Handcycling: a biophysical analysis

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Summary

Physical activity of the upper body is very important to increase the general health of persons with SCI or with lower limb impairment. The negative consequences of increased physical activity are related to overload of the upper extremities, which could lead to overuse injuries and pain of the musculoskeletal system. Prevalence rates of 30 – 73% for shoulder pain indicate that overload injuries to the musculoskeletal system are a serious long-term problem in persons with SCI.
A solution to avoid these injuries is to improve physical capacity and muscle strength by regular and appropriate exercise, starting already in early rehabilitation. The manual handrim wheelchair, which is the main mobility device of persons with SCI, has been shown to be strenuous and inefficient. Therefore, alternative devices, such as the handbike, should be considered for daily outdoor mobility or training.
So far it is known that the handbike is more efficient and physiologically less straining than the handrim wheelchair, which makes it a suitable device for rehabilitation and sports. Whether it is also beneficial for the musculoskeletal system, and whether its increased use can contribute to lower the incidence of shoulder pain in the SCI population, is still unknown.
The aim of this thesis was to analyze the physical strain and efficiency of handcycling and its accompanying mechanical load on the shoulder complex. This was done by comparing handcycling to manual handrim wheelchair propulsion and by analyzing different setups of the handbike, using a combination of biomechanical and physiological outcome measures.

Biomechanical studies analyzing the applied force during handcycling are still scarce. So far it was not known how the force characteristics of handcycling are affected by the exercise conditions. In **chapter 2**, various exercise conditions, such as the speed and the method to impose power, and their effect on force characteristics (the applied force, force effectiveness and distribution of work) were investigated. This study was performed to establish a base for the planning and interpretation of future handbike studies. Ten able-bodied men without any experience in handbike use performed submaximal handcycling on a treadmill. This group was chosen because these participants were expected to respond relatively homogeneous to handbike exercise since they were equally inexperienced and had no restriction due to disabilities. Results showed that the choice of propulsion speed at equal power output had an influence on the force characteristics. With increased speed, the amount of the applied force, the force effectiveness, as well as the work distribution within the cycle changed. Propulsion speed should therefore be considered when analyzing force application. The method to impose power had no effect: there was no difference in the force characteristics between

propelling on an incline or on a level treadmill with the same speed when the resistance was applied by the pulley system. Therefore, the results of studies that examined handbike propulsion with either of these methods are largely comparable under conditions of equal power output and speed.

In **chapter 3** it was analyzed whether the use of the handbike is not only physiologically but also mechanically less straining than handrim wheelchair propulsion. Thus, the applied forces and the propulsion characteristics of handcycling were compared with handrim wheelchair propulsion under the same power output conditions. Since the occurring internal forces in the shoulder complex are related to the externally applied force, this study was a first approach to indirectly compare the shoulder load during handbike and handrim wheelchair propulsion under equal conditions. It was found that due to the continuous force application, considerably lower total forces were applied during handcycling than during handrim wheelchair propulsion. The mean propulsion forces over the propulsion cycle of wheelchair propulsion were 20% higher than during handcycling, and for the peak forces the relative difference was even 170%. These results confirmed the assumption that handcycling is not only physiologically but also mechanically less straining.

One of the main goals of this thesis was the analysis of the shoulder load during handcycling. Compared to the external applied propulsion forces, a more accurate and comprehensive indicator of shoulder load is the glenohumeral contact force. In **chapter 4**, the glenohumeral contact force and the relative muscle forces occurring during handcycling were analyzed for the first time. The aim of this study was to get a basic understanding of the operating shoulder load at different exercise conditions. Additionally, the results were compared with findings from previous studies of handrim wheelchair propulsion, in order to get a first idea of the difference in shoulder load between the two devices. As expected, the results showed that the glenohumeral contact force increased while propelling at the higher incline due to the higher power output and consequently due to the higher external force applied to the crank. While propelling at a higher speed, and therefore a higher cadence at equal power output, the external force decreased. The glenohumeral contact force, however, did not change, similar to the force produced by most of the shoulder muscles. At the faster speed conditions the shoulder muscles produced therefore muscle force which did not contribute to the external force. The initial comparison with results from wheelchair propulsion showed that due to the circular movement of the hands and the continuous force application, mean and peak glenohumeral contact forces, as well as muscle forces, are clearly lower during handcycling. These findings further support the assumption that handcycling is mechanically less straining compared to handrim wheelchair propulsion, which may reduce the risk of overuse to the shoulder.

