Paraplegia is due to a lesion of the spinal cord or the cauda. The neurological deficits concern motor, sensory, and autonomic functions. The consequence is a dysfunction of the motor (spastic, para- or tetraplegia, flaccid paraplegia in cauda lesions), sensory (hyp- or anaesthesia, algesia below the level of lesion), and autonomic (neurogenic, bladder, bowel, and sexual dysfunction, cardiovascular dysfunction) spinal nervous systems. Recent progress in the understanding of movement control allows us to define more precisely the requirements for the successful rehabilitation of patients with motor deficits following a spinal cord injury (SCI) [1,2]. There is increasing evidence that a defective utilization of afferent input in combination with secondary compensatory processes is involved in typical movement disorders after central motor lesions. This has implications for therapy that should be directed to take advantage of the plasticity of the central nervous system. When signs of spinal shock disappear in patients with incomplete and complete paraplegia, a locomotor pattern can be induced and trained under conditions of body unloading with the use of a moving treadmill. Load and hip joint position-related afferent input seems to be of crucial importance for regeneration and for the success of locomotor training. In these patients an increase of gastrocnemius electromyographic activity occurs during the stance phase of a step cycle with a daily locomotor training, coincident with a significant decrease of body unloading. The locomotor pattern depends on the level of lesion; i.e., the higher the level of spinal cord lesion, the more normal is the locomotor pattern. In the future, a combination of various approaches, including interventions to induce some regeneration, will provide an optimal base for functional locomotor recovery also in severely affected paraplegic/tetraplegic patients. For the assessment of the effectiveness of any new interventional therapy, standardized functional tests have to be established.

References

A combination treatment paradigm for developing functional ambulation in wheelchair-dependent individuals with chronic, incomplete spinal cord injury was investigated. By coordinating epidural stimulation of the dorsal
structures of the spinal cord with partial-weight-bearing treadmill therapy, we observed improvement in treadmill and over-ground ambulation in two individuals with chronic incomplete spinal cord injury. The first subject, 3-1/2 years post-injury with a lesion at C6, was assessed as ASIA C with a lower-extremity motor score of 15/50. The second subject, 10 years post-injury with a lesion at T8, was ASIA C with a motor score of <10/50. Both subjects went through 12 weeks of partial-weight-bearing treadmill training (PWBT) before receiving the epidural spinal cord stimulation (ESCS). Thereafter, PWBT and ESCS were applied concurrently. Gait kinematics, leg muscle EMG, and whole-body metabolic was recorded to evaluate the performance of functional ambulation during both treadmill and over-ground walking. The application of partial-weight-bearing therapy alone was not sufficient to achieve functional ambulation over-ground, although treadmill ambulation improved significantly. Combining epidural spinal cord stimulation (T10–T12 vertebral levels) with partial-weight-bearing therapy resulted in further improvement during treadmill ambulation. Moreover, the combination of therapies facilitated the transfer of the learned gait into over-ground ambulation and enabled functional ambulation in a community environment (home, parking lot, and supermarket). Performance improvements were elicited by applying continuous, charge-balanced, monophasic pulse trains at a frequency of 40–60 Hz, a pulse duration of 800 s, and an amplitude determined by the midpoint (50%) between the sensory and motor threshold values. Both participants initially reported a reduction in sense of effort for over-ground walking from 8/10 to 3/10 (Borg scale), and were able to double their walking speeds. After several weeks of over-ground training, they reached a maximum walking speed of 0.35 m/s, and were able to ambulate over 325 m and 150 m (first and second subjects, respectively). We propose that ESCS facilitated locomotor recovery in this patient by augmenting the use-dependent plasticity created by partial-weight-bearing therapy. Confirmation of these promising results in a controlled study of groups of spinal cord injured subjects is warranted.

3 METABOLIC AND PERFORMANCE EVENTS FOLLOWING EPIDURAL SPINAL CORD STIMULATION IN SUBJECTS WITH INCOMPLETE, WHEELCHAIR-DEPENDENT SPINAL CORD INJURY

R. Herman, W. Willis, J. He, M. Carhart, S. D’Luzansky, A. Thompson

Banner Good Samaritan Medical Center, Phoenix, Arizona; Harrington Department of Bioengineering and Arizona BioDesign Institute, Arizona State University and Department of Kinesiology, Arizona State University, Tempe, Arizona, USA; Email: richard.herman@bannerhealth.com

It was observed that two wheelchair-dependent spinal cord injury (SCI) subjects (low ASIA C), trained to elicit clinically improved rhythmic locomotor patterns following 4 months of partial-weight-bearing therapy on a treadmill, did not reveal corresponding changes in preferred rates of walking, endurance, and perceived sense of effort (PE) during over-ground walking. In the presence of improved synergic construction of lower-limb movements, these impaired performance variables restricted the subject’s ability to perform functional walking. Over-ground walking was examined (1) under two conditions in one tetraplegic subject (C5,C6), i.e., with (supra-sensory, submotor) and without stimulation with an epidural spinal cord stimulation (ESCS) system, and (2) under four conditions in one paraplegic subject (T8), i.e., with no stimulation, with FES of the common peroneal nerve to elicit a phase-dependent reflex activity, and with ESCS at supra-sensory and motor threshold levels with/without FES. When the ESCS system was implanted to excite upper-lumbar neural segments, there was a strikingly rapid switch in locomotion behavior, in that endurance and preferred rates of walking increased by threefold and sense of effort for a given distance decreased by roughly the same magnitude. These observations were virtually spontaneous; the enhanced behaviors were noted soon after the current was applied and were abolished when the current was discontinued. Shortly after the training with the ESCS was initiated, it became clear that the improved performance variables transferred,
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in part, to the nonstimulated condition. ESCS improved locomotion performance more than FES with respect to preferred rates of walking (increasing in order of conditions in the second subject), endurance, PE, and reliance on a walker, but improvement in movement kinematics were much less significant. Indirect calorimetry revealed that the enhanced physical performance and attenuation of PE was associated with only a modest reduction in O₂ cost of transport; in contrast, ESCS promoted a profound switch in fuel selection by active muscle, increasing the apparent fat oxidation rate by approximately eightfold. It is our view that the change in fuel selection accounts for the principle observations of “sense of lightness” of the limbs and reduced PE noted by Cook and Weinstein [1] among MS patients when they applied ESCS to the upper thoracic cord. It is also our interpretation that, in muscle, fat mobilization is a rather passive process utilizing a central command signal from the central nervous system. This suggests an attempt to reduce the error between descending motor and ascending sensory feedback signals. In contrast, mobilization of carbohydrate (CBO) oxidation rate requires metabolic activators triggered by a fall in cellular energy. This will exert a braking effect on the energy-utilizing sites in the muscle cell, which reduces functional output and is sensed by the central nervous system as an efferent-afferent mismatch, leading to increased PE. Thus, the sensation of effort during walking (and presumably wheelchair propulsion) is intimately linked to metabolic events associated with recruitment of CBO fuel. Further, ESCS may modify fuel selection by preferentially recruiting fat oxidative (slow-twitch) motor units.

