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Human Balance Control: Effects of Fear and Attention in Standing and Walking

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Chapter 5

Epilogue

5.1 Introduction

The general aim of the present project was to assess the effects of fear of falling and attention on human balance control. Knowledge of the neurophysiological and psychological mechanisms that have an adverse effect on balance may ultimately help to design interventions to counteract mobility loss in the elderly, anchored in scientific theory and based on empirical evidence. To achieve this goal two experiments were conducted, one at the Manchester Metropolitan University and one at the Vrije Universiteit Amsterdam. The first experiment investigated the effects of fear of falling on vestibular balance reflexes. Full body kinematics was collected from young healthy adults standing at ground level and at height to induce a fear of falling. Participants were stimulated with GVS to induce vestibular balance reflexes. In the second experiment the influence of focus of attention and fall history on gait performance was studied by applying random mechanical perturbations to gait, in a sample of elderly participants. In this Epilogue the main findings of these studies are summarised and discussed in light of the extant literature. Furthermore, the scientific implications of this work and recommendations for future research are discussed.

5.2 How fear affects balance control

As falls pose a significant threat to the elderly population, a large body of research is dedicated to identifying risk factors for falls, in particular factors that reduce balancing capabilities. In addition to physiological risk factors, psychological/cognitive constructs such as fear of falling and attentional focus have also been found to be important in relation to the occurrence of falls in the elderly.

5.2.1 Vestibular balance control

The literature shows that fear of falling can directly affect fall-risk through impairment of balance control. However, the mechanism behind this relation has not yet been clarified. For example, it is unknown whether fear of falling can influence balance at the level of fast vestibular reflexes. An often-used paradigm to elicit these balance reflexes is by applying GVS. With GVS the vestibular nerves are electrically stimulated, which induces a sensation of lateral rotation of the body. This illusory rotation elicits a whole body sway response towards the side of the anode electrode on the head. Therefore the sway response (i.e. triggered by the vestibular balance reflex) depends on the orientation of the head, see Figure 1.1. Osler *et al.* (2013) collected

head and trunk kinematics of the GVS response of participants standing at height to induce fear of falling by means of a postural threat. Each participant was also tested while standing at ground level (no postural threat). They found that height-induced fear of falling did not affect the sway response. Thus, it was concluded that fear of falling does not affect the vestibular-evoked balance response.

Other studies have collected GRF (Mian & Day, 2009; Dakin *et al.*, 2010; Mian *et al.*, 2010; Horslen *et al.*, 2014; Mian & Day, 2014) and lower extremity EMG data (Britton *et al.*, 1993; Fitzpatrick *et al.*, 1994; Ali *et al.*, 2003; Fitzpatrick & Day, 2004; Son *et al.*, 2008; Mian *et al.*, 2010; Muise *et al.*, 2012) in order to characterize the same (GVS induced) vestibular balance reflex. They consistently found a bi-phasic response pattern consisting of a short- and a medium-latency response (see Figure 1.2). Importantly, GRF data from Horslen *et al.* (2014) showed that height-induced fear of falling increases the gain of this bi-phasic vestibular balance reflex, which seems to be in contrast to the kinematic data collected by Osler *et al.* (2013). As such, it was subsequently debated whether the fear-induced increase of the bi-phasic GRF response functionally contributes to balancing movements (Horslen *et al.*, 2015a, b; Reynolds *et al.*, 2015a; Reynolds *et al.*, 2015b).

To investigate whether fear of falling affects vestibular balance reflexes, we reasoned that a more detailed characterisation was needed of the kinematic pattern constituting this vestibular balance reflex. As opposed to head and trunk kinematics, full body kinematics of the GVS response could clarify how the balancing movements relate to the bi-phasic GVS response found in EMG and GRF data. Our findings are presented in the following paragraphs; we first discuss how the short- and medium-latency response are coupled (5.2.2) and next the effects of fear on this reflex pattern (5.2.3).

5.2.2 Short- and medium-latency response of vestibular balance reflexes

As described in Chapter 2, participants were stimulated with GVS to elicit vestibular balance reflexes. Full body kinematics was collected to characterise the balancing response. In the literature the GVS response has mainly been described with lower extremity EMG and shear GRF data; both types of data showed evidence of a short- and medium-latency response (Marsden *et al.*, 2005; Mian & Day, 2009; Day *et al.*, 2010; Mian *et al.*, 2010; Horslen *et al.*, 2014; Mian & Day, 2014). Interestingly, the short-latency response seemed to ‘mirror’ the medium-latency response.

