Orthotic interventions to improve standing balance in somatosensory loss

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Introduction

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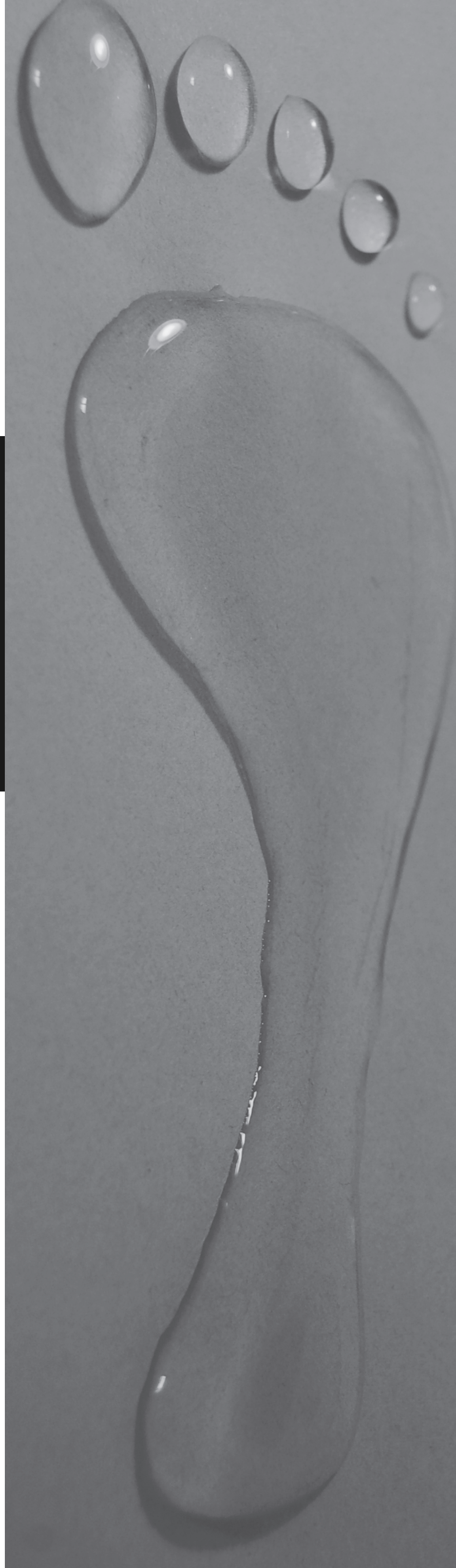

Introduction

Older people and people with peripheral nervous system disorders (PNSD) (e.g. neuropathies, nerve compression syndromes) show a similar decline in the control of posture [1-5]. Both groups are at risk of falling [1]. More than 30% of the older people (over 65 years of age) fall at least once a year and 50% of these fall more than once [6-9]. Diabetic neuropathy (DN) is the most common PNSD [10]. Together, these groups (older people and DN) account for the majority of the population with deteriorated balance due to somatosensory loss, although in older people somatosensory loss is not the only explanation of the deteriorated balance [10;11]. Postural control in people with somatosensory loss is impaired because of decreased tactile and proprioceptive feedback from the lower limbs [1-3]. Possibly, tactile and proprioceptive sensation from the lower limbs can be improved with an orthotic intervention of the ankle and foot. By increasing tactile or proprioceptive sensation from the lower limb, balance is thought to improve concurrently. In this thesis orthotic interventions to improve standing balance in people with somatosensory loss are studied.

Somatosensory loss

Falling in older people is related to increased postural sway, mainly in mediolateral (ML) direction [12;13]. It can be expected that improvement of postural control leads to a decreased risk of falling. Research concerning possibilities to improve balance is therefore of great importance. Balance impairment in older people is a result of degeneration of multiple systems. Mechanical, motor and sensory deteriorations all contribute to balance problems that occur with aging [14;15]. One of the reasons for loss of balance is decreased somatosensory input from the lower limbs [12;16], mainly a result of increased thresholds for fast adapting type II receptors [17].

Diabetes mellitus (DM) leads to the development of DN in about 30% of the cases [10;18;19]. Prolonged disease duration, older age and poor glycemic control lead to an increased chance to develop DN [10;18;19]. Patients with type II DM have a higher risk of developing DN [10]. DN is present in about 50% of patients with type II DM over the age of 60 [10]. The main cause of the DN is axonal degeneration and demyelination. Due to severe microvascular changes a reduced nerve blood flow and consequently reduced oxygenation is present [20]. Some of the symptoms of DN are increased thresholds for joint position sense (JPS), tactile and vibrotactile sensation [21-23]. Large diameter fibres mainly conduct somatosensory information [24;25], however, medium-size afferent fibres seem to play the most important role in standing balance control [26-28]. It has been shown that in DN a range of fibre types can be selectively affected [29;30].