Reference

4 SPASTICITY REDUCTION OF THE TRICEPS SURAE USING ELECTRICAL STIMULATION

A. van der Salm, P. H. Veltink, A. V. Nene, H. J. Hermens, M. J. IJzerman
Roessingh Research & Development, Enschede, The Netherlands; Email: a.vandersalm@rrd.nl

The most commonly used definition for spasticity [1] defines spasticity as the result of a hyperexcitability of the stretch reflex. Spasticity is found to be an important impairment in SCI patients, especially in gait [2]. Electrical stimulation has been advocated to reduce spasticity [3], but there is no consensus about the optimal method. Thus, it is important to determine the most effective stimulation method. The goal of this study is to determine the most optimal electrical stimulation method for reduction of triceps surae spasticity with the use of antagonist (m. tibialis anterior [TA]), agonist (triceps surae) and dermatome stimulation. We measured 10 patients with a certain amount of spasticity in at least one of the triceps surae muscles. The patients, who could not voluntarily contract the triceps surae, were measured over 4 days. Every day began with a baseline measurement session, including the modified Ashworth scale (MAS) and H-reflex. This was followed directly by one of the interventions, a 45 min electrical stimulation of the TA, triceps surae, or dermatome. On one of the days, the patient received a placebo intervention; i.e., the application was the same, but no stimulation was given. Immediately after the intervention, a post-measurement was performed. Data were analyzed with the 95 percent confidence interval (95% CI). The MAS showed a significant decrease of spasticity for the agonist and antagonist only. The 95% CIs for the agonist and antagonist changes for the MAS are 1.34 to 0.16 (p < 0.05) and 1.10 to 0.10 (p < 0.05), respectively. The H-reflex showed decreased values for all post-measurements, but no significant changes were found. The effects found in this study are significant for a few interventions. It shows that agonist and antagonist stimulation for 45 min have a beneficial effect on the clinical assessment of spasticity,
i.e., MAS. In the H-reflex measurement, this effect is not found. On the other hand, it is known that the MAS and the H-reflex are not directly comparable [4]. The mean effect in the MAS of agonist and antagonist electrical stimulation is 0.75 and 0.6, respectively. The MAS is a 5-point scale, thus the decrease of spasticity corresponded to about 15 percent of the total MAS, assuming a linear relationship. It can be questioned whether such an effect is clinically relevant. In the literature, the effects found in reduction of spasticity by electrical stimulation are much higher than the effects we found. One reason for this might be that the patients we measured were not very spastic (mean MAS value 1+, range 1 to 3). Another possibility is that this difference may have resulted from restraining the ankle during the intervention, excluding possible effects of muscle stretching. This effect may be present in other studies. Furthermore, the effect might increase when a series of electrical stimulation sessions was performed. Spasticity in the triceps surae of spastic SCI patients can be reduced significantly with the use of agonist or antagonist electrical stimulation. The effect of the stimulation only is, however, rather small.

References

5. CARDIOVASCULAR RESPONSES TO ELECTRICAL STIMULATION-INDUCED LEG CYCLING VERSUS VOLUNTARY ARM-CRANKING EXERCISE

Rehabilitation Center Amsterdam, Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam; University Medical Center St. Radboud, Nijmegen, The Netherlands;
Email: t.janssen@fbw.vu.nl

Electrical stimulation-induced leg cycling (ESLCE) in persons with spinal cord injury (SCI) is, in contrast to voluntary arm-crank exercise (VAC), performed in the absence of central command and exercise pressor reflex, resulting in different cardiovascular responses. This study evaluated the differences in cardiovascular responses to ESLCE and VAC in persons with SCI, as well as the effect of cardiac sympathetic denervation in persons with tetraplegia (TP) compared to persons with paraplegia (PP). Nine men with motor-complete SCI (4 PP, 5 TP) performed 30 min of ESLCE and VAC at equal and constant VO2 levels (±0.6 L/min) on two separate occasions. Before, during, and after exercise, measurements were recorded for heart rate (HR) (Polar Sport tester), blood pressure (BP) (auscultation + Finapres), stroke volume (SV), and cardiac output (CO) (CO2 rebreathing), and VO2 (Oxycon Alpha). At 30 s after the onset of exercise, HR had increased more ($p < 0.05$) during VAC than ESLCE (22 ± 3% from rest vs. 1 ± 4%) and steady-state HR was reached faster ($p < 0.05$) during VAC than during ESLCE (4 ± 1 min vs. 24 ± 3 min). At 30 s after exercise cessation, HR had decreased more ($p < 0.05$) during VAC than during ESLCE (12 ± 2% vs. 2.2 ± 3%). Initial BP increases were similar for ESLCE and VAC, remained constant in VAC, but decreased markedly from minute 10 to minute 30 in ESLCE (10 ± 2%). CO increased initially and remained constant for both ESLCE and VAC. While SV and total peripheral resistance remained constant in VAC, they progressively
decreased during ESLCE. To maintain a stable CO and meet the oxygen demand, HR must increase, which is probably realized via vagal withdrawal. No differences in cardiovascular responses were found between PP and TP during ESLCE, whereas during VAC, HR in TP was lower than in PP. HR responses to ESLCE and VAC differ markedly. During ESLCE, in the absence of central command and exercise pressor reflex, either a blood-born factor or baroreflex-induced vagal withdrawal leads to a slow and progressive increase in HR over 25 min. The similar responses in PP and TP suggest that cardiac sympathetic control does not play a major role in cardiovascular responses during ESLCE, whereas during VAC when central command is present, sympathetic activity does play a role.

6 HORMONAL REGULATION IN WHEELCHAIR ATHLETES
A. Schmid, D. Bültermann, A. Blum, S. Vogt
University of Freiburg, Center for Internal Medicine, Department of Preventive and Rehabilitative Sports Medicine, Freiburg, Germany;
Email: andi@msm1.ukl.uni-freiburg.de

The alterations of spinal cord injury (SCI) are, besides the reduced functional muscle mass, a result of the interruption of sympathetic pathways in the spinal cord. Analysis of metabolic or hormonal alterations at rest and during physical exercise is dependent on the level of the lesion that results from the SCI. 50 spinal cord injured persons (tetraplegics, lesions level C4–C7; high paraplegics, Th1–Th5; low paraplegics, below Th6); and 8 control persons, all male, underwent a graded wheelchair ergometry until subjective exhaustion. Epinephrine, norepinephrine, cortisol, insulin, glucose, and free fatty acids in serum were measured before and after ergometry. Tetraplegics showed significantly lower epinephrine and norepinephrine levels at rest and only slight increases during physical exercise. Furthermore, the tetraplegic subjects had significantly higher levels of glucose (99.6 mg/dl) and insulin (18.2 µE/ml) at rest than the other groups. During exercise, an increase of glucose, free fatty acids, and insulin was found in high paraplegics (15.8 mg/dl, 0.27 mmol/l, 4.4 µE/ml), low paraplegics (21.5 mg/dl, 0.39 mmol/l, 5.4 µE/ml), and control persons (8.4 mg/dl, 0.1 mmol/l, 8.4 µE/ml), but not in tetraplegics (14.4 mg/dl, 0.04 mmol/l, 6.9 µE/ml). SCI persons present higher glucose and insulin levels, indicating a higher insulin resistance because of a lack of physical activity, especially in tetraplegics. The response to physical exercise is comparable in paraplegics and control persons. Tetraplegics showed an impaired hepatic glycogenolysis during physical exercise as a result of the interruption in the sympathetic system.

7 THE EFFECTS OF 4 WEEKS OF DAILY ONE-LEG FES STIMULATION ON ARTERIAL COMPLIANCE AND ENDOTHELIAL FUNCTION IN SPINAL CORD INJURED INDIVIDUALS
P. de Groot, J. Crozier, M. Rakobowchuk, M. Hopman, M. MacDonald
Department of Physiology, University Medical Center Nijmegen, The Netherlands; Department of Kinesiology, McMaster University Hamilton, Ontario, Canada;
Email: p.degroot@fysiol.umcn.nl

