Understanding the motor learning process in handrim wheelchair propulsio

Leving, Marika Teresa

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INTRODUCTION

BACKGROUND AND RELEVANCE

Motor learning is defined as 'a set of processes associated with practice or experience leading to relatively permanent changes in the capability for responding' [1]. It is a demonstration of an amazing property of our body and mind to observe and interpret the environment in order to perfect our actions. While some motor skills like skiing or playing a violin may not be vital for most, there is a range of skills, like walking, that have the ability of defining our way of life. When the ability of walking is lost due to trauma or a disease, a new skill of wheelchair propulsion needs to be learned. This skill, if perfected, can be the key to independence [2,3] and when neglected, be a sentence to social isolation [3,4].

Approximately 1% of the World population i.e. about 65 million people depend on a wheelchair for their mobility [5]. In that group, nearly 90% is assumed to use a handrim wheelchair [6]. Becoming wheelchair dependent has a profound effect on all domains of human functioning. The model of the International Classification of Functioning, Disability and Health [7] adapted for a population of wheelchair users with a spinal cord injury (SCI) [8] represents the impact of this disability on three domains: Body function and structure, Activities and Participation (Figure 1). This model also indicates the interrelations between the three mentioned domains, as well as their dependence on the external and personal factors. The main goal of rehabilitation is improving participation. While it is important to realize that there are various ways to influence participation according to the ICF model, this thesis will focus on the level most inherently representative of the motor learning process: Activities, as well as the Body functions and structures as prerequisites of being able to perform various Activities, which are in turn required for successful participation.

The domain of Activities, here especially focused on the broadly defined wheelchair skill, is central to the ICF model and will also be central in this thesis. Wheelchair skill is a complex multilayered phenomenon which cannot be measured with a single test. In this thesis being skilled in the wheelchair is defined as: being able to efficiently perform all daily wheelchair-related activities, including wheelchair propulsion. As such, wheelchair skill has multiple ingredients including: mechanical efficiency, propulsion technique and level of functional wheelchair skills e.g. negotiating a threshold or performing a transfer or a wheelie. It could be argued that mechanical efficiency (ME; ratio of power output and energy expenditure) and propulsion technique (spatio-temporal variables measured at the level of the handrim) belong in the domain of Body functions and structures, since both are parameters extracted from physiological or biomechanical data. However, in contrast to e.g. peak oxygen consumption, mechanical efficiency and propulsion technique do not describe a function of a specific bodily structure, but instead describe an activity. Moreover they represent a dynamic and multilevel process of motor learning and complex optimization of function on a higher level than just that of a single body structure. Additionally, the efficiency of walking was also previously described under the domain of Activities [9]. Wheelchair skill is a very modifiable domain and some of its ingredients, such as the functional wheelchair skills can be used to target improvements in participation in socially-valued activities such as work, sports, family [2,10]. This is confirmed by various studies which showed that high level of functional wheelchair skill corresponds to higher independence, self-efficacy, participation and quality of life [2,3]. In contrast, low levels of wheelchair skill relate to social isolation and dependence on others [3,4].

The focus of this thesis is a description of the outcomes of the motor learning process of handrim wheelchair skill taking place under the influence of various interventions or during regular rehabilitation. Understanding the motor learning process in a fully novel skill such as wheelchair propulsion, and factors that may influence it, will allow to understand human motor learning and optimization and help to design future evidence-based interventions targeting the improvement in wheelchair skill. Higher wheelchair skill proficiency facilitates mobility and independence, which are the prerequisites of social participation.

