2000) Correlations between force plate measures for assessment of balance. *Clinical Biomechanics* **15**, 365-369.

Kemmlert, K. and Lundholm, L. (2001) Slips, trips and falls in different work groups - with reference to age and from a preventive perspective. *Applied Ergonomics* **32**, 149-153.

Kincl, L.D., Bhattacharya, A., Succop, P.A. and Clark, C.S. (2002) Postural sway measurements: a potential safety monitoring technique for workers wearing personal protective equipment. *Applied Occupational and Environmental Hygiene* **17**, 256-266.

King, P.M., Tuckwell, N. and Barrett, T.E. (1998) A Critical review of functional capacity evaluations. *Physical Therapy* **78,** 852-866.

Kinzey, S.J. and Armstrong, C.W. (1998) The reliability of the star-excursion test in assessing dynamic balance. *The Journal of Orthopedic and Sports Physical Therapy* **2**, 356-360

Kohen-Ratz, R., Kohen-Ratz, A., Erel, J., Davidson, B., Caine, Y. and Froom, P. (1994) Postural control in pilots and candidates for flight training. *Aviation, Space and Environmental Medicine* **65**, 323-326.

Kollegger, H., Baumgartner, C., Wöber, C., Oder, W. and Deecke, L. (1992) Spontaneous body sway as a function of sex, age, and vision: posturographic study in 30 healthy adults. *European Neurology* **32**, 253-259.

Kuo, A.D. and Zajac, F.E. (1993) Human standing posture: multi-joint movement strategies based on biomechanical constraints. *Progress in Brain Research* **97**, 349-358.

Kuo, W., Bhattacharya, A., Succop, P. and Linz, D. (1996) Postural stability assessment in sewer workers. *Journal of Occupational and Environmental Medicine* **38**, 27-34.

Lamb, K. (1998) Test-retest reliability in quantitative physical education research: a commentary. *European Physical Education Review* **4**, 145-152.

Laughton, C.A., Slavin, M., Katdare, K, Nolan, L., Bean, J.F., Kerrigan, D.C., Phillips, E., Lipsitz, L.A. and Collins, J.J. (2003) Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait Posture* **18**, 101-108.

Leamon, T.B. and Li, K.W. (1991) Load carrying and slip length. *Proceedings of the Human Factors Society, 35th Annual Meeting; 1991 Sept 2-6; San Francisco*. Santa Monica, California: Human Factors Society. 1159-1161.

Le Clair, K. and Riach, C. (1996) Postural stability measures: what to measure and how long. *Clinical Biomechanics* **11**, 176-178.

Leonard, C.T., Matsumoto, T., Diedrich, P.M. and McMillan, J.A. (1997) Changes in neural modulation and motor control during voluntary movement of older individuals. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **52A:M**, 320-325.

Leroux, A., Fung, J. and Barbeau, H. (2002) Postural adaptation to walking on inclined surfaces: I. Normal strategies. *Gait Posture* **15**, 64-74.

Lord, S.R. and Clark, R.D. (1996) Simple physiological and clinical tests for the accurate prediction of falling in older people. *Gerontology* **42**, 199-203.

Louhevaara, V., Soukainen, J., Lusa, S., Tulppo, M., Tuomi, P. and Kajaste, T. (1994) Development and evaluation of a test drill for assessing physical work capacity of fire-fighters. *International Journal of Industrial Ergonomics* **13,** 139-146.

Louhevaara, V., Tuomi, T., Korhonen, O. and Jaakkola, J. (1984) Cardiorespiratory effects of respiratory protective devices during exercise in well-trained men. *European Journal of Applied Physiology* **52**, 340-345.

Lusa, S. (1994) *Job demands and assessment of the physical work capacity of fire fighters. Studies in Sport, Physical Education and Health 33.* Doctoral thesis, University of Jyväskylä, Jyväskylä.

Lusa, S., Louhevaara, V. and Kinnunen, K. (1994) Are the job demands on physical work capacity equal for young and aging firefighters? *Journal of Occupational Medicine* **36**, 70-74.

Magnusson, M., Enbom, H., Johansson, R. and Pyykkö, I. (1990) Significance of pressor input from the human feet in aterior-posterior postural control. The effect of hypothermia on vibration-induced body-sway. *Acta Oto-Laryngologica* **110**, 182-188.