In individuals with a spinal cord injury (SCI), extensive adaptations to inactivity and paralyses occur in the peripheral circulation. These vascular adaptations are characterized by a reduced diameter, a decrease in blood flow, and an almost doubling in shear stress in the common femoral artery. The exact mechanisms behind these changes are not clear. Although the life expectancy of SCI individuals has increased over the years, they are still at an increased risk for secondary complications such as cardiovascular diseases (CVD), pressure ulcers, and impaired wound healing. Impaired endothelial function and decreased arterial compliance have been suggested to be related to CVD incidence and progression, and endurance exercise has been shown to improve endothelial function and arterial compliance in able-bodied individuals. These days, it is not clear whether local arterial compliance and endothelial function are impaired in SCI, and the time course of vascular
changes to functional electrical stimulation (FES) training is unknown. To assess the effects of 4 weeks of one-leg FES training on local endothelial function (flow-mediated dilation [FMD]) and arterial compliance of the carotid artery (CA), brachial artery (BA), and superficial femoral artery (SFA) in SCI individuals. Six SCI individuals (mean age 43 ± 4) with motor-complete injury between T4 and L2 underwent 4 weeks of FES training and 8 age- and gender-matched controls (C) (mean age 37 ± 11) were assessed on one occasion. The one-leg standardized training protocol consisted of 4 weeks training of quadriceps, tibial anterior, and gastrocnemius muscle for 30 min per day. Measurements of hyperaemic flow and FMD response after 10 and 5 min of arterial occlusion of the leg (SFA) and the arm (BA), respectively, were performed on the SCI individuals prior to training at week 1, week 2, and post-training. To calculate arterial compliance, blood pressure changes (tonometer) and diameter changes (B-mode ultrasound) were obtained at similar time points. Pretraining leg arterial compliance (SCI: 0.18 ± 0.06; C: 0.46 ± 0.10) and hyperaemic flow (SCI: 417 ± 201; C: 915 ± 165) were decreased, and FMD response (SCI: 10.9 ± 2.7%; C: 7.9 ± 0.9%) was enhanced in SCI compared with C. Daily FES training of one leg resulted in an increase in arterial compliance (pre: 0.18 ± 006, post: 0.30 ± 0.07) and hyperaemic flow (pre: 417 ± 201 ml/min, post 623 ± 243 ml/min) and a decrease in FMD response (pre: 10.9 ± 2.7%; post: 9.0 ± 1.8%) in the trained leg, whereas no training-dependent changes were observed in the untrained leg. No changes were found for CA and BA properties over the 4-week training period. The results of the present study demonstrate that 4 weeks of daily one-leg FES training in SCI individuals results in an increase in arterial compliance, an increase in hyperaemic flow, and a decrease in FMD response in the trained leg, whereas no changes are observed in the femoral artery of the untrained leg and in CA and BA properties.

8 OXYGEN PULSE DURING INCREMENTAL UPPER BODY EXERCISE IN ABLE-BODIED AND SPINAL CORD INJURED ATHLETES

M. J. Price, C. D. Thake

Coventry University, Priory Street, Coventry, United Kingdom;
Email: m.price@coventry.ac.uk

Oxygen pulse (O$_2$P) represents the oxygen consumption per heart beat (ml.beat$^{-1}$) and in accordance with Fick’s principle ($\dot{V}O_2 = Q \cdot \Delta [CaO_2 - CrO_2]$) is equal to $SV \times [CaO_2 - CrO_2]$ [1]. As spinal cord injury results in disruption to the sympathetic nervous system in proportion to the lesion level and affects cardiovascular parameters such as stroke volume and maximal heart rate [2], different levels of spinal cord lesion may have significant effects on oxygen delivery and exercise capacity. Therefore the aim of this study was to examine the oxygen pulse in spinal cord injured individuals with a range of lesion levels and consider its implications on exercise capacity. Thirty-one healthy spinal cord injured subjects volunteered to take part in the study that had received University Ethics Committee approval. The group included tetraplegics (TP) ($n = 7$), high-level paraplegics (HP) (T1–T6; $n = 10$) and low-level paraplegics (LP) (T7 and below, $n = 14$). Subjects were matched in terms of age, training status, and competitive level (national/international). Each subject undertook four submaximal exercise stages (4 min), followed by an incremental exercise test for peak oxygen uptake ($\dot{V}O_2$peak) on a wheelchair ergometer [3]. For comparison, a group of matched able-bodied individuals (AB) ($n = 12$) was examined during an incremental arm-crank ergometry protocol. Expired gas was collected with the use of the Douglas bag technique, during each stage and at volitional exhaustion. Heart rate was continually monitored (Polar, Favour). O$_2$P was calculated and plotted against relative exercise intensity (% $\dot{V}O_2$peak). Individual regression equations of O$_2$P against % $\dot{V}O_2$peak were generated. The gradient and intercept for each equation and O$_2$P at intensities of 40, 60, and 80% $\dot{V}O_2$peak were calculated. O$_2$P data were analyzed by a two-way
analysis of variance, with repeated measures on both factors (intensity × group). No differences in \( \text{O}_2\text{P} \) were observed between TP, HP, and LP for each intensity, although the LP tended to be greater, whereas \( \text{O}_2\text{P} \) for the AB was greater than all groups at 60 (7.7 ± 2.4, 7.8 ± 2.3, 9.1 ± 2.5, 14.4 ± 2.6 ml·beat\(^{-1}\)) for TP, HP, LP and AB, respectively; \( p < 0.05 \)) and 80% \( \text{VO}_2\text{peak} \) (9.0 ± 2.8, 9.3 ± 2.6, 10.5 ± 2.7, 16.8 ± 2.9 ml·beat\(^{-1}\)) for TP, HP, LP, and AB, respectively, \( p < 0.05 \)). Similarly, the gradient and intercept for AB were greater \( (p < 0.05) \) than for the TP, HP, and LP, but similar for each group of spinal cord injured athletes. The results of this study suggest that differences in oxygen pulse are related to the level of spinal cord lesion. The relative contribution and determinants of oxygen delivery and extraction resulting in established differences in exercise capacity remain to be elucidated.

References

9 THE CONTRIBUTION OF THE SYMPATHETIC NERVOUS SYSTEM AND NO IN THE OBSERVED INCREASE IN LEG VASCULAR TONE IN SPINAL CORD INJURED INDIVIDUALS

Department of Physiology St. Radboud and Department of Rehabilitation Medicine Sint Maartenskliniek, Pharmacology-Toxicology, University Medical Center Nijmegen, The Netherlands; Email: m.kooijman@fysiol.umcn.nl

In spinal cord injured individuals (SCI), loss of supraspinal control of somatic efferents and the subsequent extreme deconditioning of leg muscles appears to be associated with peripheral vascular adaptations. These vascular adaptations are characterized by a decrease in leg blood flow and an increase in leg vascular resistance. As a consequence, SCI are prone to secondary complications, like pressure ulcers and impaired wound healing. In order to prevent these complications, the mechanisms behind these tremendous adaptations have to be unraveled. Although supraspinal sympathetic control of leg vascular tone is lost, it is not known whether the sympathetic nervous system still contributes to the increased vascular tone in SCI. Besides, an impaired release of nitric oxide (NO) from the endothelium in the leg vessels may play a role. This study assessed the contribution of both the sympathetic nervous system—by blocking the alpha-adrenergic receptor—and of NO—by blocking the NO production by N(G)-monomethyl-L-arginine (L-NMMA)—to basal leg vascular tone in SCI. Upper-leg vascular resistance responses to local infusion of incremental doses of phentolamine (a competitive antagonist of the alpha-adrenoceptor) into the femoral artery were determined in 10 SCI individuals and 8 healthy, age-matched controls during local beta-adrenergic receptor blockade with propranolol. In an other study population that consisted of 7 SCI and 7 healthy controls, L-NMMA was infused in incremental doses to
inhibit NO production and responses in leg vascular resistance were established. The maximal phentolamine-induced reduction in leg vascular resistance normalized to each individual’s minimal resistance did not differ between the groups (68 ± 17% and 51 ± 4% for SCI and controls, respectively; \( p > 0.1 \)). In both groups, the vasoconstrictor response to L-NMMA, expressed as percentage change in leg vascular resistance, reached a maximum at the two highest infused doses and did not significantly differ: 102 ± 33 percent in SCI versus 69 ± 9 percent in AB (\( p = 0.9 \), Mann-Whitney U-test). These results indicate that the alpha-adrenoceptor-mediated vascular tone in the leg is preserved in SCI individuals without supraspinal sympathetic control, but cannot explain the observed increase in leg vascular tone since the response is of the same magnitude as in controls. In addition, the observed increase in leg vascular tone in SCI cannot be explained by an impaired contribution of NO to the basal leg vascular tone, since the responses to inhibition of NO did not differ between SCI and controls.