More specifically, tibialis anterior, soleus and gastrocnemius muscles showed a pattern of short-latency activation that was followed by medium-latency inhibition (or vice versa, dependent on the anode/cathode configuration and head orientation).

With respect to GRF data, the literature revealed that short-latency cathode directed shear force was typically followed by medium-latency anode directed (i.e., opposite direction) shear force. Head and trunk kinematics data of this response showed a unilateral whole body sway response towards the anode side of the GVS electrodes that was consistent with the medium-latency EMG and GRF response data (Day *et al.*, 1997; Osler *et al.*, 2013). However, the contribution of the short-latency response to balance control was not yet clarified in relation to the kinematic data. Various hypotheses have been tested that might explain the origin of the short-latency response, but they all have been refuted (Britton *et al.*, 1993; Cathers *et al.*, 2005; Mian *et al.*, 2010).

From Newton's second law of motion it follows that the GRF pattern is proportional to the body COM acceleration. Therefore one could expect to find similar short- and medium-latency responses in the acceleration pattern of the entire body. However this was not reflected in the limited kinematic data that have been presented in the literature (Day *et al.*, 1997; Day *et al.*, 2010; Osler *et al.*, 2013). Therefore in the study described in Chapter 2, we aimed to characterise the vestibular balancing response in more detail using full body kinematics.

In our study we did find the short- and medium-latency acceleration responses, which were directed towards the cathode and anode electrode, respectively. We found this bi-phasic response pattern only in body COM, pelvis and lower extremities acceleration, but not in the head and trunk acceleration. This finding could explain why short- and medium-latency responses were not found in the kinematic data obtained in previous studies, as these were collected from the trunk and head, but not the lower extremities. These findings update the traditional model (Figure 1.1) of the GVS induced sway response. See a link to a video of the GVS sway and acceleration response in the supplementary materials section.

In addition, we proposed a mechanism that includes a functional contribution of the short-latency response to balancing movements. To be specific, we proposed that both the short- and medium-latency reflexes are biomechanically coupled as one coordinated response to guarantee whole body postural stability. The medium-latency sway response could be facilitated by a short-latency response that moves the centre of pressure towards the cathode, whereas the COM does not move to the same extent. This would allow the pull of gravity to aid in swaying the body towards the anode electrode. This balancing mechanism could be compared to balancing an upright stick on the palm of your hand. To move the stick (COM) to the right, you move your hand (COP) to the left. Thus, the hand moves the base of support (short-latency response) in a lateral direction, which then changes the gravitational moment on the stick, facilitating the medium-latency response. The study was not designed to test this theory, as vestibular balance reflexes were tested in one postural configuration and the short latency sway responses in the lower extremities were very small. On the other hand, this theory is consistent with GRF data from other studies where vestibular balance reflexes were tested in multiple configurations (Mian *et al.*, 2010; Horslen *et al.*, 2014).

5.2.3 Effects of fear of falling on vestibular balance reflexes

In the literature, height-induced fear of falling was found to increase the gain of short- and medium-latency vestibular balance reflexes. However, no consensus has been reached whether these changes functionally contribute to balance control. Opposing publications (Osler *et al.*, 2013; Horslen *et al.*, 2014) on this topic were discussed in a recent cross-talk debate (Horslen *et al.*, 2015a, b; Reynolds *et al.*, 2015a; Reynolds *et al.*, 2015b). We investigated how vestibular balance reflexes are influenced by fear of falling. The GVS induced vestibular reflexes were studied for participants standing at ground level but also while standing on a 3.85 m high narrow walkway to induce a fear of falling. Participants' physiological arousal (skin conductance) and self-evaluated levels of fear of falling were increased while standing at height, indicating that we could successfully induce fear. More importantly, analysis of whole body kinematics showed that the lower extremity short- and medium-latency acceleration responses were altered at height. Our main finding was that the response amplitude was increased, while the time interval during which the responses were executed was decreased, indicating that fear of falling induced stronger and 'brisker' balancing

reflexes. However, fear of falling had no effect on the early (0-400 ms) GVS induced torso and head acceleration.