Maki, B.E., Holliday, P.J. and Fernie, G.R. (1990) Aging and postural control. A comparison of spontaneous- and induced-sway balance tests. *Journal of the American Geriatrics Society* **38**, 1-9.

Marigold, D.S. and Patla, A.E. (2002) Strategies for dynamic stability during locomotion on a slippery surface: effects of prior experience and knowledge. *Journal of Neurophysiology* **88**, 339-353.

Massion, J. (1994) Postural control system. *Current Opinion in Neurobiology* **4,** 877-887.

Matheson, A.J., Darlington, C.L. and Smith, P.F. (1999) Further evidence for age-related deficts in human postural function. *Journal of Vestibular Research: Equilibrium & Orientation* **9**, 261-264.

McComas, A.J. (1996) *Skeletal muscle*. Human Kinetics, Champaign, IL.

Metitur (2001) *In Good Balance, user's manual*. Version 2.54. Metitur Oy, Jyväskylä. See also http://www.metitur.com

Misner, J.E., Boileau, R.A. and Plowman, S.A. (1989) Development of placement tests for firefighting. *Applied Ergonomics* **20**, 218-224.

Monsell, E.M., Furman, J.M., Herdman, S.J., Konrad, H.R. and Shepard, N.T. (1997) Computerized dynamic platform posturography. *Otolaryngology - Head and Neck Surgery* **117**, 394-398.

Mouchnino, L., Aurenty, R., Massion, J. and Pedotti, A. (1992) Coordination between equilibrium and head-trunk orientation during leg movement: a new strategy built up by training. *Journal of Neurophysiology* **67**, 1587-1598.

Mustalampi, S., Era, P., Kiviranta, I. and Selänne, H. (2003) Test-retest reliability of postural stability tests in uninjured subjects and in patients after ACL reconstruction. In: *Abstracts of 8th Annual Congress of European College of Sport Science; 2003 Jul 9–12; Salzburg, Austria*. Eds: Müller, E., Schwameder, H., Zallinger, G. and Fastenbauer V. 18.

Nashner, L.M. (1997) Physiology of balance, with special reference to the healthy elderly. In: *Gait disorders of aging: falls and therapeutic strategies*. Eds: Masdeu, J.C., Sudarsky, L. and Wolfson, L. Philadelphia: Lippincott-Raven. 37-53.

Niinimaa, V. and McAvoy, T. (1983) Influence of exercise on body sway in the standing rifle shooting position. *Canadian Journal of Applied Sport Sciences* **8**, 30-33.

Noback, C.R. and Demarest, R.J. (1981) The human nervous system. Basic principles of neurobiology. McGraw-Hill, Tokyo.

Nordahl, S.H.G., Aasen, T., Dyrkorn, B.M., Eidsvik, S. and Molvaer, O.I. (2000) Static stabilometry and repeated testing in a normal population. *Aviation, Space and Environmental Medicine* **71**, 889-893.

Okada, S., Hirakawa, K., Takada, Y. and Kinoshita, H. (2001) Age-related differences in postural control in humans in response to a sudden deceleration generated by postural disturbance. *European Journal of Applied Physiology* **85**, 10-18.

O'Neill, D.E., Gill-Body, K.M. and Krebs, D.E. (1998) Posturography changes do not predict functional performance changes. *The American Journal of Otology* **19**, 797-803.

Pajala, S., Era, P., Koskenvuo, M., Kaprio, J., Tolvanen, A., Heikkinen, E., Tiainen, K. and Rantanen, T. (2004) Contribution of genetic and environmental effects to postural balance in older female twins. *Journal of Applied Physiology* **96,** 308-315.

Pan, C.S., Chiou, S. and Hendricks, S. (2003) The effect of drywall lifting method on workers' balance in a laboratory-based simulation. *International Journal of Occupational Safety and Ergonomics* **3,** 235-249.

Panzer, V.P., Bandinelli, S. and Hallett, M. (1995) Biomechanical assesment of quiet standing and changes associated with aging. *Archives of Physical Medicine and Rehabilitation* **76**, 151-157.