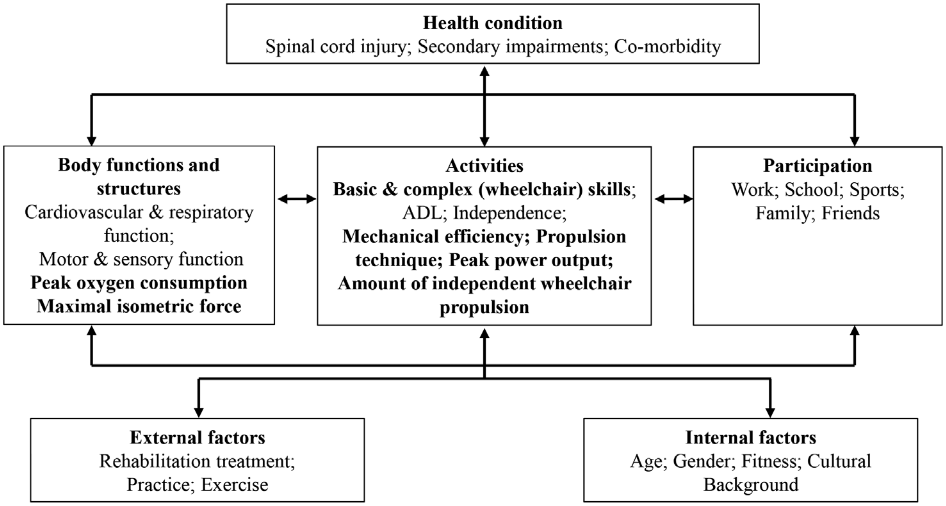

Figure 1. ICF model [7], as applied to persons with a spinal cord injury [8] and supplemented with the outcome measures of this thesis (in bold).

MOTOR LEARNING PROCESS AND WHEELCHAIR SKILL

Interpreting the outcomes of the motor learning process in wheelchair propulsion can sometimes be challenging because of the complexity of the process and a number of variables that influence it. According to the constraint-based model proposed by Sparrow and Newell [11], all movements emerge from an interaction of three factors; the organism, the environment, and the task being performed (Figure 2). In wheelchair propulsion, this means that the observed movement is a result of an interplay among a large number of factors including: personal characteristics such as demographic features, talent or preexisting movement repertoire; task characteristics, specifically the user-wheelchair interface, and environmental constraints such as obstacles or uneven terrain. A frequently used approach of studying the individual motor learning trajectories in wheelchair propulsion is to keep the constraints of the task and the environment constant throughout practice and observe the changes in movement efficiency as well as the emergent movement pattern. In wheelchair propulsion, those changes can be quantified using mechanical efficiency and wheelchair propulsion technique.

Mechanical efficiency and propulsion technique are very well established outcomes in wheelchair literature. Apart from their role in ergonomic optimization of the wheelchair-user interface, they were used to describe motor learning [12-16] and physical adaptation [17,18] in novice [14,16] and experienced [19] wheelchair users. Also in this thesis they are used as primary outcomes of motor learning process in wheelchair propulsion. Mechanical efficiency is an outcome measure which quantifies the optimization of energy consumption in the human system needed to perform a submaximal steady-state cyclic task. Mechanical efficiency is expected to increase, across the motor learning process, as mastering a task results in more optimal kinematics and kinetics which in turn leads to lower energy expenditure [13]. In wheelchair propulsion, improvements in ME are thought to be related to the physiological adaptation or changes in coordination and movement pattern taking place during practice. To quantify the latter, it is useful to look at the changes in wheelchair propulsion technique. Measuring torques and forces applied to the handrim allows to quantify temporal and spatial kinetic changes in the movement and coordination pattern of upper extremities.

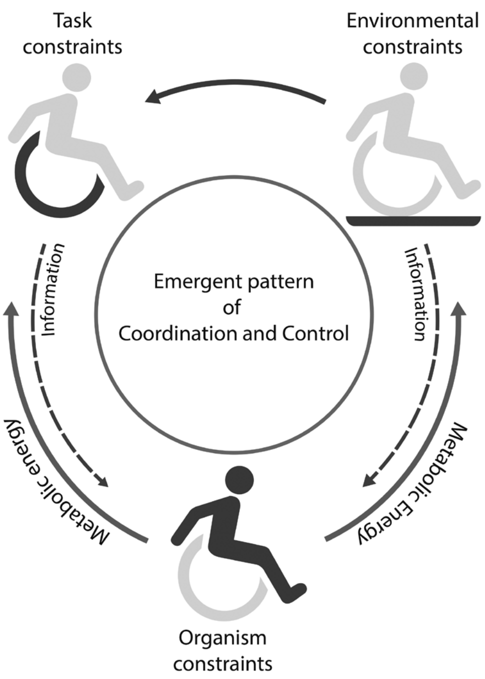

Figure 2. According to the constraint-based framework, all movements occur as a result of an interplay among three factors; the organism, the environment, and the task being performed [11]. Figure reproduced with permission [15].