Our findings are consistent with the findings from Horslen *et al.* (2014) who found an increased gain of GRF-SVS short- and medium-latency vestibular balance responses with a height-induced fear of falling. Based on our full body kinematic data we concluded that the gain of the appendicular short- and medium-latency vestibular balancing reflexes increases with fear of falling. However, the fast axial neck and thoracolumbar muscle responses are governed by different neuromuscular mechanisms that seem to be unaffected by fear of falling. Our findings are also consistent with the seemingly opposing findings from Osler *et al.* (2013). They found no effect of height-induced fear of falling on the vestibular balance reflex, as measured with kinematic recordings of the head and trunk only. The distinct dependencies of axial and appendicular vestibular reflexes may reflect different functional goals (head stabilisation vs. whole body balance) and differential innervation (medial vs. lateral vestibulospinal tracts) (Forbes *et al.*, 2015).

In conclusion, Chapter 2 showed that height-induced fear of falling increases the gain of vestibular balance reflexes. Full body kinematic data suggest that both the short- and medium-latency appendicular vestibular balance reflexes functionally contribute to whole body balance and are biomechanically coupled into one coordinated response. Furthermore, axial vestibular reflexes were found to be unaffected by fear of falling and the goal of these reflexes may be more closely related to stabilise the head in space than to whole body balance.

5.3 Attentional focus

A different psychological/cognitive factor that is related to fear of falling and falls in the elderly is focus of attention. Individuals who experience fear of falling or who have low balance confidence may choose to consciously monitor their body movements in an effort to improve motor control (Wong *et al.*, 2008). This change from an implicit, more automated form of motor control to an explicit, more conscious form of motor control has been termed reinvestment, and seems to constitute a cognitive (adaptive) mechanism. Furthermore, a relation was found between reinvestment scores and fall history in elderly (Wong *et al.*, 2008). A separate but related body of literature on attentional focus is based on the 'constrained action hypothesis' (Wulf *et al.*, 2001;

Wulf, 2013). This hypothesis asserts that an attentional focus on the movement outcome in the environment ('external focus') results in improved motor performance and motor learning, whereas a focus on movement execution itself ('internal focus') hampers motor performance and motor learning. Beneficial effects of an external focus were found for various sports and balancing tasks, and were reviewed by Wulf (2013). In the following paragraphs the main findings of Chapter 3 (5.3.1) and Chapter 4 (5.3.2) are discussed, followed by a critical evaluation of the attentional focus paradigm (5.3.3). In 5.3.4 we discuss the relations between attentional focus, fear of falling and gait.

5.3.1 Attentional focus and perturbed gait responses

The potential benefits of an external attentional focus on motor performance has not been demonstrated for gait in healthy elderly. The literature suggests that when the task is relatively easy, an external attentional focus yields no additional motor performance benefits. For example, benefits with respect to balance control were only found in more challenging balancing tasks, e.g. standing on an unstable balancing surface, and not for standing on solid ground (Wulf *et al.*, 2007).

As such, steady gait might not be challenging enough for the effect of attentional focus to occur. To tackle this issue, we introduced mechanical gait perturbations to make the walking task more challenging. An experiment was conducted at the Vrije Universiteit Amsterdam and was covered in Chapters 3 and 4 of this thesis. The main aim of this study was to investigate whether an external focus of attention could temporarily enhance gait performance in elderly. If so, this could open up possibilities for cognitive intervention programmes in elderly with fear of falling. Elderly participants walked on a split belt treadmill that was used to apply mechanical gait perturbations at random time intervals to challenge gait stability. A virtual reality environment of a forest road with mountains was projected on a semi-circular screen in front of the treadmill to create a realistic optic flow while walking. Using full body kinematics the effects of internal vs. external attention instructions on the balancing responses to gait perturbations were tested, as described in Chapter 3. Gait performance is associated with gait variability. As a measure of gait variability, CV of step length and step width of the first step after gait perturbations was analysed. As such, we expected reduced variability (CV values) for external focus compared to internal focus. In addition, velocity of the body COM in three dimensions was used to

calculate the orthogonal distance from unperturbed gait, based on the method from Bruijn *et al.* (2010). We used a novel technique (SPM) for statistical analysis of the resultant time series as a whole, in which the temporal dependency within the time series data were taken into account. The first four post-perturbation strides between internal and external attention were tested. Contrary to our expectations, no significant effect of focus of attention was found in any of these dependent variables. We therefore concluded that, relative to an internal focus, an external focus on the walking surface does not benefit balancing responses to gait perturbations.

