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Skill acquisition of manual wheelchair propulsion: initial motor learning

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Abstract

Changes in propulsion technique due to motor learning might account for a higher mechanical efficiency (ME, the ratio of internal power over external power). The changes in ME and propulsion technique were studied in a learning experiment, three times a week for eight minutes, with nine able-bodied subjects, simulating early rehabilitation. Instrumented wheels measured three-dimensional forces and torques on the handrim.

During practice peak torques were reduced, work per cycle increased, while push frequency decreased, at a stable power output and speed of the treadmill. Over the three weeks of practice propulsion technique kept changing in combination with an increase of ME.

Results suggest skill acquisition because of motor learning. The rise in ME seems logically related to propulsion technique, but is not yet fully understood. More insight in motor learning and skill acquisition will contribute to understanding and optimizing rehabilitation strategies in the light of wheelchair provision in early rehabilitation.

1. Introduction

Hand rim wheelchair propulsion is the means of transportation for people no longer capable of walking. To propel the wheelchair forward two rotating handrims have to be caught, pushed and released simultaneously while the hands are partly out of the visual field. People in a wheelchair depend on their upper body for physical activity to maintain an active lifestyle, which is associated with less secondary complications such as pain, fatigue and depression [15]. A proper execution of the propulsion task is important in maintaining this ability, especially because injury to the upper extremities is common [2; 18].

During rehabilitation the new propulsion task needs to be learned. Several studies have reported on the development of propulsion technique using different experimental set-ups [5; 11-13; 16]. In its setup the current study tries to combine two earlier studies performed by de Groot et al, one a twelve-minute learning study [7], the other a three-week learning study [6]. These studies were performed separately, with different participants and used an instrumented ergometer instead of instrumented handrim wheels on a motorized treadmill. A combination of the design of these two studies will give more insight in the time scale of learning. The use of new measurement wheels and a treadmill instead of an ergometer makes the task less constrained and approximates real life conditions better [9]. Further variability during the practice period was introduced by changes in power output because of tire pressure and added wheelchair weight.

Able-bodied subjects, novice to handrim wheelchair propulsion, performed the three-week practice, simulating early rehabilitation. No specific feedback or instructions on propulsion technique were given to study how they naturally adapt to the task. Reduction of energy cost in the course of learning a new motor task is often evaluated by change in mechanical efficiency (ME), the ratio of power output over power input, [3; 4; 8; 14]. Because of the very low-intensity, low-dosage practice intervention the physiological adaptations are expected to be minimal since they are well below ACSM guidelines [1]. Goal of this study is to evaluate wheelchair skill acquisition (ME and propulsion technique) in handrim wheelchair propulsion on a motor-driven treadmill in able-bodied male novices to simulate early rehabilitation. We hypothesize that for a cyclical task, such as handrim wheelchair propulsion, energy cost is used as an optimisation criterion for tuning performance. A higher mechanical efficiency is expected because of the motor learning process, which causes propulsion technique to change. Both mechanical efficiency and technique variables are measured to see if both change because of practice.

2. Methods

2.1 Subjects

After having given written informed consent, 9 able-bodied subjects participated in the study. Criteria for inclusion were male, no prior experience in wheelchair propulsion, and absence of any medical contra-indications.

2.2 Protocol

Subjects practiced on a treadmill (Forcelink) in a wheelchair (Double Performance) with 24-inch wheels. They received a total practice dose of 80 min over three weeks (fig 1). Each practice trial consisted of four minutes practice of which the last minute was analyzed. The first three trials were used as the pre-test in which subjects propelled at 0.21 W/kg. This power was imposed by adding mass to a pulley system [19] after performing a dragtest [17]. During the practice sessions (three times a week two 4 minute trials) power differences were introduced by deflating the tires (100%, 75%, 50% en 25%, solids), adding mass to the chair (10 kg, 5 kg), and the use of measurement wheels (with or without). After completing the 7 practice sessions a post-test was performed to compare the pre- and post-test values.

Figure 1: Practice protocol. Each trial is four minutes of wheelchair propulsion; in between each trial is two minutes rest.

2.3 Measurement wheels

The rear wheels of each subject's wheelchair were replaced with two instrumented wheels; the OptiPush (Max Mobility) and the Smartwheel (3 Rivers). Both wheels measure 3-dimensional forces and moments applied to the handrim, combined with the angle under which the wheel is rotated. Data are wirelessly transferred to a laptop at 200 Hz (Optipush) and 240 Hz (Smartwheel). Both wheels together with oxygen uptake and heart rate from the Oxycon delta (Carefusion) were synchronised by a pulse at the start.