10 FUNCTIONAL GAINS WITH UPPER EXTREMITY NEUROPROSTHESES

P. H. Peckham, K. L. Kilgore, M. W. Keith

Case Western Reserve University, Veterans Affairs Medical Center, and MetroHealth Medical Center, Cleveland, Ohio, USA;
Email: pxp2@po.cwru.edu

A first-generation neuroprosthesis for restoration of hand function has been developed and commercialized. This neuroprosthesis (Freehand®) provides controlled grasp and release for individuals with mid-cervical level spinal cord injury, with the use of implanted electrical stimulation. The neuroprosthesis provides grasp and release to enable users to perform activities of daily living and thus gain independence. This neuroprosthesis is based on an implanted system that stimulates the paralyzed muscles of the hand and forearm. A multicenter trial of the use of the neuroprosthesis demonstrated statistically improved function by the study participants. Our research team has developed a second-generation neuroprosthesis that provides greater control of more functions and uses implanted sensors or myoelectric signals for control of muscle activation. The neuroprosthesis provides finer grasp dexterity (by adding stimulation of the finger intrinsics), overhead reach (by stimulation of triceps), and pronation. Control is achieved by the ipsilateral limb. One control method uses an implanted sensor placed at the wrist. Five people currently have this system. The user benefits by having an increased working volume, which enables performance of more tasks, and better control provided by the stable implanted sensor. Furthermore, the donning is easier since the external controller is eliminated. Measurements have shown improvement in several measures of impairment and disability, and user acceptance is high. The second control technique employs myoelectric signals that are recorded from muscles that retain voluntary control, such as the brachioradialis and the neck muscles. This system has been implanted in two subjects. The second-generation system is based on advanced technology, which includes the implanted sensor systems and an advanced implanted stimulator-telemeter, which provides bidirectional transmission of signals into and out of the body. This platform technology is implemented as this 10- or 12-channel stimulator, as described above, and is extendable to 16 channels of stimulation. This provides for implementation in a broader population of users, for restoring both upper and lower extremity function. Advanced technology is also under development that will provide a fully new platform based on a network of small implantable units and a central power source. This will enable a fully implanted neuroprosthesis with no external components that is expandable to multiple disabilities and neurological disorders.
This study investigated the effect of varying pedal cadence on torque production, muscle fatigue rates, and physiological responses during isokinetic functional electrical stimulation-evoked leg-cycling exercise (iFES-LCE). Nine subjects with SCI (T4–T9, ASIA A) volunteered to participate. The study investigated a low (15 rev·min⁻¹) versus a high (50 rev·min⁻¹) pedal cadence upon instantaneous peak torques (Nm) and power output (W) during 35 min of cycling. Total work (kJ) over 35 min was also calculated from power output and time. Muscle performance data were collected for isolated L quadriceps (12 s data collection) and for bilateral quadriceps, hamstrings, and glutei (12 s data collection). Stimulation amplitude was closely controlled for day-day reproducibility and to mimic stimulation parameters commonly used during a “typical” FES training session. At 5 min intervals, performance data (crank torque and power output), measures of aerobic metabolism (VO₂ and muscle O₂ saturation), and cardiovascular responses (heart rate, stroke volume, and cardiac output) were collected. Over the 35 min trial, peak crank torque generated by isolated L quadriceps was significantly greater at 15 rev·min⁻¹ than torque generated at 50 rev·min⁻¹. After 5 min, peak quadriceps torques were 8.0 ± 1.3 Nm and 3.8 ± 0.9 Nm for 15 and 50 rev·min⁻¹, respectively. By 35 min, peak torque at 15 rev·min⁻¹ had declined to 4.1 ± 0.9 Nm, while peak torque at 50 rev·min⁻¹ had dropped to 2.6 ± 0.6 Nm. For all muscles acting during iFES-LCE, average power output during the 35 min session was slightly greater at 50 rev·min⁻¹ (7.9 W) compared to 15 rev·min⁻¹ (6.3 W), but this difference was not statistically significant. However, power output became significantly greater at the higher cadence from the 15th minute on. The total work produced over 35 min of iFES-LCE was 26 percent higher at 50 rev·min⁻¹.
12 FES OF CHRONIC LOWER-MOTONEURON DENERVATION IN HUMANS REVERSES MUSCLE DEGENERATION: A TIME COURSE STUDY

C.N.R. Institute of Neuroscience, Laboratory of Applied Myology of the Department of Biomedical Science, University of Padova Medical School, Padova, Italy; Ludwig Boltzmann Institute of Electrostimulation and Physical Rehabilitation, Department of Physical Medicine, Wilhelminenspital, Vienna, Austria; Department of Biomedical Engineering and Physics, University of Vienna, Vienna, Austria; CeSI, Centro Scienze dell’Invecchiamento, University G. d’Annunzio Medical School, Chieti, Italy; Email: ugo.carraro@unipd.it

This study describes the effects of long-term lower-motoneuron denervation on human muscle and evaluates the restoration of function and structure induced by a chronic progressive FES training. In subjects that have experienced complete traumatic conus cauda lesion, more than one year after injury, electrodes made of conductive silicone rubber are applied directly to the skin with the use of a wet sponge cloth (at the beginning of training) or gel (later on, when skin trophism improves). During the several months of muscle training, a muscle twitch is only elicited by impulses lasting 150 to 200 ms, with amplitudes up to ±200 mA. Once muscle excitability increases, the stimulation impulses are shortened to 40 ms. Based on interpulse intervals of 10 ms, impulse frequencies of 17 to 20 Hz are achieved, which results in tetanic muscle contractions. By the tetanic training, muscle size almost returns to that of sedentary subjects. Muscle power increases to a level that allows subjects to stand on their own stimulated legs. CT scan confirms increase of quadriceps’ size. Spinal cord injury (SCI) causes a rapid loss of muscle, which is especially severe when the injury involves lower motoneurons. Over the last 30 years, there has been a good deal of interest in the use of functional electrical stimulation (FES) to restore movement of the limbs of patients paralyzed by upper motoneuron lesion. The results of our clinical and structural studies are extremely encouraging, since the progressive FES training has proven to be effective in reverting long-term DDM atrophy and in maintaining the trophic state of newly regenerated myofibers. The recovery of muscle tetanic excitation, and therefore of muscle mass and power seems to be the product of both a size increase of the surviving fibers and the regeneration of new myofibers.
13 INCREASED PHYSICAL FITNESS AFTER 4-WEEK HYBRID TRAINING IN PERSONS WITH SPINAL CORD INJURY

P. Heesterbeek, D. Thijsen, M. Hopman, J. Duysens
Sint Maartenskliniek Research, Nijmegen, Department of Physiology, University Medical Center Nijmegen, The Netherlands; Email: P.Heesterbeek@smk-research.nl

FES-LCE (functional electrical stimulation-induced leg cycle ergometry) is an accepted training method to improve the physical fitness of individuals with spinal cord injury (SCI). When combined with voluntary arm-crank exercise in a new training device, a larger muscle mass is exercised and this training method may induce an increase of physical fitness. The major parameters to indicate physical fitness are peak oxygen consumption and expired ventilation. This study determined the effect of a 4-week hybrid training program on physical fitness of individuals with SCI. Ten persons with SCI (age 23–53 years, lesion levels range T3–T11) participated in the study. The participants trained 812 times in 4 weeks on the BerkelBike. This newly developed hybrid-training device is a mobile FES cycle with voluntary arm crank that can be used independently indoors as well as outdoors by individuals with SCI. Measurements of peak oxygen consumption (pVO2), peak carbon dioxide output (pCO2), peak heart rate (pHR), expired ventilation (Ve), and power output (PO) were performed during a graded exercise test on the BerkelBike prior to training (T0) and after 4 weeks of training (T4). PO increased from 86 ± 23 to 98 ± 26 W after training (paired t-test, two-tailed, p = 0.028). PVO2 and pCO2 increased from 25.70 ± 5.78 to 29.23 ± 6.92 ml/min/kg and 29.52 ± 7.29 to 33.31 ± 8.20 ml/min/kg, respectively (p = 0.022 and p = 0.012). The Ve increased from 67.2 ± 16.0 to 73.7 ± 19.3 L/min; however, this difference was not significant (p = 0.088). The pHR did not change after training (152 ± 16 vs. 152 ± 18 bpm). Power output increased significantly, as well as peak oxygen consumption and carbon dioxide output. Ve did not increase significantly, but there was a trend toward improvement (p < 0.10). Even though the duration of training period was only 4 weeks, considerable training effects were observed. The results of this study indicate that hybrid training on the BerkelBike is a good alternative training method for individuals with SCI. The results of this study indicate that training on the BerkelBike leads to an improvement of physical fitness within 4 weeks.