Parnianpour, M., Frankel, V.H. and Nordin, M. (1989) Safety and older workers in the workplace. In: *Advances in industrial ergonomics and safety I*. Ed: Mital, A. London: Taylor and Francis. 367-374.

Patla, A.E. (1997) Understanding the roles of vision in the control of human locomotion. *Gait Posture* **5**, 54-69.

Patla, A., Frank, J. and Winter, D. (1990) Assessment of balance control in the elderly: major issues. *Physiotherapy Canada* **42**, 89-97.

Paulus, W.M., Straube, A. and Brandt, T.H. (1984) Visual stabilization of posture. Physiological stimulus characteristics and clinical aspects. *Brain* **107**, 1143-1163.

Pendergrass, T.L., Moore, J.H. and Gerber, J.P. (2003) Postural control after a 2-mile run. *Military Medicine* **168**, 896-903.

Perrin, P.P., Jeandel, C., Perrin, C.A. and Béné, M.C. (1997) Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults. *Gerontology* **43,** 223-231.

Peterson, B. and Harrell, F. (1990) Partial proportional odds models for ordinal response variables. *Applied Statistics* **39**, 205-217.

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

Pohjonen, T. (2001a) Age-related physical fitness and the predictive values of fitness tests for work ability in home care work. *Journal of Occupational and Environmental Medicine* **43**, 723-739.

Pohjonen, T. (2001b) *Perceived work ability and physical capacity of home care workers. Effects of the physical exercise and ergonomic intervention on factors related to work ability. Publications D. Medical Sciences.* Doctoral thesis, University of Kuopio, Kuopio. 260.

Pohjonen, T., Liimatainen, M., Toikka, T. and Lindholm, H. (2003) *Työn kuormitustekijöiden hallinnan kehittäminen vanhusten laitoshoidossa. Loppuraportti 2003.* Helsinki: Helsingin kaupunki ja Työterveyslaitos.

Pokorski, J., Niteck, J. and Ilmarinen, J. (2004) Work ability index in fire fighters and medical doctors. In: *Past, present and future of work ability*. *People and Work Research Reports 65.* Eds: Ilmarinen, J. and Lehtinen, S. Helsinki: Finnish Institute of Occupational Health. 106-113.

Pollock, A.S., Durward, B.R., Rowe, P.H. and Paul, J.P. (2000) What is balance? *Clinical Rehabilitation* **14,** 402-406.

Pollock, M. and Wilmore, J. (1990) *Exercise in health and disease. Evaluation and prescription for prevention and rehabilitation.* 2nd edition. W.B. Saunders Company, Philadelphia.

Punakallio, A., Louhevaara, V. and Lusa-Moser, S. (1997a) Evaluation of a functional test for assessing dynamic balance of fire fighters. In: *From experience to innovation*. Eds: Seppälä, P., Luopajärvi, T., Nygård, C-H. and Mattila, M. Proceedings of the 13th Triennial Congress of the International Ergonomics Association; 1997 Jun 29-Jul 4; Tampere, Helsinki. *Finnish Institute of Occupational Health 4*. 393-395.

Punakallio, A., Louhevaara, V., Lusa-Moser, S. and Korhonen, O. (1997b) Work ability and physical fitness of fire fighters in different age groups. In: *From experience to innovation*. Eds: Seppälä, P., Luopajärvi, T., Nygård, C-H. and Mattila, M. Proceedings of the 13th Triennial Congress of the International Ergonomics Association; 1997 June 29-July 4, Tampere, Helsinki. *Finnish Institute of Occupational Health* 5, 75-77.

Punakallio, A., Lusa-Moser, S., Louhevaara, V., Viikari-Juntura, E. Ilmarinen, R., Ollila, J., Korhonen, O., Luukkonen, R. and Lindqvist-Virkamäki, S. (1999) Health, physical and mental capacity of fire fighters in different age groups. In: *FinnAge - respect for the aging: action programme to promote health, work ability and well-being of aging workers in 1990-96. People and work. Research reports 26.* Eds: Ilmarinen, J. and Louhevaara, V. Helsinki. *Finnish Institute of Occupational Health.* 117-127.

