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Current Opinion

Power output and energy cost: crucial measures to understand motor skill learning in handrim wheelchair propulsion

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ABBREVIATIONS

J	Work
ME	Mechanical efficiency
N	Force
W	Speed

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BACKGROUND: This current opinion is a call for standardization of measurements of manual wheeling ability among larger and diverse populations to support our understanding of motor control and learning.
VIEW OF THE PAST: Handrim wheelchair propulsion remains the most common mode of wheeled ambulation and has stood the test of time as a practical upper-body alternative to walking.
CURRENT STATE: Two theoretical models appeared useful in understanding the demands on the wheelchair-user combination and the role of motor skill acquisition: Power Balance Model and Constraint-based Approach.
FUTURE PERSPECTIVE: Power output and energy cost measures are crucial mediators in the development of a motor control theory of cyclic motions in rehabilitation, adapted sports and beyond.

KEYWORDS: Handrim | Wheelchair | Skill | Rehabilitation | Adapted sports

Following World War-II and being recognized as crucial mobility modalities for lower limb disabled individuals, biophysical sciences became worldwide involved in research on stress, strain, work capacity and ergonomic design of manually propelled wheelchairs [1]. Studies in the 1960ties compared wheeling modes, using cardio-respiratory strain measures during (sub)maximal (steady state) wheelchair exercise on a motor driven treadmill or ergometer. Outcomes of oxygen-uptake, energy cost and heart-rate underscored the relatively high upper-body strains of handrim wheelchairs, compared to lever and crank propulsion [1]. These early studies sometimes already measured drag force(N), work(J) or power (=drag force x speed(W)) using adapted bicycle ergometers or treadmill drag tests.

Today, handrim wheelchair propulsion remains the most common mode of wheeled ambulation and has stood the test of time as a practical upper-body alternative to walking. Yet, it is a relatively complex bimanual discontinuous form of upper-body work, as the hands cyclically contact the rotating rims outside the visual field, requiring appropriate wheeling skills from the user. This complexity is illustrated by the low gross mechanical efficiency (ME (%)) and high relative physical strains on the upper-body, often causing upper-body overuse injuries and/or risks for inactivity. Hence, there is a continued need for research on ergonomic innovations, but especially on optimal motor skill acquisition and performance building [2]. Natural motor skill development was first stressed in observational cohort studies among wheelchair users with a spinal cord injury during and after rehabilitation. Repeated measures of power output and energy cost during individually standardized bouts of (sub)maximal wheelchair exercise on a motor driven treadmill, showed increments in peak work capacity over time, while submaximal energy cost dropped (and ME↑) [3].

Two theoretical models appeared useful in understanding the demands on the wheelchair-user combination and the role of motor skill acquisition. First, the Power Balance Model for cyclic movements[4] provides equations from exercise physiology, biomechanics and engineering to understand the generation and dissipation of power output. Detailed measures of power output, energy cost and propulsion technique, incorporated in this model, helped to understand motor control and performance in the context of environmental energy dissipation, wheelchair-user interfacing and individual abilities in manual wheelchair propulsion [2]. Secondly, the constraint-based approach places energy cost as the central optimization criterion of cyclic motor skills, within the potential and limitations of the user, task and environment [5]. Indeed, different handrim wheelchair learning studies in novices confirmed the reduction of energy cost at constant submaximal power and speed Interestingly, individual differences in learning occurred [6].

Similar to gait labs, wheelchair research is evolving towards detailed combined biomechanical and physiological measurements and modelling of upper-body function for clinical or sports performance decision-making. The Dutch Wheel-I project was a first example for a standardized monitoring and feedback lab-approach during rehabilitation, in which technology and standardization provide a time-dependent picture of energy cost, performance and skill evolution [7]. Yet, such labs are scarce and technical infrastructure, guidelines for testing and fitting of wheelchairs in combination with handrim propulsion training are (inter)nationally unstandardized and data provide a limited evidence-base [8]. Fortunately, technological advances such as commercial wheelchair ergometers and inertial measurement units lay a strong foundation for future more standardized wheeling performance and skill observations among much larger collaborative study populations [3].

Therefore, this current opinion is a call for standardization of measurements of manual wheeling ability among larger and diverse populations to support our understanding of motor control and learning. This knowledge could guide clinical decision making on the fitting of wheelchairs and training of wheelchair-users, to obtain healthy functioning and participation in daily-life as advocated with WHO's ICF model [9]. To that end, proper measures of power output and energy cost are key components of the wheelchair-user combination's performance-evaluation. Technical means are there, but the challenge is to get all relevant parties on the same page to develop and maintain a commonly shared knowledge-base and technical infrastructure to interpret individual results.

With the growing interest in wheeled motor learning and motor skill acquisition, power output and energy cost measures are crucial mediators in the development of a motor control theory of cyclic motions in rehabilitation, adapted sports and beyond [5, 6, 8, 10]. Questions that may drive the future research agenda on wheeling motor skill development are e.g.:

- What dose-characteristics drive natural optimization of cyclic motor behavior and how is this expressed in energy cost and mechanical efficiency and in the coordination of power production?
- How are physiological adaptation and motor skill acquisition connected, and how does this evolve over different time scales, feedback forms and retention periods in the context of environmental complexity, inter-individual diversity and the dynamical systems theory [5]?

- How does this interact with ergonomics of the wheelchair-user interface and with the continuum of power-assist handrim, daily and lightweight sports wheelchairs?

Indeed, intriguing questions that ideally may be answered with systematic standardized power output and energy cost measures in manual wheeled mobility.

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