Summary
INTRODUCTION

Children and adolescents with cerebral palsy (CP) often have problems in performing activities of daily life, like walking. This might be due to muscle weakness of the lower extremities, which is commonly assessed as the strength from a single maximal contraction. However, most activities of daily life involve a series of repetitive submaximal contractions. This thesis reports on studies on the ability of children and adolescents with CP to perform such repetitive contractions, referred to as lower limb muscle endurance, and how to measure muscle endurance in a clinically meaningful way in young individuals with CP. In addition, this thesis focusses on how muscle endurance relate to problems in daily life, as subjectively reported fatigue, walking capacity and limitations in participation. Furthermore, muscle co-activation was investigated as an underlying factor potentially contributing to reduced muscle endurance. The epilogue on the relationship between muscle endurance and muscle strength is pointed out in the General Discussion. This summary will provide a short overview of the main findings, clinical implications and conclusion of the studies presented in this thesis.

MAIN FINDINGS

In Chapter 2, the maximal voluntary fatigue protocol was evaluated as a method to assess knee extensor and flexor muscle endurance in children with CP, typically developing (TD) children and TD adults. Muscle endurance was defined as the decline in peak torque generated per consecutive contraction. The fact that children with CP showed the smallest decline in peak torque seem to suggest that children with CP would have a better muscle endurance than TD children and adults. Though, lack of changes in EMG recordings of knee flexor and extensor muscles indicate that the maximal voluntary fatigue protocol was invalid to maximally fatigue muscles of children with CP and therefore to assess muscle endurance.

Therefore, in Chapter 3 a submaximal repetitions-to-fatigue (RTF) protocol was described to assess muscle endurance in both adolescents with CP and TD adolescents. Three separate tests were performed on a computer controlled dynamometer, where individuals were asked to extend their knee against fixed submaximal loads and perform as many repetitions as possible until exhaustion. Load endurance curves were constructed, plotting the submaximal loads against the number of repetitions that were performed. The slope of the relative load endurance curve, in which the load normalized to the maximal isometric torque, was slightly steeper in adolescents with CP compared to their TD peers, suggesting a slightly reduced endurance at muscle level in CP. This reduced muscle endurance might be explained by a slight decrease in muscle fiber type I.

From the absolute load endurance curves presented in Chapter 3 it is clear the absolute loads that adolescents with CP were able to endure were substantially lower than those of TD peers. This was related to the reduced maximal torque of adolescents with CP. Consequently, certain absolute load levels that are encountered in daily life (e.g. bodyweight) can be too high for individuals with CP to comply with to perform large
numbers of repetitive movements. While previous research showed that the maximal muscle strength of children with CP is considerably reduced, this thesis provides evidence that muscle endurance is also reduced in these individuals.

Remarkably, the absolute load endurance curves, presented in Chapter 3 as well, reveal that muscle endurance is largely related to maximal muscle strength. It can therefore be concluded that although we sought to investigate the contribution of muscle endurance to motor functioning in adolescents with CP next to the effect of maximal muscle strength, the influence of this factor largely overlaps with the effect of maximal muscle strength.

The results presented in Chapter 4 show that the co-activation index was 1.5 to 2 times higher in adolescents with CP classified in GMFCS II compared to those classified in GMFCS I and TD adolescents at different submaximal and maximal load levels. Hence, one should acknowledge that these increased levels of muscle co-activation might lead to an underestimation of individuals’ muscle strength and muscle endurance in adolescents with CP classified in GMFCS level II. The level of co-activation seemed to be independent of the load level at which the test was performed. In addition, co-activation indexes remained constant in both adolescents with CP and TD adolescents, suggesting that fatigue did not influence co-activation either.

As presented in Chapter 5, fatigue was reported more often as a problem during daily life by adolescents with CP than by TD adolescents, even though TD adolescents are also known to report fatigue. In addition, walking capacity was reduced by 23% in adolescents with CP compared to TD adolescents. The reduced muscle endurance related moderately to both subjectively reported fatigue and a reduced walking capacity in adolescents with CP, while no relationships were observed for TD peers. Training of muscle endurance might therefore contribute to reducing fatigue and improving walking capacity in CP. The reduced muscle endurance did not seem to have an effect on participation rates.

The laboratory test is time-consuming and expensive equipment is needed. Normally, clinicians benefit from a valid test that can be performed quickly and easy during a consult. In Chapter 6, we investigated whether the clinical squat test is a valid tool to assess lower limb muscle endurance in children with CP. Since squat test performance was significantly reduced in the group of children with CP compared to their TD peers. Squat test performance and movement execution were monitored in 20 children with bilateral CP and 16 TD peers. Squat test performance was defined as the number of two-legged squats until fatigue occurred, to a maximum of 20 repetitions. Early test termination in children with CP could therefore be due to a reduced muscle endurance. Hence, it was concluded that the squat test could be used to distinguish between CP and TD children in lower limb muscle endurance. Only minor differences in movement execution were observed when performing the repetitive squats, except for the knee range of motion, which showed to increase in children with CP and decrease in TD children. Therefore,
clinicians are advised to closely monitor movement execution to avoid compensation strategies.

The results presented in this thesis suggest muscle endurance seem to relate largely to individuals’ maximal muscle strength, and hence, muscle endurance does not necessarily provide a better indication of muscle function in both muscle strength and muscle endurance provide valuable information about the ability of children with CP to perform (repetitive) movements. Hence, there is no preference for testing (isometric) maximal muscle strength or submaximal muscle endurance. Since the squat test was shown to be a feasible test that can easily be conducted in clinical practice, the squat test was recommended to use as a tool to assess lower limb muscle endurance in children with CP.

CONCLUSIONS
- Lower limb muscle endurance is considerably reduced in children and adolescents with CP, which can lead to limitations in the performance of activities in daily life.
- Both the laboratory RTF protocol and the clinical squat test can be used to assess lower limb muscle endurance in individuals with CP.
- A reduced muscle endurance relates moderately to subjectively reported fatigue and reduced walking capacity in adolescents with CP.
- Muscle endurance and maximal muscle strength are closely related, so both can be used to express individuals’ ability to exert a single or repetitive physical force(s).