14 CLINICAL APPLICATION OF AN EIGHT-CHANNEL STIMULATION SYSTEM FOR MOBILIZATION OF PARAPLEGIC PATIENTS: FIRST RESULTS

M. Bijak, M. Rakos, C. Hofer, W. Mayr, M. Strohhofer, D. Raschka, H. Kern
Department of Biomedical Engineering and Physics, University of Vienna, Otto Bock, Vienna, and Department of Physical Medicine and Rehabilitation, Wilhelminenspital, Vienna, Austria; Email: manfred.bijak@univie.ac.at

Six paraplegic functional electrical stimulation (FES)-experienced users volunteered to test a newly developed eight-channel stimulation system. The goal was to discover the influence of various stimulation parameters on the gait quality. As an additional task, the usability should be simplified as much as possible. Improved strategies for electrode placement were investigated. In the beginning, commercially available hydrogel electrodes were attached to quadriceps and glutaeus muscles for hip and knee extension, peroneal nerve to elicit flexion reflex, and later also on adductor muscles. All patients were positive about the handling of the stimulation system. In particular, the wireless crutch or walker-mounted remote control was highly approved. Nevertheless, the stimulation modules have to be further miniaturized. First results demonstrate the importance of an amplitude ramp during stimulation onset, resulting in a smoother and more “natural” movement. For an adequate step length, an overlapping stimulation of quadriceps and peroneal nerve during heel strike is crucial. Activation of the adductor muscles lead to a better knee trajectory.
during standing up and better leg movement during the swing phase. A decrease in the number of skin-attached stimulation electrodes could be accomplished by replacing nearby electrodes with one common electrode for two or more channels. This is applicable for the distal quadriceps electrodes and one of the peroneal electrodes, as well as for the proximal gluteus electrodes, leading to a reduction in the number of required electrodes from 16 to 13. The analysis of the stimulation sequences used should bring up guidelines for a fast and effective parameter optimization procedure.

15 VALUATION OF IMPROVEMENT OF ELBOW EXTENSION IN TETRAPLEGIA

G. J. Snoek, J. A. van Til, M. J. IJzerman
Rehabilitation Centre Het Roessingh,
Roessingh Research and Development,
Enschede, The Netherlands;
Email: g.snoek@rrd.nl

In tetraplegic subjects at or above C6 level, deltoit to triceps transfer improves active elbow extension, as well as upper limb kinematics, and this may contribute to improved mobility. The study objective was to determine the valuation of improvement of elbow extension compared to other treatment characteristics of upper extremity interventions on the decision of tetraplegic subjects for surgery. This study was a discrete choice experiment. Treatment characteristics were formulated and used to establish different treatment scenarios. Tetraplegics were given 20 different sets of treatment scenarios and asked to choose the best scenario of each set. The relative importance of treatment characteristics with respect to the decision for reconstructive surgery was calculated. 47 tetraplegic subjects with C5–6 lesions, motor group M14, were selected. The relative importance of treatment characteristics were intervention type 13 percent, number of operations 15 percent, in-patient rehabilitation period 22 percent, ambulant rehabilitation period 9 percent, complication rate 15 percent, improvement of elbow function 10 percent, and improvement of hand function 15 percent. Effects of various changes of treatment protocols were determined. An inpatient rehabilitation period to a maximum of 4 weeks increases the relative preference for treatment with 32 percent. One instead of two operative procedures increases the relative preference with 25 percent. Improvement of elbow extension increases the relative preference with 19 percent. In-patient rehabilitation period has the greatest impact on the patient’s decision to have surgery or not. Despite the fact that professionals consider improvement of active elbow extension very rewarding, and research has shown the benefits on overall upper limb kinematics, the valuation of restoration of elbow extension by tetraplegic subjects is low compared to other treatment characteristics. The relative low valuation of the possibility to restore active elbow extension may result in non-optimal use of this treatment possibility with negative impact on restoration of mobility. In this respect, patient information about the effect of this procedure needs more attention.

16 REHABILITATION ROBOTS FRIEND-I AND FRIEND-II WITH THE DEXTEROUS LIGHTWEIGHT MANIPULATOR

O. Ivlev, C. Martens, A. Graeser
Institute of Automation, University of Bremen, Bremen, Germany;
Email: ivlev@iat.uni-bremen.de

The rehabilitation robotic systems FRIEND belong to the category of “intelligent” wheelchair-mounted manipulators. The systems have been developed at the Institute of Automation (IAT), University of Bremen, since 1997 as a personal assistant to support disabled persons with upper-limb impairments in daily life situations, as well as in the working environment, including people with multiple sclerosis, paraplegia, cerebral palsy, etc. The system FRIEND-I consists of a robot arm MANUS, mounted on an electric wheelchair. Currently commercial available systems of such kind offer support on a relatively low task level, which means the user has to control the arm movements “one by one.” This puts a high cognitive load on the users, so that controlling these systems turns out to be very tiresome. To relieve the user, the system has to be able to “understand” high-abstraction-level commands, such as “grasp the object” or “serve a drink,” and then carry out it (semi-) automatically,
considering the current situation. To this purpose the system is equipped with elements of “local intelligence.” The system is controlled by a multiprocessor PC, mounted on the backside of the wheelchair. As a suitable user interface, a speech recognition system is used. For object detection and autonomous arm control, the system is equipped with a moveable stereo-camera system and a gripper-mounted camera. To reduce the complexity of environmental perception, which is very high if only visual information is available, the system is equipped with external smart sensor devices. At first, IAT developed a “smart” tray, which is mounted at the front side of the wheelchair. On the one hand, the tray offers the possibility to measure objects’ weights, so that an action like pouring a drink can be performed without user interaction. On the other hand, it returns all relative positions of objects placed on the top of the tray. The latter information is used for the support and simplification of image-based object detection. By means of a “pour a beverage” task it has been shown that the tray enhances the system’s capabilities without an unjustifiable enlargement of its inertial complexity. The first practical experience show that the system FRIEND-I achieves a certain degree of autonomy. So, the objects on the tray can be detected and gripped autonomously, and even the task “serve a drink” in an unknown situation can be done successfully. During these tests the insufficient kinematic flexibility of the 6-joint manipulator was recognized. Therefore, the next-generation rehabilitation robot FRIEND-II is a successor of FRIEND-I, with a dexterous lightweight robot arm with 7 joints. This electrically driven robot arm has humanoid kinematics and was developed by Amtec Robotics under functional specification by IAT. The arm will be equipped with a wrist torque/force sensor and a 5-finger artificial hand, developed by IAI FZK. This dexterous robotic system has increased manipulatory facilities in comparison with FRIEND-I and is now in the installation phase.