As a continuation of the previous research, a direct comparison of shoulder load between handbike and handrim wheelchair propulsion was performed in **chapter 5**. There, glenohumeral contact forces and relative muscle forces were measured during propulsion at different everyday power output levels. This study was performed with eight wheelchair users with SCI in order to analyze the directly affected persons. The results showed that both mean and peak glenohumeral contact force were considerably lower during handcycling than during wheelchair propulsion. During wheelchair propulsion at the most straining condition (55W), the mean glenohumeral contact force over the propulsion cycle was 70% higher and the peak value was even 95% higher than during handcycling. Also the relative muscle forces were lower during handcycling. There, the load was nicely spread over all muscles involved and they produced a relative muscle force of less than 10% of its maximal value. During wheelchair propulsion, however, some of the muscles were relatively highly stressed. The highest difference of relative muscle force between the two devices was found in the supraspinatus (20.7% vs. 4.5%) and infraspinatus (16.5% vs. 3.7%). These muscles are both part of the rotator cuff, which is most prone to overuse injuries. A lower muscle force could thus decrease the risk of fatigue and overuse. As a conclusion, these results showed that the handbike is a preferable alternative propulsion mode for outdoor mobility and exercise, likely to reduce the development of overuse injuries.

Since the results from the previous chapters showed that the handbike is preferable over the handrim wheelchair regarding shoulder load, the further chapters of the thesis concentrated on handcycling only. There, the aim was to analyze whether the handbike setup and its optimized use could further lower the mechanical and physiological strain.

So far, it was not known whether there are different styles to propel the handbike, and whether they also differ in physiological strain. The aim of **chapter 6** was to examine which styles are used by trained handbike users with SCI and whether there is a certain style associated with a higher mechanical efficiency. Recommendations based on this knowledge would improve training methods of athletes or could increase the cycling capacity of recreational users. The results of this chapter showed, that during handcycling at power outputs of 20-70W on a motor driven treadmill, two different propulsion styles were predominately used: the pull style and the pull plus style. During the lower power output conditions, mainly the pull plus style was used. With higher power output levels, where also mechanical efficiency increased, it was the pull style that predominated. It could not be concluded that one propulsion style is most efficient; yet, subjects seemed to adapt the propulsion style to different power output levels. This suggests that subjects choose the style that is most economical, depending on the power output level.

The handbike-user interface is a further factor that could positively influence shoulder load and mechanical efficiency. An optimal handbike setup might contribute to decrease the risk of overuse injuries to the musculoskeletal structures of the upper extremity: Furthermore, an increase in mobility is to be expected due to a setup that results in a higher mechanical efficiency. Both backrest inclination and crank position are essential parameters in handcycling that should be considered when optimizing the handbike-user interface. The analysis of these parameters was performed in **chapter 7**, where 13 handbike users with paraplegia cycled with different setups at constant power outputs. This study showed that, while cycling under laboratory conditions, the handbike-user interface does influence shoulder load but not mechanical efficiency. Regarding the shoulder load, an upright backrest inclination of 60° was most favorable. In this setup, the glenohumeral contact force as well as the modeled muscle forces of the supraspinatus and infraspinatus were the lowest. The position of the crank only affected the relative force of the subscapularis. There, the distant crank position (15° elbow flexion angle) was favorable. According to these results, handbike users, whose main interest does not lie in achieving high performances but improving health and physical capacity in a shoulder-friendly way, should set up their handbike with an upright backrest inclination and a distant crank placement.

In **chapter 8**, the main findings of the studies described in this thesis were summarized and discussed. The results of these studies contributed to a better understanding of mechanical and physiological strain of handcycling as an alternative mobility device. This thesis showed that the choice of the mobility device as well as its optimal setup can contribute to lower the risk for overuse injuries to the shoulder complex. Since the mechanical load on the shoulder joint was lower during handcycling than during handrim wheelchair propulsion, the increased use of the handbike in early rehabilitation could contribute to improve the physical fitness and mobility of persons with spinal cord injury while lowering the risk for overuse injuries. An optimal handbike setup, which is characterized by an upright backrest and a distant crank placement, could further contribute.