5.3.2 Attentional focus and continuous gait

In Chapter 4 the effects of attentional focus on the gait bouts of continuous walking were described. By analysing the gait bouts between the perturbations, we measured the unperturbed gait pattern, which might be more sensitive to cognitive influence than abrupt reflexive responses following a perturbation.

Gait variability was assessed with CV's of step length, step width, stance time and swing time of the unperturbed gait bouts between the perturbations, while gait stability was calculated with LDE. For reasons outlined above, we expected to find reduced gait variability and increased stability for external attention compared to internal attention. However, also for these variables no effect of attentional focus was found. Hence, we concluded that external attention to the walking surface does not affect gait stability or variability in unperturbed elderly gait compared to internal attention.

In a review on the effects of internal and external focus of attention on motor performance (Wulf, 2013), several other studies were evaluated where null effects of attentional focus were found as well. For some of these studies participants were presented with information on a screen about their movements or the effects of their movements in the environment (De Bruin *et al.*, 2009; Shafizadeh *et al.*, 2013). For example, a moving dot representing the centre of gravity relative to a target (De Bruin *et al.*, 2009). Wulf (2013) argued that null effects in these studies were caused by powerful visual feedback, which presumably obfuscated attentional focus effects.

In the experiments described in Chapter 3 and 4, participants were presented with realistic and gait-specific optic flow. One might therefore also attribute our null-effect

to the presence of powerful visual feedback: It might well be that the presented optic flow overruled the effects of the instructions to concentrate on the movements of the treadmill or legs.

However, there is reason to believe that the effects of attentional focus can still manifest themselves in the presence of powerful visual feedback. It is well established that visual information of the surroundings aids to determine one's location in space and bodily orientation. This visual feedback is powerful, e.g. as balancing on an unstable surface (e.g. stabilometer or balance disk) with the eyes closed is much more challenging than with eyes open. For the balancing experiments described earlier in this chapter, effects of attentional focus were found (Wulf *et al.*, 1998; Shea & Wulf, 1999; Wulf *et al.*, 2001; McNevin *et al.*, 2003; Wulf & McNevin, 2003; Wulf *et al.*, 2004; Wulf *et al.*, 2007; Chiviakowsky *et al.*, 2010). These attentional focus effects occurred while participants had their eyes open and were highly dependent on the visual information to regulate their balance. Therefore, the powerful visual feedback did not obfuscate attentional focus effects in these studies. As such, it also seems unlikely that the optic flow one perceives with gait obfuscates attentional focus effects on gait performance.

5.3.3 Limitations of the internal/external focus paradigm

The absence of attentional focus effect on walking performance in general might also be related to the nature of the walking task. During gait, the goal is to maintain an upright walking pattern and to walk in a particular direction. To achieve this goal one does not have to control or manipulate an external object. The aim is to control the movement of the body itself with respect to the environment. In other studies where the task was to control body movement without an external object to manipulate, effects of attentional focus have been inconsistent. E.g., improved swimming performance was found for an external compared to internal focus of attention (Freudenheim *et al.*, 2010; Stoaate & Wulf, 2011). However, Lawrence *et al.* (2011) compared the effects of internal and external focus on motor learning for a gymnastics floor routine, and they found no effect of attentional focus on motor learning. Additionally, Kal *et al.* (2015) even suggested an opposite effect, whereby external focus in fact reduced performance of paretic leg movement of stroke patients.

As such, some authors argued that benefits of an external focus of attention do not apply to motor tasks where performance only depends on the movement form or movement pattern of the body itself, and where movement effects on the environment are not of main importance (Lawrence *et al.*, 2011; Peh *et al.*, 2011). Subsequently, Wulf (2013) criticised this view by arguing that the instructions adopted in their gymnastics study (Lawrence *et al.*, 2011) were not relevant for performance of the gymnastics task. Furthermore, multiple other studies did show improvements in movement form (kinematics) with an external focus of attention, e.g. for golf swing (An *et al.*, 2013), darts (Lohse *et al.*, 2010a), rowing (Parr & Button, 2009) and throwing (Southard, 2011). However, for all of these studies manipulation of an external object was involved and the effect of the movement in the environment was crucially important.

