Summary

In this thesis, I analyzed behavioral consequences of augmented visual feedback (VF) on postural control. Subsequently I sought to transfer these findings to clinical application by testing whether VF-based balance training may have beneficial effects for patients suffering from Parkinson's disease.

*Feedback* can be considered all the information that informs the individual about his or her performance in the physical environment. *Sensory* feedback is generated by receptors that convert physical stimuli into signals that are transmitted to the central nervous system by means of nerves. Movements will nearly always result in some change in the sensory feedback. This feedback loop is an essential component of movement coordination, as it is only through sensory feedback that one can assess whether or not the movement goal was reached. Most relevant for postural control is the sensory information about the posture and movement of body segments (proprioception), information from the vestibular organs, information from mechanoreceptors that detect pressure in the foot, and visual information. *Augmented* feedback is feedback that supplements the above-mentioned sources of information with additional information. As I have here studied augmented feedback that is presented to the subject on a monitor, this is here referred to as augmented *visual* feedback. However, even a simple body-sized mirror can be considered to provide augmented visual feedback; it is not coincidental that such mirrors are applied in ballet training and certain forms of movement therapy.

Parkinson's disease (PD) is a progressive neurodegenerative disorder with the seminal motor signs bradykinesia, tremor, rigidity, and – here most important – postural instability. Prevalence of PD in the elderly is about 1% in the industrialized countries, which for the Netherlands implies anywhere between 50,000 and 90,000 cases. Improving or at least maintaining motor function in this patient group is of great relevance as it can crucially improve the individual's mobility and thereby their quality of life.

To pinpoint generic effects of VF, I first contrasted balance performance without VF with conditions of so-called congruent or incongruent VF. *Congruent* VF here refers to VF that matches with other sensory information. As such it forms a reliable representation of (the consequences of) movements, thereby supplementing
sensory feedback. In other words, congruent VF provides the subject with useful information about task performance. *Incongruent* VF, on the other hand, is VF that has been manipulated in such a way that it conflicts with the sensory feedback. Incongruent VF therefore does not provide the subject with reliable information about their performance. I hypothesized that congruent VF would improve postural control, whereas incongruent VF would impair it.

VF was implemented as a visual representation of the location of the body’s center-of-pressure (COP) estimated via ground-reaction forces measured using a conventional force plate. Several statistics of the COP served to quantify postural control during either quiet stance or rhythmic swaying. In Chapter 2, I used a static balance task with a fixed target to assess postural control during congruent and incongruent VF. While congruent VF was fed back directly (in real time), incongruent VF was produced by artificially delaying the VF. That is, by manipulating the delay the ‘degree of congruency’ could be modified to the millisecond. As expected, performance improved during real-time VF as compared to when feedback was absent, and deteriorated in conditions with incongruent VF. Low-frequency components of the COP signals, i.e. slow components of postural sway, displayed a monotonic increase in sway amplitude with increasing delay. By contrast, fast components of postural sway, i.e. high-frequency components of the COP signals, revealed a reduction in amplitude if the delay exceeded half a second. Slower components likely reflect the excursion of the body’s center-of-mass while the faster components signify more rapid changes in ankle torques. The results of this study imply that VF differentially affects these distinct components of postural control.

In Chapter 3, I adopted the same delayed VF paradigm and compared performance in patients with PD and contrasted that with healthy, age-matched controls. Here I asked whether PD patients would be more affected by incongruent VF than healthy controls in a dynamic weight-shifting task. This question was motivated by studies that report that patients with PD rely more on visual information than healthy controls. Hence, distorting the visual input through the (in-)congruency manipulation may affect patients from this group more than controls.

Participants were asked to follow a moving target, which required shifting their weight within the limits of their base of support. For conditions without feedback and with real-time, congruent VF, patients with PD performed lateral swaying motions with greater error and with more variable movement patterns than healthy controls. Patients with PD were nevertheless able to use VF to improve tracking
performance. As expected, however, patients with PD were not able to adapt to a certain amount of visual incongruity, whereas controls were able to do so. This study thus seems to support the idea of an increased reliance on visual feedback in PD.

In Chapter 4 I examined to what extent the differences found in Chapter 3 could be explained by differences in neural activation of the cortex. I measured oscillatory cortical activity using EEG during the weight-shifting task. Movement-related activity was dominant in the alpha and beta bands (8-14 Hz and 15-30 Hz, respectively). While the two groups did not display any differences under congruent VF, the incongruent VF was accompanied by a difference in movement-related alpha/beta modulation in the perceptual-motor network between groups. The PD group showed significantly more pronounced modulation than healthy controls in beta activity in primary motor areas (M1), and in alpha activity in primary visual area (V1). Beta modulation in M1 is commonly considered to mimic cortical control of (rhythmic) motor performance while alpha modulation in V1 is believed to reflect (low-level) visual processing. The results of this study complement the behavioral data from Chapter 3 and support the idea that patients have more difficulty using incongruent VF.

In the subsequent chapters I addressed the clinical prospect of using VF for balance training in PD. Although balance exercises form an integral part of conventional rehabilitative therapy, the effectiveness of current interventions is limited. In Chapter 5, I presented the rationale for developing a VF-based balance training (VFT) program for use in PD, as well as a research design in order to investigate the feasibility and efficacy of such a program. The motivation for developing this specific training program was based on earlier studies that showed that externally-guided movements, rather than internally-generated movements, have high potential to help improve motor function in patients with PD. And, providing enhanced VF via computer games can provide an attractive alternative to conventional therapy. The objective of the corresponding pilot RCT was to determine whether a training program capitalizing on virtual-reality-based VF would be more effective than conventional training in improving standing balance performance in PD. Patients participated in a five-week balance-training program. They were randomly allocated to an experimental group that received balance training using augmented VF or a control group that received conventional balance training.

The results of this pilot RCT have been summarized in Chapter 6. VF-based training was indeed feasible to implement in a therapeutic setting and took place
without adverse events. Change scores for all balance measures favored VF-based training, but the change in neither the primary outcome measure nor in any other outcome differed significantly between groups. That is, this study failed to establish VFT to be superior over conventional balance training. However, the study also showed that there is plenty of room to increase the training intensity and load. In addition, the heterogeneity of the group of included patients had a larger (negative) influence on statistical power than had been anticipated. In other words, effects that were not statistically significant in this study might become significant upon improvements in the study protocol.

In summary, this thesis has shown that VF can help to improve postural control, as long as this VF is reliable (congruent). Healthy controls can adapt to a certain degree of incongruency, but for the group of patients with PD this is generally more difficult. A balance training program based on VF does not yet appear to be more effective than regular therapy. That being said, the pilot RCT reported in Chapter 6 should be considered exploratory, offering important starting points for future research.