Summary

The aim of this thesis is to provide more insight into postural control during early development, both typical and atypical. Posture refers to the relative position of the body and its parts with respect to each other and the environment. Postural control or the regulation of posture is necessary for practically all motor actions. It involves maintaining balance (i.e., keeping the centre of gravity within the support surface) and providing the prerequisite link between perception and action. The development of postural control is therefore highly intertwined with development of other motor skills.

In this thesis, the Neuronal Group Selection Theory (NGST) is used to explain aspects of the development of postural control. According to NGST, in the initial phase of neural development, groups of interconnected neurons are formed (the primary neural repertoire) based on genetic and epigenetic processes. During the second phase, afferent information and feedback processes strengthen and weaken connections between neurons to form a more adaptive secondary neural repertoire. When applied to motor development, this translates into two phases of development: primary and secondary variability. Primary variability consists of exploration of all possibilities of the motor repertoire. Through trial-and-error, the child learns to adapt the various motor strategies to the specifics of the situation, resulting in the phase of secondary variability (adaptability). These concepts may also be used to explain development of postural control. According to the central pattern generator model, postural control is organised into two functional levels. The first or basic level consists of direction-specificity, which means for instance that when balance is threatened by a forward body sway, the muscles on the dorsal side are primarily activated. The second level consists of fine-tuning of the direction-specific adjustments to the specifics of the situation, for example in the number of direction-specific muscles activated, the order in which they are activated, and the strength of the contraction.

In this thesis, postural adjustments during reaching movements are examined in infants at the age of 4-21 months. Postural adjustments of typically developing infants are compared to those of infants at high risk of cerebral palsy (CP). Cerebral palsy is a permanent disorder of the development of movement and posture, causing
activity limitation, that is attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. CP is usually characterized by spasticity, but the motor problems of CP are often accompanied by disturbances of perception and cognition. Although modern imaging techniques enable detection of a high risk of very early in life, due to the plasticity of the brain CP is usually only reliably diagnosed at 2 years of age. Therefore, of the high-risk infants described in this thesis, who were included before 9 months corrected age, only about a quarter to half of the infants developed CP while most of the others had minor neurological dysfunction.

Chapter 2 describes postural adjustments during reaching of 11 typically developing infants at 4, 6, 10 and 18 months of age. Reaching was elicited from the infants seated in an infant chair or on their parent’s lap, by presenting toys at an arm’s length distance. Muscle activity was recorded with surface EMG of four arm muscles (deltoid, pectoralis major, biceps brachii, and triceps brachii) and five postural muscles (neck flexor/sternocleidomastoid, neck extensor, rectus abdominis, thoracal extensor and lumbar extensor). The entire session was recorded on video, which was time-coupled to the EMG signal in order to select time intervals in the EMG recordings that represented muscle activity during the reaching movements. Onset of muscle activity was determined with a statistical algorithm. At 4 and 6 months of age, we found direction-specific postural adjustments in the trunk muscles in only 50-63% of the reaching movements. The rate of direction-specificity increased to 88% at 18 months of age. Direction-specificity at the neck level was present in 40-50% of reaches at all ages studied. The dominant pattern of activation at all ages was the ‘complete pattern’, in which all three direction-specific muscles were recruited. The recruitment order was characterized by variation; however, at 4 months, a slight preference for top-down (i.e., cranial to caudal) recruitment existed, which was gradually replaced by a modest preference for bottom-up (caudal to cranial) recruitment.

Chapters 3 and 4 describe postural adjustments during reaching at 4, 6, and 18 months of infants at high risk of cerebral palsy. These infants were enrolled in the Early Intervention Project (in Dutch: Vroegtijdige Interventie Project; VIP), a randomized controlled trial that compared the effect of the newly developed family-centred programme COPCA (COPing with and CARing for infants with special needs) to typical infant physiotherapy (TIP, the control group). Forty-six infants were enrolled based on the presence of definitely abnormal general movements at 10
weeks corrected age, and were randomized to receive either COPCA or TIP from 3 to 6 months corrected age.

