Abstract
Hand cycling is an efficient form of wheeled ambulation and a relatively new
devolution in wheelchair sports. Overall, more upper body power can be
developed in hand cycling compared to hand rim wheelchair propulsion. However,
within the domain of hand cycling ergonomic optimization is crucial for performance
and endurance. The ‘hand cycle-user interface, as well as the vehicle mechanics of
the chair play a dominant role in the fine-tuning of performance, both in sports as well
as in daily life. Experimental research on hand cycling is still scarce and much of its
understanding comes from other forms of cyclic upper body exercise, such as hand
rim propulsion and from general vehicle technology. There is a need for more self
standing research.

Introduction
The use of modern technology and lightweight materials has led to the re-introduction
of the tricycle - especially the hand cycle or hand bike - for outdoor use. Disadvantages of the earlier hand cycles in the 60ties – such as weight, size
and limited maneuverability – have partly been overcome. The contemporary
lightweight well-looking tricycles have multiple gears, as well as good braking and steering qualities. Above that, task-specific configurations have been developed. Even those individuals with high level spinal cord lesions can in- and egress and can couple to the pedals with special gloves. The use of tracker or attach-unit system (an add-on front wheel crank unit, which is combined with the daily hand rim wheelchair) has made the crank propulsion mechanism much more practical in daily life, but obviously the hand rim propelled wheelchair remains crucial for indoor use. In addition, the hand cycle has been and still is the prime form of ambulation in lower limb disabled in non-western countries\textsuperscript{10}. Given the often limited resources of the upper body, the hand cycle must be optimally tuned to the environment and the functionality of the user.

Vehicle mechanics
In order to optimize performance and endurance, the vehicle mechanical losses must be minimized and the hand cycle well maintained. Rolling resistance issues that play in hand rim wheelchairs are equally relevant in hand cycles (Table 1.). Rolling resistance must be minimized through lightweight design and quality material, wheel alignment and maintenance\textsuperscript{7}. Generally air resistance will be more prominent in hand cycling, given the higher velocities outdoors. Air friction is highly speed dependent on and determined by the frontal plane area of the wheelchair-user combination and the aerodynamic drag coefficient, the latter is both form and surface dependent. Especially minimization of frontal plane area is suggested to be effective. Little systematic scientific knowledge is available on the specifics of aerodynamics in hand cycling.

‘Hand cycle-user interface’
Performance in a hand cycle is dependent on the fine-tuning of the crank set, handle bars, seat and the individual. Little research has been done to date in this realm. What we do know is the higher performance capacity and efficiency of hand cycling (and arm crank exercise) over hand rim wheelchair propulsion\textsuperscript{4, 11, 12, 18}. Hand cycling is 3-5% more efficient at optimal conditions of performance (Figure 1.). In itself the explanation seems self-evident: a continuous motion, no coupling or decoupling actions of the hands, a large muscle mass involved, muscles being activated in a push as well as pull range of motion, a natural coupling and orientation of the hand to
the handle bars, where possible the use of the trunk in power production, and force production of the shoulders and arms in a natural envelop of the upper body. However limited research has been done to date.

What we do know are the consistent beneficial effects of synchronous over asynchronous hand cycling. As is shown in Figure 2. Peak performance is significantly higher in synchronous hand cycling; the same holds for the efficiency, which tends to be 2-3% higher. This has not been consistently shown in arm crank exercise. Van der Woude et al showed a comparable external power output in both modes at similar speed and grade conditions, using ambulant technology (SRM), thus not explaining an apparent difference in energy cost between the two modes. Based on recent unpublished results, significantly higher local subjective discomfort in the lower arms may be indicative for a higher local muscular strain in the need for stabilizing the crank set in the asynchronous compared to the synchronous mode. Also, no higher mean medio-lateral force was seen over time in the asynchronous mode however.

In addition to the above, mechanical efficiency has been shown to be dependent upon the gear ratio or cycle frequency at a given power output, showing a more or less curvilinear trend with increasing cycle frequency. This has also been described in arm crank exercise and other cyclic motions and allows subjective optimization in association to speed and power conditions.

Other phenomena of hand cycle fit, i.e. the orientation of the crank set, back rest and seat, posture or hand bars, have not been dealt with in detail in scientific hand cycle research yet. Only studies in arm crank exercise may help at this stage to some extent, although limited in number and consistency. In order to understand the underlying mechanisms of differing energy cost or mechanical efficiency requires the more detailed study of kinetics, kinematics and electromyography, as well as study of the interaction of the cardio-respiratory system with the movement pattern.

Discussion & conclusions

The hand cycle has evolved into a contemporary assistive device for sports, leisure and daily use, as well as for training, outdoors. Even in rehabilitation, hand cycling is being advocated as a good training alternative in early rehabilitation of also frail individuals. Within that context there is a need for further research into optimal hand cycle design and fitting for different user groups.
Apart from optimizing the wheelchair-user interface, one needs to carefully consider maximizing overall work capacity of users and further reduction of the vehicle mechanical losses to ensure a real optimum level of mobility.  

It is expected that the current booming development of crank propelled tricycles in the industrialized countries serves not only the young and active wheelchair user, but also the less well-trained individual or those with more extensive limitations. In the end, the frequent active use of other than hand rim propelled wheelchairs may help prevent some of the secondary complications among the wheelchair user population today.  

What has been assumed till today, is a lower overall mechanical strain (in conjunction with a higher efficiency) in hand cycling compared to hand rim propulsion. However, the upper body may be yet vulnerable to mechanical overuse when ‘too much and too often’ go together. Little is known of underlying mechanisms of overuse and should be on the future APA research agenda.

References


Table 1. Mechanical factors and their way in which they influence rolling resistance in a hand cycle and/or hand rim wheelchair.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Rolling resistance</th>
</tr>
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<tbody>
<tr>
<td>Body Mass ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Wheelchair Mass ↑</td>
<td>↑</td>
</tr>
<tr>
<td>Tire pressure ↓</td>
<td>↑</td>
</tr>
<tr>
<td>Wheel size ↑</td>
<td>↓</td>
</tr>
<tr>
<td>Hardness floor ↓</td>
<td>↑</td>
</tr>
<tr>
<td>Camber angle ↑</td>
<td>?</td>
</tr>
<tr>
<td>Toe-in/out ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Castor shimmy ↑</td>
<td>↑</td>
</tr>
<tr>
<td>For-aft position center of mass closer to large rear wheels</td>
<td>↓</td>
</tr>
<tr>
<td>Folding frame (vs box frame)</td>
<td>↑</td>
</tr>
<tr>
<td>Maintenance ↓</td>
<td>↑</td>
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</tbody>
</table>
Figure Gross mechanical efficiency in hand cycle performance versus hand rim propulsion at the same power output on a motor driven treadmill in a group of persons with a spinal cord injury (n=9) and non-wheelchair users (n=10).
Figure 2 A significantly higher peak hand cycle performance in the synchronous mode during biking on a motor driven treadmill in a group of non-wheelchair users (n=9)\textsuperscript{15}. 

![Peak Hand Cycle Capacity](chart.png)