Prochazka, A. and Hullinger, M. (1983) Muscle afferent function ant its significance for muscle control mechanism during voluntary movements in cat, monkey and man. *Advances in Neurology* **39,** 93-132.

Prochazka, A. and Wand, P. (1980) Tendon organ discharge during voluntary movements in cats. *The Journal of Physiology* **303,** 385-390.

Pyykkö, I., Aalto, H., Hytönen, M., Starck J., Jäntti, P., Ramsay, H. (1988) Effect of age on postural control. In: *Posture and gait: development, adaptation and modulation. Proceedings of the 9th International Symposium on Postural and Gait Research; 1988 May 29 – June 1; Marseille*. Amsterdam-New York-Oxford. Eds: Amblard, B., Berthoz, A. and Clarac, F. Excerpta Medica. 95-104.

Pyykkö, I., Jäntti, P. and Aalto, H. (1990) Postural control in elderly subjects. *Age Ageing* **19,** 215-221.

Räty, H.P., Impivaara, O. and Karppi, S-L. (2002) Dynamic balance in former elite male athletes and in community control subjects. *Scandinavian Journal of Medicine & Science in Sports* **12,** 111-116.

Rankin, J.K., Woollacott, M.H., Shumway-Cook, A. and Brown, L.A. (2000) Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* **55A:M**, 112-119.

Ratzon, N., Froom, P., Leikin, E., Kristal-Boneh, E. and Ribak, J. (2000) Effect of exposure to lead on postural control in workers. *Occupational and Environmental Medicine* **57,** 201-203.

Redfern, M.S., Cham, R., Gielo-Perczak, K. Gronqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Pai, C.Y. and Powers, C. (2001 Biomechanics of slips. *Ergonomics* **44**, 1138-1166.

Rinne, M.B., Pasanen, M.E., Miilunpalo, S.I. and Oja, P. (2001) Test-retest reproducibility and inter-rater reliability of a motor skill test battery for adults. *International Journal of Sports Medicine* **22,** 192-200.

Robbins, S., Waked, E., Allard, P., McClaran, J. and Krouglicof, N. (1997) Foot position awareness in younger and older men – the influence of footwear sole properties. *Journal of the American Geriatrics Society* **45,** 61-66.

Røgind, H., Lykkegaard, J.J., Bliddal, H. and Danneskiold-Samsøe, B. (2003) Postural sway in normal subjects aged 20-70 years. *Clinical Physiology and Functional Imaging* **23**, 171-176.

Runge, C.F., Schupert, C.L., Horak, F.B. and Zajac, F.E. (1998) Role of vestibular information in initation of rapid postural responses. *Experimental Brain Research* **122**, 403-412.

Runge, C.F., Shubert, C.L., Horak, F.B. and Zajac, F.E. (1999) Ankle and hip postural strategies defined by joint torques. *Gait Posture* **10,** 161-170.

Rutenfrantz, J. (1981) Arbeitsmedizinische aspekte dess stress-problems. In: *Theorien, Untersuchungen, Massuahmen*. Ed: Nitsch, J.R. Bern-Stuttgart-Wien:Verlag Hans Huber. 379-390.

Samo, D.G., Bahk, J.K. and Gerkin, R.D. (2003) Effect of firefighter masks on monocular and binocular peripheral vision. *Journal of Occupational and Environmental Medicine* **45,** 428-432.

SAS Institute (1989) *SAS user's guide, Version 6.* 4th ed. Cary, NC: SAS Institute.

SAS Institute (1999) *SAS user's guide, Version 8.* Cary, NC: SAS Institute.

Shumway-Cook, A. and Woollacott, M.H. (1995) *Motor control: Theory and Practical Applications*. 1st ed. Baltimore, MD: Williams & Wilkins. 119-142.

Shumway-Cook, A. and Woollacott, M. (2000) Attentional demands and postural control: the effect of sensory context. *The Journals of Gerontology Series A, Biological Sciences and Medical Sciences* **55A:M**, 10-16.

Shumway-Cook, A., Woollacott, M., Kerns, K.A. and Baldwin, M. (1997) The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *The Journals of Gerontology Series A, Biological Sciences and Medical Sciences* **52A:M**, 232-240.