17 CHANGES IN MUSCLE COALITIONS AFTER ISOLATED MUSCLE TRANSPosiTIONS IN THE UPPER EXTREMITY

Y. J. M. Janssen-Potten, C. Pons, H. A. M. Seelen
Institute for Rehabilitation Research, Hoensbroeck, The Netherlands;
Email: HAM.Seelen@iRv.nl

In cervical spinal cord injured (SCI) patients muscle transpositions are sometimes performed to improve arm-hand function. In order for this intervention to be successful, new coalitions in muscle activation must be acquired by these patients, for which rehabilitation training is necessary. This study aimed to quantify changes in muscle coordination in the upper extremity as a result of the surgical intervention. In a (multiple) single-case design, changes in muscle activation patterns due to specific muscle transpositions in the forearm were investigated. During standardized upper-extremity task performance, muscle activity of 21 muscles of the trunk, shoulder girdle, upper arm, and forearm was recorded with the use of surface EMG. Measurements were performed once every week, starting 3 weeks prior to the operation and lasting until clinical discharge. Follow-up recordings were performed at 3, 6, and 12 months after discharge. Participants were asked to perform a simple task involving the displacement of a small and lightweight object in medio-lateral direction over a distance of approximately 25 cm. During each session eight trials were recorded. Time to perform the task was normalized to a movement cycle. Intraclass correlation coefficients (ICC) were calculated as an indicator of EMG signal reproducibility. As an example, clear differences in timing of dominant muscle activity during task execution were observed in one of the single cases, despite the fact that none of these muscles were transposed in this particular subject. Before the operation, dominant activity in most muscles occurred between 60 and 95 percent of the movement cycle, indicating less temporal differentiation between activities of muscles. In contrast, after the operation the temporal pattern of muscle activity was more differentiated. The latter is mainly caused by changes in activation timing in the following muscles:
rhomboids, infraspinatus, lattisimus dorsi, anterior deltoid, lateral head of the triceps, short head of the biceps, brachioradialis, extensor carpi radialis, and ulnaris. The vast majority of ICC values ranged from 0.86 to 0.99, both before and after operation. Isolated muscle transpositions do have an influence on existing muscle synergies in the upper extremity. The observed changes in upper-extremity muscle use cannot be (solely) explained by the localized, structural effects of the operation procedure itself, e.g., damage to the muscles and fascia. The operation changed the possibility to handle the object, thereby altering the whole movement of the upper extremity. Improving the grasp function proved to have profound consequences for the kinematics of the wrist, elbow, and shoulder during task execution. This may be an explanation of the observed differences in both the occurrence of dominant muscle activity and the within-subject variation. The generally high ICC values indicate that the subjects performed the task in a standard manner after surgery, suggesting that the patient has acquired new and stable patterns of muscle coordination.

18 THE “LINK HAND FUNCTION TEST” FOR SUBJECTS WITH A CERVICAL SPINAL CORD LESION

C. Link
Occupational Therapy, University Hospital Balgrist, Zürich, Switzerland; Email: claudia.link@balgrist.ch

The need to document and evaluate interventions, also in occupational therapy, is by now commonly known and widely discussed in the literature. In the treatment of subjects with a cervical spinal cord lesion, a meaningful assessment tool for the evaluation and documentation of the hand function was missing, especially for German-speaking patients. Often instruments are used that have not been evaluated for this specific client group. The newly designed Link Hand Function Test (LiHFT) aims to fill in this gap, assessing hand function in the everyday activities of persons with an acute chronic cervical spinal cord lesion. The LiHFT will especially support occupational therapists, to objectively assess a client’s hand function and document treatment progress. The LiHFT is designed to assess all patients suffering from a cervical spinal cord lesion that causes neurological deficits in the upper extremity. Because of its design, the LiHFT can already be used in a very acute stage, when patients are only able to sit up in bed with a back support; but it can also be used for subjects with chronic tetraplegia. The test is based on 10 activities of daily living and covers 5 of the 8 most common grasps defined by C. Sollermann [1]. It assesses only the function of the hand, not including aspects of gross motor function of the arm and shoulder or trunk stability. While these aspects are relevant for hand function, they are not assessed by the LiHFT; other tests do exist to evaluate these criteria. The LiHFT assesses the hand function for the five grasps: pulp pinch, lateral pinch, tripod pinch, five-finger pinch, and transverse volar grip, focusing on the quality of the grasp, as well as the time needed to perform the task. The test is performed in one session for both hands, with the scoring showing whether the tasks were performed uni- or bimanual. The time needed to perform the LiHFT is 30 min maximum, with an active time for the subject of 10 to 15 min. The integration of activities of daily living supports the relevance of the results for the subjects in everyday life. The LiHFT, which is easy to administer in a clinical setting, is currently under statistical evaluation for reliability, reproducibility, and clinical applicability by 45 occupational therapists in 18 spinal cord rehabilitation centers in Germany, Austria, and Switzerland.

Reference
19 DEVELOPMENT OF A LIGHT-WEIGHT DEXTEROUS HAND AND MODULAR ROBOT ARM FOR A PERSONAL ASSISTANT SYSTEM
C. Mehne, C. Pylatiuk, S. Schulz, G. Bretthauer
Institute of Applied Computer Science (IAI) Forschungszentrum Karlsruhe, Karlsruhe, Germany; Email: christian.mehne@iai.fzk.de

People with upper-limb impairments caused by spinal cord injuries or central affections depend on assistance in everyday life situations. A personal-service robot that can assist these people in increasing their independence and re-integrating them in a job must be easily instructable. Such a robot system has to be able to perform a variety of tasks and to manipulate objects of different size, shape, and weight. This flexibility requires a robot gripper that mimics the functionality of a human hand as closely as possible. A new approach uses an anthropomorphic five-finger hand that can perform the most significant grip types and hand postures for everyday use: cylindrical power grasp, lateral grasp, tripod pulp precision grasp, spherical grasp, and hook grasp. Additionally, the index finger can be used to press a key or operate a switch. These movements are achieved by 11 flexible fluidic actuators that are integrated in the fingers of the hand. They are driven by a hydraulic pressure unit, including a micropump, microvalves, a reservoir, and a local controller with drivers for the pump and the valves. Each actuator can be controlled individually via a serial RS232 interface. A new lightweight modular robot arm is under development, the objective being to reach a robot arm weight/load ratio of 1:1 or better. In case of a collision between the user and the robot, the lightweight construction contributes to minimizing injuries. Both the hand and arm are part of the LeRoSF research project, which stands for lightweight robots with flexible servo-fluidic actuators. The project is funded by the German Federation of Industrial Cooperative Research Associations (AiF) and also includes the development of an adequate torque control for actuators with inherent compliance. The new project is based on the experience gained from the semiautonomous personal assistant system FRIEND (Functional Robot Arm with User-friendly Interface for Disabled People) that was developed at the Institute of Automation Technology (IAT), University of Bremen, Germany. Cooperation between the two research institutes will give rise to a new generation of lightweight service and rehabilitation robots.

20 CELL AND GENE THERAPY STRATEGIES TO PROMOTE REPAIR OF THE INJURED RAT SPINAL CORD
J. Verhaagen
Netherlands Institute for Brain Research, Amsterdam, The Netherlands; Email: j.verhaagen@nih.knaw.nl

It is evident that the injured mammalian spinal cord has a very limited capacity for self-repair. Studies in developmental biology and neurobiology have led to the identification of factors that can either promote regeneration (neurotrophins, anti-apoptotic proteins, growth-associated proteins) or are responsible for regenerative failure (NoGo, semaphorins, chondroitin sulfate proteoglycans). Strategies to stimulate regeneration derived from these discoveries will hopefully be applicable in the treatment of several major neurodegenerative conditions, including traumatic spinal cord injury. Here we summarize our studies using gene therapy and cell transplantation as strategies to promote the regeneration of injured rat spinal cord and dorsal and ventral spinal roots. Gene therapy with adenoviral vectors encoding neurotrophin-3 (AdVNT-3) has been shown to enhance and direct the regeneration of a subpopulation of dorsal root axons deep into the spinal cord. Direct gene transfer with adenoviral vectors, however, elicits an immunological response resulting in death of inter- and motorneurons at and near the site of vector injection [1,2]. This hampers studies on the functional outcome of direct adenoviral vectormediated gene transfer. Transplantation of (1) peripheral nerve bridges transduced ex vivo with AdVNT-3 or (2) olfactory ensheathing glial cells transduced ex vivo with AdVNT-3 or an adenoviral vector encoding BDNF (AdV-BDNF) in the hemi-sected
spinal cord promotes regrowth of corticospinal tract and rubrospinal tract fibers and improves hind-limb function [3,4]. Transgene expression in these transplants is gradually lost during the first two to three weeks post-implantation due to mitosis of the transduced cells, resulting in loss of the episomal AdV-genome. Moreover, immunological clearance of the transduced cells may have contributed to the loss of transgene expression. These results with adenoviral vectors show that developing integrating and nontoxic vectors is central to the success of gene therapy for repair of the injured nervous system. To date, two options are available: adeno-associated viral vectors (AAV) and lenti-viral vectors (LV). Following avulsion of ventral nerve roots, most spinal motoneurons die. We have recently shown that AAV-mediated expression of BDNF or GDNF in the ventral horn following ventral root avulsion results in rescue of motoneurons. The rescued motoneurons elaborate numerous processes in the ventral horn, where the level of neurotrophic factor is high, but do hardly regrow axons into the reimplanted ventral root. Currently we are combining gene transfer in the ventral horn with genetic modification of ventral root implants with the use of LV to study whether this leads to attraction of motoneuron axons toward the periphery and to the restoration of hind-limb function.