Table 1 Explanation of propulsion technique variables

Variable:	Calculation:
Mechanical efficiency (%)	Power output divided by metabolic power
Pushtime (s):	Time from the start of postitive torque to the stop of postitive torque for a push.
Work/push (J):	The power integrated over the duration of the push.
Frequency (1/min):	Pushes per minute.
Pmean/push (W):	The mean power (Tz*Angular velocity) during the push time.
Fpeak (N):	3d peak force ((Fx+Fy+Fz)^0.5) during the push time
TnegStart (Nm):	Maximum negative torque before the start of a push
TnegEnd (Nm):	Maximum negative torque after the end of a push
Contact angle (˚):	Angle at the end of a push minus the angle at the start.

2.4 Data analysis

Data from the instrumented wheels were further analyzed using Matlab. First individual pushes were defined as each period of continuous positive torque with a minimum of at least 1 Nm. Further calculations were done during the push time and later averaged over all pushes within the fourth minute of each practice block. Calculated variables are further explained in table 1.

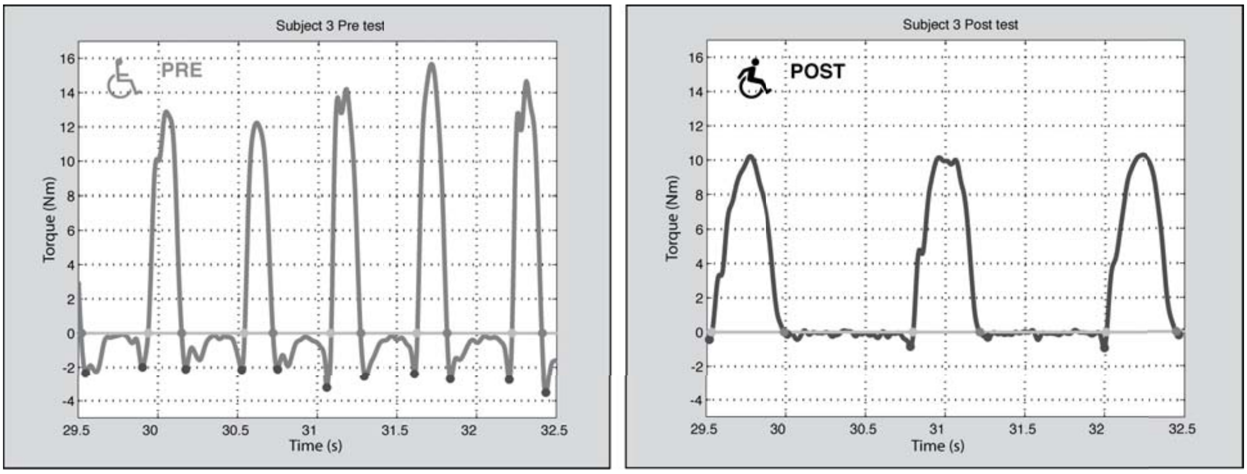

Figure 2 Typical example of change in propulsion technique for 1 subject. Note the decrease in frequency, increase in push time, contact angle and work per push. Also negative power just before and direct after the push decreases indicating a more efficient coupling.

3. Results

Already within the first 12 minutes changes in timing and force production occurred, but no changes in ME were found. However over the course of the three weeks ME increased together with the propulsion technique variables. Figure 2 shows a typical example of change in propulsion technique of one subject. The frequency goes down while the push time, contact angle and work per push rise. Also the negative dips before and after the push decrease leading to less work necessary to maintain power output.

4. Discussion

Changes in propulsion technique mostly took place within the first twelve minutes of propulsion. These changes are in line with the study of de Groot on this initial phase of learning [7]. The variable practice during the following sessions led to a further change of propulsion technique although not as much as expected. Because most changes took place in the pretest the effect of variability in power output during the practice sessions probably did not influence the learning process much compared to the repeated practice of de Groot [6].

The fast changes in propulsion technique did not directly lead to a higher ME, this was only found over the three weeks of practice. Some of the changes in propulsion technique, such as the reduction in breaking torques, should have led to less work to maintain the same power output. This should have caused a reduction of internal power production even within those first minutes. Perhaps other technique variables or possible physiological adaptations despite the low training intensity are important to account for the change in ME over the three weeks. Further study will have to expand on the technique variables of influence on ME. For instance principle component analysis [10] could be used to identify coordination structures of wheelchair propulsion, which might be used to see how propulsion technique changes towards these coordination patterns.

Whether ME is the only optimization criterion for motor learning remains unclear. Another possibility to consider are other task demands besides energy consumption. For instance load on the shoulder or attentional demands might be of influence on changes in motor behavior and could have driven the early changes as well.

More insight in motor learning and skill acquisition will contribute to understanding and optimizing rehabilitation strategies in the light of wheelchair provision in early rehabilitation.

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