Seliga, R., Bhattacharya, A., Succop, P., Wickstrom, R., Smith, D. and Willeke, K. (1991) Effect of work load and respirator wear on postural stability, heart rate, and perceived exertion. *American Industrial Hygiene Association Journal* **52,** 417-422.

Shimada, H., Obuchi, S., Kamide, N., Shiba, Y., Okamoto, M. and Kakurai, S. (2003) Relationship with dynamic balance function during standing and walking. *American Journal of Physical Medicine & Rehabilitation / Association of Academic Physiatrists* **82,** 511-516.

Sihvonen, S., Hofmann, C. and Era, P. (1998) Development of postural abilities across the life span parallels changes in muscle strength. In: *Proceedings of the International Conference on Weightlifting and Strength Training, 1998 Nov 10-12. Lahti, Finland*. Ed: Häkkinen, K. 215-216.

Simeonov, P. and Hsiao, H. (2001) Height, surface firmness, and visual reference effects on balance control. *Injury Prevention* **7(Suppl. 1),** i50-53.

Simeonov, P.I., Hsiao, H., Dotson, B.W. and Ammons, D.E. (2003) Control and perception of balance at elevated and sloped surfaces. *Human Factors* **45(1),** 136-147.

SPSS Inc.(1997) SPSS advanced statistics 7.5. Chicago IL: SPSS Inc.

Starck, J., Pyykkö, I., Aalto, H. and Pekkarinen, J. (1993) Measurements of postural stability: development of a force platform and some excitation systems. *Medical Progress Through Technology* **18,** 209-215.

Strandberg, L. and Lanshammar, H. (1981) The dynamics of slipping accidents. *Journal of Occupational Accidents* **3,** 153-162.

Stelmach, G.E. and Sirica. A. (1987) Ageing and proprioception. *Age* **9,** 99-103.

Stelmach, G.E., Teasdale, N., Di Fabio, R.P. and Phillips, J. (1989) Age related decline in postural control mechanisms. *International Journal of Aging and Human Development* **29,** 205-223.

Straube, A., Bötzel, K., Hawken, M., Paulus W., Brandt, T. (1988) Postural control in the elderly: differential effects of visual, vestibular and somatosensory input. In: Posture and Gait: Development, adaptation and modulation. Proceedings of the 9th International Symposium on Postural and gait research 1988, 29 May – 1 June, Marseille. Amsterdam. Eds: Amblard, B., Berthoz, A., Clarac, F. *Excerpta Medica* 105-114.

Suni, J. (2000) *Health-related fitness test battery for middle-aged adults with emphasis on musculoskeletal and motor tests*. Studies in Sport, Physical Education and Health 66. Doctoral thesis, University of Jyväskylä, Jyväskylä.

Takala, E-P., Korhonen, I. and Viikari-Juntura, E. (1997) Postural sway and stepping response among working population: reproducibility, long-term stability, and associations with symptoms of the low back. *Clinical Biomechanics* **12,** 429-437.

Takala, E-P. and Viikari-Juntura, E. (2000) Do functional tests predict low back pain? *Spine* **25,** 2126-2132.

Tang, P-F., Woollacott, M.H. and Chong, R.K.Y. (1998) Control of reactive balance adjustments in perturbed human walking: roles of proximal and distal postural muscle activity. *Experimental Brain Research* **119,** 141-152.

Teasdale, N. and Simoneau, M. (2001) Attentional demands for postural control: the effects of aging and sensory reintegration. *Gait Posture* **14,** 203–210.

Tilastokeskus. (2002) Työtapaturmat 2000. Työmarkkinat 2002;**14**.

Tilastokeskus. (2003) Työvoimatutkimus. Helsinki: Tilastokeskus; 2003.

Tilastokeskus. Palo- ja rakennusmiesten liukastumis-, kompastumis-, kaatumis- ja putomistapaturmatilastot vuosilta 1996–2001.

Toppila, E. and Pyykkö, I. (2000) Chaotic model of postural stability - a position and velocity dependent system? *Automedica* **19**, 115-134.

Toussaint, H.M., Commissaris, D.A.C.M., Beek, P.J. (1997) Anticipatory postural adjustments in the back and leg lift. *Medicine and Science in Sports and Exercise* **29,** 1216-1224.