In addition, the constrained action hypothesis as a whole has been criticised as well. Previous studies have found performance benefits for an internal focus in long jumping (Mullen & Hardy, 2010), a weight lifting case study (Carson *et al.*, 2014) and a small sample javelin throwing study (MacPherson *et al.*, 2008). Carson and Collins (2015) proposed that the reason for the adverse effects of internal focus on motor performance and motor learning in other studies is due to the partial self-focus of attention. They argued that an internal focus on the body as a whole also yields performance benefits. Most internal focus instructions have only referred to movement of a specific part of the body. However, in nearly every movement task the whole body needs to be coordinated. Especially when a new movement pattern needs to be learned, internal focus is often inevitable when one cannot refer to (the effect of) a previously learned movement pattern.

Furthermore, a possible limitation is the relatively low sample size of participants that experienced a fall (nine) compared to the number of non-fallers (seventeen).

5.3.4 Relations between attentional focus, fall history and gait

In Chapter 4 the effect of fall history on gait stability and gait variability of unperturbed gait was studied as well. One of our findings was that participants who had experienced a fall in the 12 months preceding the experiment had significantly higher stance time CV and higher LDE (reduced gait stability). This supports the established findings that elderly fallers have reduced gait stability (Liu *et al.*, 2008;

Lockhart & Liu, 2008; Toebes *et al.*, 2012) and increased gait variability (Hausdorff *et al.*, 1997; Toebes *et al.*, 2012). However, no effect of fall history was found on the balance recovery response to gait perturbations, based on the variability of spatiotemporal gait parameters and COM velocity data. This shows that fallers and non-fallers had a similar movement pattern of the balancing responses to the perturbations, to recover to a steady gait pattern. However, as the sample size for this between-subjects comparison (8 fallers vs. 17 non-fallers) was relatively small, a larger sample size might be needed to find an effect of fall history for these gait variables.

Furthermore, no significant interaction effect between attentional focus and fall history was found for any of the gait variables. Additionally our data did not support the relation between reinvestment and fall history as previously found by Wong *et al.* (2008), as no significant differences were found between fallers and non-fallers. The process of reinvestment entails a more conscious monitoring of the movement, where one switches back to an earlier and more explicit stage of learning that involves less automated motor control. It might be possible that reinvestment does not occur in phylogenetic (learned in early life without declarative knowledge) motor skills as normal postural control and steady gait. For these skills, earlier stages of learning involved implicit learning and probably did not involve more conscious explicit learning (Young & Mark Williams, 2015).

5.4 Implications

This PhD project was part of the Move-Age joint doctorate programme that aims to improve mobility in the elderly population. Falls and mobility problems in elderly are critical issues worldwide. The literature on the factors that might contribute to fall risk shows that fear of falling and attention are important psychological factors. However the mechanisms by which these factors could affect fall risk are unclear. Investigation of the interaction between fear of falling, attention and balance in postural control and gait is needed to gain more insight into fall prevention.

The findings of Chapter 2 provide evidence that fear of falling increases the gain of vestibular balance reflexes. This supports an emergent theme that fear of falling increases sensitisation to balance relevant information (Balaban & Thayer, 2001; Horslen *et al.*, 2014). However, head-in-space stabilization reflexes were unaffected by fear of falling and seemed to be governed by different mechanisms. A direct relation

between vestibular balance reflexes and fall risk in the general population or the elderly has not yet been determined. However, increased gain and faster execution may negatively affect the speed accuracy trade-off involved in the required balancing responses. Furthermore, ageing involved with deterioration of sensory and vestibular function could be vulnerable to added effects of fear on balance reflexes (Horak *et al.*, 1989; Baloh *et al.*, 1993; Kristinsdottir *et al.*, 2000).

In addition, our more detailed characterisation of the GVS induced vestibular balancing movements expands our understanding of the manner in which humans regulate their balance. Future studies using full body kinematic measurement of vestibular balance reflexes while standing with different head orientations could provide evidence for our suggested coupling between short- and medium-latency responses. Various authors have used Stochastic Vestibular Stimulation (SVS) instead of GVS. It has been shown that SVS also elicits short- and medium-latency vestibular balance reflexes that can be measured with EMG and GRF (Dakin *et al.*, 2007). Full body kinematic measurement of SVS responses could confirm whether these responses induce the same short- and medium-latency acceleration pattern throughout the body. Additionally, with the SVS method the vestibular stimulation durations needed are much shorter than with conventional GVS, and therefore more experimental conditions could be tested for each participant. As such, in future studies the effect of fear of falling on full body kinematic data of the vestibular balance reflex could be compared between elderly fallers and non-fallers. This might improve the tools we have for fall risk assessment.