To assess if postural adjustments differed between high-risk infants and typically developing infants, we first compared the postural parameters during reaching of the control group (TIP) to those of the typically developing infants described in chapter 2. The results of this comparison are described in chapter 3. Similar to the typically developing infants, the postural adjustments of the high-risk infants were characterized by variation. The increase of direction-specific adjustments in the trunk muscles, however, was absent in the high-risk infants: it remained at 50-58% of reaches at all ages studied. At the age of 4 months, the high-risk infants less often used top-down recruitment, but this rose to a rate similar to that of typically developing infants at 18 months.

Chapter 4 compares postural adjustments of the COPCA-group to those of the TIP-group; the results were largely similar after both interventions and there were no significant differences between the groups. However, compared to TIP-infants, development of direction-specificity and anticipatory activation in COPCA-infants mimicked typical development slightly better. These two parameters were also associated with COPCA-type physiotherapeutic actions. This may suggest a beneficial effect of trial-and-error experience in early postural development. However, given the lack of effect at RCT level, caution in the interpretation of these findings is warranted.

Since the increase of direction-specificity in the typically developing infants occurred between 6 and 18 months of age, we wondered if this increase might be related to the development of independent sitting or walking. To answer this question, we compared postural adjustments during reaching of assessments before and after acquisition of independent sitting (chapter 5) and walking (chapter 6). We used data from the typically developing infants described in chapter 2 for the comparison with regard to sitting, but these data were not suitable to answer the question related to the development of independent walking, so for this purpose a new group of typically developing infants was recruited. In both studies, the typically developing infants were compared to infants who participated in the LEARN 2 MOVE (L2M 0-2) study, the second RCT to evaluate the effect of COPCA. These infants were enrolled at different ages (before 9 months corrected age) based on the presence of brain lesions or neurological dysfunction suspect for CP, and thus had a higher risk
of CP than the VIP-infants. Postural adjustments during reaching of L2M-infants were assessed at inclusion, at 6 and 12 months after inclusion, and at 21 months corrected age.

Chapter 5 describes postural adjustments during reaching in typically developing infants and the very high-risk (VHR) infants of the L2M 0-2 study, before and after they developed the ability to sit independently. In both groups, we did not find any differences between postural parameters before and after development of independent sitting. Postural adjustments were however associated with the success and duration of reaching: in TD-infants better reaching was related to more frequent direction-specificity in the neck muscles and more frequent top-down recruitment, and in VHR-infants better reaching was related to more frequent bottom-up recruitment and less frequent simultaneous recruitment of the postural muscles.

Finally, chapter 6 describes postural adjustments during reaching before and after the development of independent walking. A newly recruited control group of typically developing infants was assessed when they were able to pull up to standing but unable to walk independently, and when they could walk independently for about one month. For the VHR-infants, two assessments matching the abovementioned developmental criteria were selected for this study. Not all L2M-infants developed the ability to walk independently, so the VHR-infants in this chapter were a subgroup of L2M-infants with relatively more favourable development than the average L2M-infant. Since the infants were older at the second assessment than at the first, we performed two separate analyses based on age and developmental stage, respectively. Again, we found that direction-specificity in the trunk muscles increased with age in the typically developing infants but not in the VHR-infants. This increase was not significant with respect to learning to walk, but the study may have been underpowered.

Summarizing, the results reported in this thesis show that postural adjustments during reaching in infants are characterized by variation. The frequency of direction-specific postural adjustments in the trunk muscles increases between 6 and 18 months of age in typically developing infants; this may be related to the development of independent walking, but we were unable to demonstrate this. Infants at risk of cerebral palsy may have a delayed development of postural control, as a result of which they do not show an increase of direction-specificity during reaching at 18
Summary

months. In all infants, fine-tuning of the postural adjustments was characterized by variation, with small differences, for example in recruitment order, between typically developing infants and infants at risk of cerebral palsy.