References


TUESDAY 20 APRIL

1 UPPER-EXTREMITY OVERUSE PROBLEMS AND PAIN IN SPINAL CORD INJURY

M. L. Boninger, R. A. Cooper, D. A. Koontz

Human Engineering Research Laboratories, Department of Physical Medicine and Rehabilitation; Department of Rehabilitation Science and Technology; Department of Bioengineering, University of Pittsburgh; Department of Veterans Affairs, Center of Excellence in Wheelchair and Related Technology, Pittsburgh, Pennsylvania, USA; Email: boninger@pitt.edu

Over 50 percent of manual wheelchair users with spinal cord injury (SCI) are likely to develop upper-limb pain and injury. The most common injuries are rotator cuff disease and/or impingement at the shoulder, and carpal tunnel syndrome (CTS) at the wrist. The majority of studies related to upper-limb pain in SCI have implicated the wheelchair propulsion as a causative factor. The purpose of our studies is to determine if there are specific aspects of wheelchair propulsion biomechanics that are related to injury. In addition, we are investigating if biomechanics factors related to injury may be modifiable through alteration in wheelchair setup and propulsion technique. A biomechanical evaluation of wheelchair propulsion was completed on over 50 individuals with paraplegia. Kinetic data were collected with SmartWheels™ as subjects propelled on a dynamometer. Kinematic data were also collected bilaterally. In addition, each subject was examined by a physician and filled out a questionnaire related to upper-limb pain. Subjects completed shoulder magnetic resonance imaging (MRI) studies, which were scored by a radiologist blinded to symptoms. Nerve conduction studies (NCS) of the median nerve at the wrist were completed to assess nerve damage. Median nerve damage is the underlying
pathology in carpal tunnel syndrome. More than 20 patients returned over the 2 years following their initial visit and repeated all studies. In a series of papers, propulsion variables were found to relate to evidence of median nerve damage. Variables related to median nerve injury included cadence and the peak rate at which force is applied to the pushrim as well as to subject weight. Increased range of motion at the wrist was related to decreased evidence of both median and ulnar nerve injury. Recent work has found that variables found to correlate with median nerve damage also predict progression of median nerve damage over time. MRI abnormalities at the shoulder were positively related to subject weight, and women were more likely to have progression of MRI abnormalities over time. These data clearly demonstrate a link between subject characteristics, wheelchair use, and upper-limb injury. When combined with other studies, clinical recommendations based on this work are possible. These recommendations include the need to provide wheelchairs that are as lightweight as possible, that wheelchair users should set up their chair to minimize rolling resistance, and that they should take long smooth strokes. Larger sample sizes are needed to develop a more complex model of the interaction between pathology of the upper limb, physical examination findings, symptoms, and wheelchair propulsion biomechanics. There is currently a multisite study being funded that will complete the testing described above on over 200 individuals with SCI. Wheelchair propulsion biomechanics research has established a link between how an individual propels a manual wheelchair and their risk of repetitive strain injury. This work has led to recommendations that may reduce the risk of injury to wheelchair users. Interventional studies are needed to look at the effect of training and wheelchair setup on risk of injury.

2 WHEELCHAIR USERS WITH SCI EXHIBIT PARADOXICAL TRUNK MOTION DURING PROPULSION

A. M. Koontz, I. Rice, M. L. Boninger, R. A. Cooper

Human Engineering Research Laboratories, VA Pittsburgh Health Care Center, and Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, Pennsylvania, USA;
Email: akoontz@pitt.edu

It would seem that to maximize propulsion efficiency, the trunk and arms should move uniformly in the same direction when exerting forces on the pushrim. The purpose of this study was to examine the direction the trunk moves when the hands are in contact with the pushrim and the extent to which direction of movement is related to user characteristics and force generation. Eighteen manual wheelchair users (12 men and 6 women) with spinal cord injuries (SCI) ranging from L4 to T4 provided informed consent prior to participation in the study. Their mean age and years post-injury were 37.1 ± 8.1, and 14.6 ± 6.6 years, respectively. Subjects’ own wheelchairs were fitted on the right side with a SmartWheel™ (Three Rivers Holding, Mesa, Arizona, USA) and secured to a wheelchair dynamometer. An infrared marker of an Optotrak™ (Northern Digital, Waterloo, California, USA) motion system was placed on a rigid body secured to the subject’s torso to measure trunk excursion. Subjects were instructed to propel at two steady-state speeds, 0.9 m/s and 1.8 m/s. Upon reaching the target speed for 1 min, SmartWheel™ and motion data were collected for 20 s. Kinetic data sampled at 240 Hz were linearly interpolated for synchronization with the kinematic data collection rate of 60 Hz. Trunk excursion was analyzed in the anterior and posterior direction and quantified in terms of percentage of time (%) and distance of travel (mm) the trunk moved forward or backward at each speed. Kinetic parameters included peak tangential force, peak resultant force, peak resultant force rate of rise, and mechanical efficiency (ratio of tangential force squared to the resultant force squared).
For each subject, kinetic and trunk excursion variables were determined for the first ten strokes and then averaged. A Pearson correlation test was used to examine the association between trunk variables and kinetic variables, as well as user characteristics (age, time since injury, and SCI level). A paired t-test was used to compare the trunk variables between the two speed conditions \( (p < 0.05) \). Inspection of the trunk excursion plots revealed that the trunk is moving backward at the beginning of the stroke and then switches direction 42 or 52 percent of the way (on average) into the push phase at 0.9 m/s and 1.8 m/s, respectively. More backward trunk motion was found at the faster speed (10 mm at 0.9 m/s and 15.4 mm at 1.8 m/s, \( p = 0.013 \)). There was no association between user characteristics, and paradoxical trunk movement patterns during propulsion. Paralysis of the abdominals and trunk muscles is likely the reason that the reaction forces from pushing forward send the trunk backward. As propulsion forces increase, e.g., from pushing at a higher speed, the trunk moves further backward. There was no association between paradoxical movement patterns and the forces applied to the pushrim. One theory is that while forces are equal, individuals whose trunks move further backward require more arm strength to generate force. It may be possible that a rigid back support could help minimize any inefficiencies produced by paradoxical trunk movement.