The assumed benefits of an external focus of attention to the walking surface do not seem to apply to gait, as the effect of the movement on the environment is less relevant for this task. Continued investigation into attentional focus effects and fear of falling on gait including effects of partial internal focus might further clarify the relations between fear of falling and attentional focus and how they could affect fall risk.

Impairment of motor control automaticity is a central theme for both the constrained action hypothesis and the reinvestment theory. For fall prevention in elderly it has been recommended to include gait automaticity training in conjunction with dual-tasks (Gschwind *et al.*, 2010). Movement regularity and movement fluency have been

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used as measures of automaticity and have shown to be affected by attentional focus (Kal *et al.*, 2013). As such, further studies could investigate whether reinvestment could affect gait automaticity in dual-task settings, and how this relates to falls in elderly. More specifically, falls and the degree of reinvestment in elderly might reveal differences in the trade-off between cognitive performance and gait automaticity in dual-tasks. A prediction would be that individuals with high reinvestment scores have greater difficulty in coordinating gait performance and cognitive (secondary) task performance.

Furthermore, brain imaging techniques could provide insight into the neurophysiological basis of how attentional focus and fear of falling might affect motor performance. Research in this area is scarce, although a functional magnetic resonance imaging (fMRI) study from Zentgraf *et al.* (2009) did find increased activity of the primary somatosensory and motor cortex for external focus compared to internal focus using finger movements. In addition, electroencephalography (EEG) studies measured the level of coherence between right hemispheric motor planning regions and left hemispheric verbal-analytical brain areas (Zhu *et al.*, 2011a; Zhu *et al.*, 2011b). These authors found increased coherence between these brain regions with more explicit conscious control of movement compared to more automated and implicit motor control. This was determined using the reinvestment scale (MSRS) and implicit vs. explicit motor learning paradigms. For future research it would be interesting to investigate how these attentional effects relate to internal and external focus conditions. This might reveal whether the same neural substrates and neural pathways are involved with the concepts of the constrained action hypothesis, reinvestment and the effects of implicit and explicit motor learning.

In addition, it has been proposed that fear of falling (Wong *et al.*, 2008) or ‘choking’ (Wulf, 2013) could instigate reinvestment and an internal focus of attention. Our results have confirmed that height-induced fear of falling affects the vestibular balance reflex. Possible neural targets for modulation of fear include the vestibular cortex, lateral vestibular nuclei, vestibulospinal tracts and subsequent spinal processing (Fitzpatrick & Day, 2004; Forbes *et al.*, 2015). In addition, excitation of the amygdala is associated with fear inducing stimuli. Two pathways connecting the amygdala and vestibular nuclei could be involved with this process, one via the parabrachial nucleus and one via the vestibular cortex (Lang *et al.*, 2000; Balaban & Thayer, 2001; Balaban,

2002; Staab *et al.*, 2013). It would be interesting to test how fall history and fear of falling affects brain activity in these regions. In addition, clinical studies involving patients with brain damage in these areas could provide more insight into the relation between fear and vestibular motor control. For example, it has been shown that amygdala deterioration prevents fear conditioning (Maren & Fanselow, 1996). It might therefore be interesting to assess whether the absence of a fear response in these patients is also reflected in balancing reflexes.

Our results corroborate converging evidence in the motor control literature that fear of falling increases sensitivity to self-motion. Future research on the effect of fear of falling and attentional focus on gait perturbation responses might provide more insight into fall prevention. There are many mechanisms from sensory integration to balancing motor execution to feedback of execution that could be impaired through ageing. Follow-up studies with clinical subgroups could further clarify the relation between fear of falling, attention and balance performance.

5.5 Main conclusions

- Fear of falling increases the gain of vestibular balance reflexes.
- Full body kinematic data suggest that both the short- and medium-latency reflexes functionally contribute to whole body balance and are biomechanically coupled into one coordinated response.
- Head-in-space stabilization reflexes are unaffected by fear of falling and seem to be governed by different mechanisms.
- External focus to a walking surface does not provide benefits for balancing responses to mechanical perturbations in gait of healthy elderly compared to internal focus.
- External focus to a walking surface does not reduce gait variability or increase gait stability in elderly compared to internal focus.
- Elderly fallers have increased gait variability and decreased gait stability compared to elderly non-fallers.