EXISTING STUDIES ON MOTOR LEARNING IN HANDRIM WHEELCHAIR PROPULSION – SHORT SYNOPSIS

Able-bodied population

When it comes to longitudinal observations, the natural motor learning of wheelchair propulsion is predominantly well documented in able-bodied individuals. Next to the changes in mechanical efficiency and propulsion technique during the very early stages of motor learning process (first 12 minutes, [13], also longer experiments, reaching 1470 min distributed over seven weeks, have been conducted [20]. All those studies, independently of practice dose, found that both mechanical efficiency and propulsion technique improve during the natural learning process (practice without feedback or instruction) of wheelchair propulsion in able-bodied participants. The exact changes in technique include a decrease in push frequency, an increase of the contact angle of the hand on the handrim and decrease in braking moment. A study using multi-level modeling showed that those changes in propulsion technique are related to the improvements in mechanical efficiency [13]. Recent findings offer a new perspective on the motor learning process and propose that movement variability is an important factor during wheelchair propulsion [14,21-23]. The variability is operationalized as intra-individual stroke-to-stroke variations in propulsion technique (e.g. alternating short and long pushes, varying push frequency). A study documenting early stages of a natural motor learning process showed that novice able-bodied participants who show higher propulsion variability, learn faster and exhibit better propulsion technique and mechanical efficiency than those who are less variable [13]. Variability was also found to enhance motor learning in studies on other motor tasks, such as reaching [24]. Variability is thought to enhance learning because it is a representation of task exploration within a motor system. Increased exploration is thought to result in finding a better task solution. Since naturally occurring variability seems to benefit the motor learning process of wheelchair propulsion it is interesting to see whether increasing variability in early stages of learning causes similar or even better learning effects. So far, the effect of variability-inducing intervention on the early stages of learning process in wheelchair propulsion is unknown.

Population with SCI

While researching healthy participants provides valuable information about early stages of motor learning in a homogenous population, direct translation of those findings into the patient populations is not possible, because of their injury-related constraints which may influence the results of the motor learning process such as sitting balance, pain or distorted muscle function. That is why the early motor learning process needs to be documented in patients who became dependent on a handrim wheelchair, such as people with a SCI. Moreover, it is interesting to study the difference between recent and experienced wheelchair users with a SCI. The population with SCI is heterogeneous when it comes to personal factors presented in the ICF model, such as age, gender but also lesion-specific characteristics, like lesion level and completeness. Even though those personal factors will not be the focus of this thesis, it is important to realize that they largely determine the function of a person after a SCI and may also influence the motor learning process. When it comes to the longitudinal observation of the motor learning process during SCI rehabilitation, the knowledge in this area is still incomplete. While a very large study, including 8 rehabilitation centers in the Netherlands showed that ME, level of functional wheelchair skills (wheelchair circuit) and wheelchair work capacity improved between the beginning of active rehabilitation, 3 months later and at discharge [19,25], no information about the course of propulsion technique in between this period is available. Additionally this study was performed more than 10 years ago and it is questionable whether results still hold since the reality of rehabilitation, such as the length of stay, changed drastically in the last decade [26]. Considering the relationship of ME and propulsion technique found in the able-bodied studies [13], as well as suggested relationships of technique with shoulder pain [27-29], it is very important to look at this factor from the early stages of active SCI rehabilitation as well. Another factor that was not yet documented in relation to the motor learning process is the amount of practice during rehabilitation. Motor learning is dependent on practice dose, i.e. frequency, duration, intensity and form. Quantifying amount of independent wheelchair propulsion throughout rehabilitation is important as more practice could relate to better propulsion technique and subsequently higher ME. It is therefore important to validate and implement an activity monitor which can continuously be used across weeks of active rehabilitation to quantify the amount of daily wheelchair practice.