A wide range of diagnostic tools are described in the literature to assess somatosensation in DN, healthy people, and other groups, although disagreement exists about the best measurement to be used [31-38]. Impaired tactile sensation of the plantar surface of the feet may lead to deteriorated balance, as changes in pressure distribution are detected less accurately [39]. In contrast with older people who have an increased sway mainly in ML direction, in DN this is mainly in anteroposterior direction. Most studies focus on standing balance, which has been shown to deteriorate with the severity of the sensory loss [40]. Balance seems to be less affected during dynamic conditions, possibly due to anticipatory strategies [26].

Postural control

In normal stance, the body is not stationary. Rather, during quiet stance the body is constantly moving with the direction of the movement constantly changing. Postural control refers to maintaining the centre of gravity (CoG) within the base of support (BoS) [41]. CoG in this case is defined as the vertical projection of the centre of mass (CoM) on the support surface [42]. The postural control system has two main functions: first a mechanical antigravity function and secondly it serves as a reference frame for perception and action with respect to the external world [14]. Because in this thesis quiet stance is studied, mainly the first function is referred to. Posture is thought to be controlled by both open loop (without the use of feedback) and closed loop mechanisms (with the use of feedback) [43].

Approximately two thirds of the human body weight is located above two thirds of the body height. Postural control is therefore a challenging task [42;44]. In order to control posture, we rely heavily on our sensory feedback systems. Three main sensory feedback systems can be distinguished for postural control, the visual, vestibular and somatosensory system [43;45]. During normal stance, somatosensory information provides the most sensitive information; standing balance is therefore thought to be controlled mainly by somatosensory information [46-48].

Visual system

The main type of visual information in relation to postural control is the motion of the person or the environment detected by the retina [49]. As the projection of an object increases on the retina, either the object is moving towards the person or the person is moving towards the object [49]. When a person is standing still, yet at the same time moving towards an object, the central nervous system has to react to stop the movement towards the object and change it in a movement in the opposite direction [50]. The importance of the visual system in postural control increases when other sensory systems are impaired [49;51]. Consequently, conflicting visual cues, darkness, or visual impairment results in an even greater loss of balance in conjunction with reduced function of the vestibular or somatosensory system.

Vestibular system

The vestibular organ can be seen as a measuring device for movements of the head in space with six degrees of freedom [52]. It can be divided in two subsystems, the semi-circular and the otolith system [52]. The otolith system, responsible for the detection of translational accelerations, plays a role in postural control, particularly in the selection of an appropriate postural movement strategy when balance is perturbed and in postural reactions to trunk movements [53-55]. The semi-circular subsystem, responsible for the detection of angular acceleration, is not accurate in detecting low frequency angular accelerations and therefore its role in detecting sway during quiet stance seems to be limited [45]. During quiet stance the role of the vestibular system seems to be limited [56]. This is in line with Mergner's model, suggesting that vestibular information plays only a role in postural control when the support surface is regarded as unstable [52].

Somatosensory system
The somatosensory system plays an important role in postural control [57]. It has been shown that posture can be controlled based on somatosensory information alone [46], and the somatosensory system is thought to be the most automatic feedback system [58]. The somatosensory system can be separated in two parts, the tactile and the proprioceptive system [57;59]. Both play a role in postural control [59].

The tactile system provides the CNS with information concerning the sense of touch. Tactile stimuli, detected by cutaneous mechanoreceptors (Meissner's corpuscles, Pacinian corpuscles, Merkel's disks and Ruffini endings) in the plantar surface of the feet provide the CNS with information concerning pressure distribution [24]. Changes in pressure distribution are often related to changes in upright position.

Studies in which plantar cutaneous mechanoreceptors are stimulated by vibration are used to investigate the role of the tactile system [60;61]. When vibratory stimuli are applied to a specific portion of the contact area e.g. one foot, anterior zones of both feet or posterior zones of both feet, the CNS reacts, resulting in movement of the centre of pressure (COP) in the opposite direction. When the afferents in the plantar foot are anesthetized by cooling, ischemic blocking or anesthetics, balance deteriorates, mainly in anteroposterior direction [46;62-71]. It is suggested that plantar sensation plays a role mainly in the magnitude and not the time-dependant structure of sway [64]. With increasing somatosensory loss, balance seems to deteriorate gradually [71]. Moreover, when tactile sensation is improved by peripheral nerve decompression or phototherapy, balance seems to improve [72;73].

The proprioceptive system provides the CNS with information concerning movement and position of body segments. Proprioceptors in muscles, tendons, ligaments and joint capsules (muscle spindles, Golgi tendon organs and joint afferents) play a part in this system [24]. The exact role of the proprioceptive information in control of posture and the detection of balance perturbation remains unclear. It seems that proprioceptive information from the legs is not required to trigger most automatic postural responses [74]. Balance seems to improve due to the "proprioceptive effects" of an ankle foot orthosis (AFO) [75;76]. It is possible that normal proprioception from the ankle and foot plays only a minor role in postural control if information from all other sensory systems is available. However, extra proprioceptive input may have a positive effect on postural control when it is impaired [76].