Tsigilis, N., Zachopoulou, E. and Mavridis, T.H. (2001) Evaluation of the specificity of selected dynamic balance tests. *Perceptual and Motor Skills* **92,** 827–833.

Tuomi, K., Ilmarinen, J., Eskelinen, L., Järvinen, E., Toikkanen, J. and Klockars, M. (1991) Prevalence and incidence of diseases and work ability in different work categories of municipal occupations. *Scandinavian Journal of Work, Environment & Health* **17(Suppl. 1),** 67-74.

Tuomi, K., Ilmarinen, J., Jahkola, A., Katajarinne, L. Tulkki, A. (1998) *Work ability index*. Helsinki: Finnish Institute of Occupational Health. Occupational Health Care 19.

Tuomi, K., Wägar, G., Eskelinen, L., Järvinen, E., Huuhtanen, P., Suurnäkki, T., Fahlström, P., Aalto, L. and Ilmarinen, J. (1985) Terveys, työkyky ja työolot kunnallisissa ammattiryhmissä. Työterveyslaitoksen tutkimuksia. 95–132.

Viitasalo, J., Viljanen, T. and Komi, P. (1977) *Dynamometers for measurement of isometric trunk and leg forces*. Jyväskylä: Univ. of Jyväskylä. Research Reports from the Department of Biology of Physical Activity 22.

Viitasalo, J.T., Era, P., Leskinen, A-L. and Heikkinen, E. (1985) Muscular strength profiles and anthropometry in random samples of men aged 31-35, 51-55 and 71-75 years. *Ergonomics* **28**, 1563-1574.

Vouriot, A., Gauchard, G.C., Chau, N., Benamghar, L., Lepori, M.L., Mur, J.M. and Perrin, P.P. (2004) Sensorial organisation favouring higher visual contribution is a risk factor of falls in an occupational setting. *Journal of Neuroscience Research* **48,** 239-247.

Waked, E., Robbins, S. and McClaran, J. (1997) The effect of footwear midsole hardness and thickness on proprioception and stability in older men. *Journal of Testing and Evaluation* **25,** 143-149.

Williford, H.N., Duey, W.J., Olson, M.S., Howard, R. and Wang, N. (1999) Relationship between fire suppression tasks and physical fitness. *Ergonomics* **42,** 1179-1186. Winter, D.A. (1995) Human balance and posture control during standing and walking. *Gait Posture* **3,** 193-214.

Woollacott, M.H., Shumway-Cook, A. and Nashner, L.M. (1986) Aging and posture control: changes in sensory organization and muscular coordination. *International Journal of Aging & Human Development* **23,** 97-114.

Woollacott, M.H. and Tang, P-F. (1997) Balance control during walking in the older adult: research and its implications. *Physical Therapy* **77,** 646-660.

You, J-Y., Chou, Y-L., Lin, C-J. and Su, F-C. (2001) Effect of slip on movement of body center of mass relative to base of support. *Clinical Biomechanics* **16,** 167-173.

Zelnik, S.D., McKay, R.T. and Lockey, J.E. (1994) Visual field loss while wearing full-face respiratory protection. *American Industrial Hygiene Association Journal* **55,** 315-321.

Zettel, J.L., McIlroy, W.E. and Maki, B.E. (2002) Can stabilizing the features of rapid triggered stepping reactions be modulated to meet environmental constraints? *Experimental Brain Research* **145,** 297-308.

Zinzen, E., Caboor, P., Van-Roy, P. and Clarys, J.P. (1996) *Testing motor physical fitness in occupational situations using the eurofit test battery*. Abstracts of 1st Annual Congress in Sport Science in the European Perspective; 1996 May 28-31; Nice, France 814-815.

10. AUTHOR BIOGRAPHY

Anne PUNAKALLIO

Employment

Researcher, Finnish Institute of Occupational Health, Department of Physiology.

Degree

PhD

Research interest

Work ability, balance control, slipping and tripping accidents and ageing in physically demanding occupations.

Email: anne.punakallio@ttl.fi

🖂 **Anne Punakallio**

Finnish Institute of Occupational Health, Department of Physiology, Topeliuksenkatu 41 a A, FIN-00250, Helsinki, Finland