During active rehabilitation, next to undergoing a motor learning process, patients are expected to improve their physical capacity. It is important to realize that the processes of learning and physiological adaptation are not totally separate. There is a possible link between physiological variables such as muscle force and cardio-respiratory fitness, which are likely to improve during rehabilitation, and the outcomes of the motor learning process. It is reasonable to assume that an increase in muscle mass and improvement in neuromuscular coordination may influence the total amount of force and its timing and application when propelling a wheelchair and therefore affect both mechanical efficiency and propulsion technique as well as the functional wheelchair skills. Moreover, improvements in cardio-respiratory fitness could influence the total energy needed to propel a wheelchair at a submaximal intensity, affecting ME. Therefore, in order to be able to indicate whether potential changes in wheelchair skill during active rehabilitation in patients with SCI result from the motor learning process or physiological adaptation, it is necessary to study the change in ME and propulsion technique during low-intensity steady state propulsion, but also to include wheelchair work capacity.

SHOULDER LOAD DURING WHEELCHAIR PROPULSION

While the motor learning process, operationalized as changes in mechanical efficiency and propulsion technique, will be the main focus of this thesis, we will also pay attention to a very clinically relevant outcome, shoulder pain. The reported incidence of pain within the shoulder complex in wheelchair users ranges from 32% to 78% [30,31], making it the most common musculoskeletal complaint within the upper-extremity in this group. The anatomy of the upper-extremities, specifically the relatively small muscle mass and high glenohumeral joint mobility, makes the shoulder complex vulnerable to overuse injuries [32]. Shoulder load and propulsion technique are thought to be linked as wheelchair propulsion is a highly repetitive task, where the same motion is performed approximately 2700 times per day [29]. The accumulation of the submaximal loads often leads to repetitive strain injuries. Since optimizing wheelchair propulsion technique is suggested to be one of the ways to minimize the load on the shoulder, it is very important to look at the relationship between those two variables. This is especially important in the early stages of learning when propulsion technique changes rapidly [13,33] and shoulder load is often developed [34]. So far, changes over time (pre-post design) in both propulsion technique and shoulder load were only investigated in the very initial stages of learning (first 12 min, [27]). It is of interest to see whether the effects found in this very short-term study would remain valid in longer studies on the motor learning process.

AIM AND OUTLINE OF THIS THESIS

This thesis attempts to widen the understanding of the motor learning process in handrim wheelchair propulsion, with special consideration for shoulder load and factors associated with it. We will extend on studies with able-bodied participants by investigating the effect of variability-inducing practice on the motor learning process. We hypothesize that increasing practice variability will benefit the motor learning process of wheelchair propulsion and contribute to an increase in ME and propulsion technique at a submaximal steady-state intensity. Subsequently, we will perform an important step aimed at describing the natural motor learning process in patients with recent SCI during active rehabilitation and compare their outcomes with experienced wheelchair users with SCI. We hypothesize that the group with recent SCI will improve ME and propulsion technique, as well as functional wheelchair skills and wheelchair work capacity between the beginning of active rehabilitation and discharge from inpatient care. Moreover, we expect the experienced wheelchair users to have a better propulsion technique, higher mechanical efficiency, achieve better results during the peak test and show better skill and higher strength than the group with recent SCI.

Chapters 2 and 3 examine the influence of various forms of variable practice on the motor learning process of handrim wheelchair propulsion in able-bodied participants. **Chapter 2** aims to increase the variability of practice by providing real-time visual feedback on the propulsion technique in a controlled lab-based environment. In contrast, **Chapter 3** introduces uninstructed variable practice in a free environment to a group of novel wheelchair users. **Chapter 4**, re-evaluates a part of the data of the participants from Chapter 2 to analyze the concomitant changes in wheelchair propulsion technique and shoulder load in order to explore whether certain changes in technique may relate to a decrease in shoulder load. **Chapter 5** is a preparatory experiment aiming to validate an activity monitor which will be able to quantify the daily amount of independent wheelchair propulsion in patients with recent SCI during active rehabilitation. **Chapter 6**

observes the natural motor learning process in patients with recent SCI who undergo inpatient rehabilitation. Their outcomes will be compared to a group of experienced community-dwelling wheelchair users with SCI. This study has an observational character and takes place within ‘care as usual’, introducing regular measurement moments, but not intervening in the regular rehabilitation schedule. **Chapter 7** provides a general discussion of the findings of this thesis, discussing their implications for clinical practice, as well as for future studies to further develop knowledge about the motor learning process in handrim wheelchair propulsion.

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