“It would be so nice if something would make sense for a change.
—Lewis Carroll, Alice in Wonderland
6. Thesis summary

The human hand has evolved to be able to perform complex hand actions in daily life and is a fundamental attribute that enables us to grasp and manipulate objects. Although it is unique in its functions and capabilities, our knowledge about the underlying mechanisms, such as muscle control, is still limited. In the aging population, the mobility and dexterity of the hand decreases. The biomechanical function of individual muscles and their neurophysiological characteristics change with age as well. The overall objective of this thesis was to better understand the degree of finger independence during natural, free finger flexion, the underlying mechanisms that influence finger movement and to quantify age-related changes on the neuromechanics of hand motor control. We assessed finger interdependency during various finger tasks in terms of movement, as well as muscle activations of the flexor (FDS) and extensor (ED) extrinsic finger muscles and the FDS tendon displacement of the index, middle and ring finger, in a group of young subjects and a group of healthy elderly. This chapter provides an overview of the experimental results of this thesis.

Finger independence was first investigated in young subjects (22-29 years) in Chapter 2, where finger enslaving and the range of independent finger movement were assessed during single and multi-finger movement tasks. It was shown that while no finger can move independently through the full-range of finger flexion, full independence was present for smaller movements only. The range of independent movement was found to be non-reciprocal and variable between fingers and subjects. These findings were in agreement with the presence of mechanical coupling between the muscle heads or tendons of the FDS. The results from the multi-finger tasks indicated that moving additional fingers increased the extent of the enslaving effect. It was concluded that although no finger can move independently through the full range of finger flexion, some degree of full independence is present for smaller movements. This initial range of independent movement is non-reciprocal and variable between fingers and between subjects.

To study the underlying mechanisms that may impact finger independence, both muscle activation (Chapter 3) and tendon displacement (Chapter 4) were studied in young subjects.

In Chapter 3, muscle activation was assessed during single finger flexion using a surface electromyography (EMG) electrode grid (90 electrodes) placed over the flexor digitorum superficialis (FDS) and the extensor digitorum (ED) muscles. Spatial
localization using cross covariance between EMG signals and finger movement was performed using the surface EMG grid to identify the location of each finger specific FDS muscle belly for every individual subject. No differences were found in the timing of muscle activation between FDS and ED muscle bellies. A high muscle coactivation was found between the instructed and non-instructed finger muscle bellies of both the flexor and extensor regions of the non-instructed finger muscles bellies. No correlation was found between muscle activation and movement of the corresponding non-instructed finger, except for the index finger. Thus, a disparity was found between muscle activation patterns and finger movement of non-instructed fingers. It can be concluded that other mechanisms, such as intertendinous and myofascial connections, may also affect finger movement independence.

The FDS tendon displacement of both instructed and non-instructed fingers during single finger flexion tasks were measured using 2D ultrasound in young subjects (Chapter 4). The aims were to investigate tendon displacement of the flexor digitorum superficialis (FDS) tendon of both the instructed finger and that of the non-instructed fingers and to assess whether tendon stretching was present in the tendon of non-instructed fingers. In two conditions, active finger flexion with all fingers free to move and restrictive finger flexion where the non-instructed fingers were restricted and only the instructed finger was free to move, displacements of FDS tendons inserting on the index, middle and ring fingers were measured. In the restricted protocol, non-instructed fingers showed substantial tendon displacement even though only minimal finger movement was observed, indicative of tendon stretching. The displacements of the non-instructed finger tendons in the active flexion protocol were also higher than expected based on the amount of non-instructed finger movement. It is especially noteworthy that when the additional tendon stretching component was subtracted from the non-instructed tendon displacement, the relationship between finger flexion angle and tendon displacement of the instructed and non-instructed finger was similar. The results indicate that, even during conditions involving minimal loads, tendon displacements can be the result of tendon movement and tendon stretching. In Chapter 3, an increased activation of the extensor digitorum muscle during single finger flexion tasks was found. Thus, the additional stretch the non-instructed fingers endure is likely caused by forces exerted by its antagonist. In conclusion, when studying tendon displacements of non-instructed fingers, it is important to consider the impact tendon strain can have on the amount of tendon displacement measured.

In Chapter 5, the results of the above described experiments in young subjects were compared with the data obtained in elderly (age 68-84) to assess how aging affects finger movement. Concerning finger movement, a higher amount of enslaving for the non-instructed fingers and a decrease in the range of independent movement for the
index finger was found for the elderly compared to the younger subjects. In the older subjects, increased EMG activity in the non-instructed finger muscle regions of the finger specific FDS and ED muscles was found, and thus a more widespread muscle activation pattern. These results are in agreement with the higher finger enslaving in the elderly. With respect to the tendon displacement, no age differences in total amount of tendon displacement for instructed and non-instructed fingers were measured. However, for the elderly a distinct period with little to no tendon displacement was found during the first phase of finger flexion. This could be explained by a change in the relationship between tendon movement and tendon length changes or by changes in the mechanical coupling between tendons and/or muscle bellies. In conclusion, the study presented in this chapter indicates that primarily finger movement independence of the index finger is affected by aging. As the index finger also has the highest movement independence, it is possible that aging changes will first become noticeable for the index finger. The sEMG data also show a more evenly distributed (more widespread) muscle activation pattern between the finger muscle regions, which supports the higher amount of finger enslaving we found.