Multisensory integration

Multisensory integration of the sensory systems described above is involved in human postural control [14]. Degeneration of one of the sensory systems used for feedback concerning balance is often compensated [55;69;77]. Therefore, during normal circumstances, the effects of the degeneration of one of the sensory systems might not be apparent. The role of the different sensory systems is re-weighted, with the relative role of the intact systems increased [77-82]. There are limits in compensatory possibilities though. When the compensating systems are challenged (e.g. when it is dark or standing on a soft surface), postural control becomes increasingly difficult, resulting in an increased risk of falling [83].

Attention

Although not a sensory system, attention also plays an important role in postural control [84;85]. Attention can be seen as the information processing capacity of an individual [85]. Research concerning the role of attention in postural control is rather new. The precise role of attention on balance is still not clear. It is known, however, that as people get older or acquire certain pathologies, the attention demands for balance increase. Attentional demands for the control of posture are usually studied using a dual task. When a dual task is presented, the CNS has to use a reasonable part of the information processing capacity for this task, meaning that limited capacity is available for the balance task [85] resulting in a deterioration of balance when this is not fully automated [83].

Manipulation and disorders of the sensory systems

In the literature, two important methods for studying the role of the different systems on balance are described. The first is the manipulation of the system. Vision is easily manipulated by closing the eyes, decreasing the intensity of light, blurring the vision, or by presenting optical illusions [49]. The vestibular system can be manipulated by galvanic vestibular stimulation (GVS) [86-88]. Using GVS the CNS is provided with sway information without the actual presence of sway. In this way the reaction on vestibular detection of sway can be studied. The somatosensory system can be manipulated in different ways. Anesthesia can decrease or eliminate somatosensory feedback from either the plantar surface of the foot, the ankle, or both [46;62-71]. The tactile system can also be manipulated by decreasing tactile input from the plantar surface of the foot by having subjects stand on foam [83;89]. Another method often used to study the role of somatosensation in the control of posture is the application of muscle vibration which can induce a proprioceptive illusion [90]. The CNS receives input about the presence of certain rotation of a limb without the actual occurrence of the rotation. The postural effects of each of these manipulations explain the relative roles of the different sensory systems.

A second method of studying the role of the different sensory systems on balance is to examine people with specific disorders of one of the systems. Similar to decreasing feedback experimentally, when examining specific patient groups, the effect of the absence of certain feedback can be studied. In this group however, people usually compensate for their sensory loss. When information from one of the systems is decreased or absent, the remaining systems become more important. Therefore, people with vestibular or somatosensory loss depend heavily on visual information for postural control.

In this thesis, the focus will be on balance in people with somatosensory loss and on possibilities to improve balance by enhancing somatosensory feedback with ankle and foot appliances.

Outline of the thesis

In this thesis, first theories and current knowledge concerning the balance improving possibilities of ankle and foot appliances were studied in a review (*Chapter 2*). Promising interventions with balance improve possibilities in people with somatosensory loss were identified. Following, these interventions that have either been show to be effective or that in theory might be effective to improve balance were further studied. *Chapter 2* presents an overview of theories concerning the role of the somatosensory system on balance followed by a systematic review about the effects of appliances on the ankle and foot on balance in people with somatosensory loss. The research presented in *Chapter 3 to 6*, in which different appliances to the lower limbs were developed and their effects on balance were investigated, was guided by the results from the review. *Chapter 3* describes the effects of ankle and foot compression on JPS and balance. From theories based on previous research in ankle instability, it seems that compression of the ankle and foot may lead to improvement of JPS due to additional tactile information from the skin of the ankle referring to the angle or angular change of the ankle. Improvement of JPS is thought to improve balance only in people with both proprioceptive and balance difficulties, which is often present in older people. In the following chapters, research and development of vibrating insoles is presented. In *Chapter 4* the effects of vibrating insoles on balance in people with DN are tested. Vibrating insoles provide mechanical noise to the plantar foot in order to improve tactile feedback concerning pressure distribution at the plantar surface of the feet. Although noise is usually associated with decreased signal information, in some cases it can improve signal detection. The mechanism behind this is called stochastic resonance, described as a counterintuitive mechanism whereby the addition of noise to a non-linear system can enhance the detection of weak stimuli or enhance the information content of a signal. *Chapter 5* describes the development of vibrating insoles. The most effective mechanical properties, components and configuration are investigated. In *Chapter 6* the most effective characteristics of the noise signal to improve balance in patients with DN are studied in a single case design. The outcomes of the research presented in this thesis and their impact will be discussed in *Chapter* 7.

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