3 DETERMINATION OF AN OPTIMAL HANDRIM COMPLIANCE

W. M. Richter, P. W. Axelson
Beneficial Designs BioMobility Laboratory, Nashville, Tennessee, USA; Email: mark@beneficialdesigns.com

The impact spike seen during the beginning of the push phase of wheelchair propulsion bears some resemblance to the impact spike found at heel strike during running, which can be attenuated by adding compliance between the person and the ground. Adding compliance between the handrim and the wheel offers a simple approach to attenuating impact loading during wheelchair propulsion. The purpose of this study was to optimize the level of handrim compliance such that it is soft enough to attenuate impact loading, but not too soft such that user acceptance is compromised. A variable compliance handrim prototype (VCHP) was designed and built that did not affect handrim size or spacing from the wheel. Three linear response settings were developed to span a range of compliance, with values of 266 N/cm (C1), 191 N/cm (C2), and 124 N/cm (C3). Seventeen full-time wheelchair users with full use of their upper extremities participated in the study. Subjects used the VCHP to negotiate a propulsion activities-of-daily-living test course in their own wheelchairs. Compliance was increased until subjects felt the compliance was too soft. Subjects then propelled their wheelchairs fitted with instrumented wheels on a wheelchair treadmill while handrim kinetics were sampled at 480 Hz. Each propulsion bout consisted of 15 pushes on each of 4 ramping conditions: (1) 2 percent grade at 0.94 m/s, (2) 4 percent grade at 0.49 m/s, (3) 6 percent grade at 0.31 m/s, and (4) 8 percent grade at 0.22 m/s. The three compliance levels and a rigid condition were randomly varied prior to each bout. Subjects were blinded from the compliance condition. Impact was characterized with the use of the peak and average rate of rise (pROR and aROR, respectively) of the resultant force. aROR was defined as the average of the positive force rate values over the push. Differences in propulsion outcomes were determined with the use of a two-way analysis of variance with repeated measures and Bonferroni post-hoc t-tests. All the subjects were tolerant of compliance at the C1 level, 71 percent at the C2 level, and 24 percent at the C3 level. In general, pROR increased while aROR decreased from the 2- to 8-percent grades. pROR was found to be statistically reduced with the use of the C1 handrim on the 6- and 8-percent grades and on the 8-percent grade with the use of the C3 handrim. aROR was found to be statistically reduced for all the compliance levels on the 2-, 4-, and 6-percent grades. Many subjects commented that the compliant handrims felt more comfortable than the rigid handrim. Trends in pROR for the C2 and C3 levels suggest that users may be adapting by pushing harder to compensate for the increased compliance. Use of aROR is
believed to be a good indicator of impact loading during propulsion. An optimal compliance was identified at which impact loading is reduced while user acceptance is preserved. There do not appear to be any adverse side effects associated with the optimal handrim compliance. It is recommended that future handrim designs incorporate compliance as a means of reducing impact loading on the wheelchair user.

4 FUZZY CLUSTERING OF HANDRIM TRAJECTORY DURING MANUAL WHEELCHAIR PROPULSION IN THE DISABLED ELDERLY

R. Aissaoui, H. Arabi

Institut de Réadaptation de Montréal, C.R.I.R (Centre de Recherche Interdisciplinaire de Réadaptation), Montréal; Laboratoire d’Imagerie et d’Orthopédie, Centre de Recherche du Centre Hospitalier Universitaire de Montréal (CHUM), Montréal; Département de Génie de la Production Automatisée, École de Technologie Supérieure, Montréal, Québec, Canada; Département d’Ergonomie, PSA Peugeot–Citroën, Montbéliard, France; Email: rachid.aissaoui@etsmtl.ca

Kinematic features of wheelchair propulsion have been observed in the past, and were associated to mechanical efficiency and minimization of joint stress. This is especially important for elderly and nonambulatory persons. Handrim movement patterns have been defined qualitatively in the literature and vary between authors. Multiple terms have been used in the biomechanics of wheelchair propulsion to describe the sagittal handrim trajectory during the wheelchair propulsion cycle: the pumping movement (PM), the semicircular (SC) motion, the single looping (SLOP), as well as the double looping (DLOP) over propulsion. The definitions proposed above rely on visual plot and qualitative description of the shape of the trajectory of the wrist joint motion and thus lack consistency because they are not defined objectively on the basis of any specific geometric criteria. The purpose of this study is to develop an objective method to distinguish and classify stroke patterns during manual wheelchair propulsion in elderly disabled persons. In this study, we develop an algorithm that extracts two geometrical normalized parameters, R1 and R2. For each single stroke, the parameters R1 and R2 were obtained from the convex-hull area of the contour of hand center of mass trajectory in the sagittal plane during the propulsion cycle. R1 defines the thickness of the contour and thereby continuously differentiates between the PM and SC patterns. R2 defines the topological aspect of the contour and continuously differentiates between SLOP and DLOP patterns. Fifteen elderly wheelchair users were asked to propel in a manual wheelchair ergometer at 3 to 3.5 km/h in nine wheelchair configurations. A motion analysis system was used to collect the trajectory of the hand during the propulsion cycle at 60 Hz, while a SmartWheel™ was used to measure ground reaction forces and moments at the handrim level at 240 Hz. The couple (R1,R2) was extracted for each stroke cycle and normalized so its value varied between 0 and 1. The Gustafsson-Kessel (GK) fuzzy clustering algorithm was used to estimate the distribution of pattern of the classes. A mechanical usage index (MUI) was used that corresponds to the ratio between the maximal resultant force during the push phase and the maximal isometric force. We analyzed a total of 2066 cycles using 4 classes, C1 to C4, defined by the two normalized variables R1 and R2. It is recognized in the literature that a handrim pattern that corresponds to the (SC, SLOP) couple is more efficient biomechanically. The efficiency is usually measured by the ratio between the tangential and the total forces applied to the handrim during the propulsive phase. Our data reveal that our subjects propel with the (SC, SLOP) pattern only 18 percent of the time. Moreover, the MSU was 47 percent higher in the C2 class, which corresponds to the (SC, SLOP) pattern comparatively to 35 percent for the (PM, SLOP), 20 percent for the (SC, DLOP), and 28 percent for the (PM, DLOP). The findings of this study have a direct implication in the design of manual wheelchairs dedicated to the geriatric population, and contribute to a more comprehensive analysis of joint pain prevalence in the elderly population.
LOAD ON THE SHOULDER DURING WEIGHT-RELIEF LIFTS IN MEN WITH A SPINAL CORD INJURY

S. van Drongelen, L. H. V. van der Woude, H. E. J. Veeger
Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam; Man Machine Systems and Control Group, Department of Mechanical Engineering, Delft University of Technology, Delft; Rehabilitation Center Amsterdam, The Netherlands; Email: s.vandrongelen@fbw.vu.nl

Wheelchair users are often subject to overuse injuries in the upper extremity (UE). Mechanical load in wheelchair-related activities of daily living (ADL) is probably one of the risk factors. Glenohumeral reaction forces during wheelchair propulsion under relatively common conditions are shown to be moderate. Until today, no glenohumeral reaction forces have been calculated for wheelchair-related ADL task. However, electromyographic studies have shown high levels of muscle activation for several UE muscles during transfers and weight-relief lifts. In general, it may be expected that wheelchair-related ADL will result in higher shoulder loads compared to mere wheelchair propulsion. The purpose of this study was to determine peak glenohumeral reaction force during a weight-relief lift and steady-state submaximal wheelchair propulsion. Eleven men with spinal cord injury (SCI) (C6–T12) performed three subsequent weight-relief lifts and 1 min of wheelchair propulsion at 3 km/hr. External forces on the right handrim were measured with an instrumented wheel (based on a 6 df force transducer; AMTI, Watertown, Massachusetts, USA). Optotrak™ (Northern Digital, Canada) was used for 3D upper-body and wheelchair kinematics. Right arm and shoulder kinematics and the exerted forces were used as input for the Delft Shoulder/Elbow Model. Joint moments were studied as output variables. Differences in peak glenohumeral reaction forces among three weight-relief lifts and five pushes were evaluated with an analysis of variance for repeated measures ($p < 0.05$). Peak joint reaction forces during the lifts were $1370 \text{ N} \pm 405 \text{ N}$ (186% of body weight (BW)). Peak joint reaction forces for wheelchair propulsion were $319 \text{ N} \pm 97 \text{ N}$ (45% of BW). A weight-relief lift poses a significantly higher load compared to wheelchair propulsion ($p = 0.00$). No significant differences were found among the subsequent trials ($p = 0.465$) or the subsequent pushes ($p = 0.963$). Mean peak joint reaction force for weight-relief lifting exceeded $1350 \text{ N}$. This value is comparable to the contact forces calculated by Anglin for standing up from, and sitting down into a chair. In our study no distinction was made between subjects with high- and low-level SCI, i.e., no muscles were turned off or minimized (partially paralyzed) in the model. However, it is expected that the mechanical load of a weight-relief lift can be notably higher for subjects with high lesions than the mean values reported. Apart from a possible role of differences in kinematics, subjects with high lesions will require compensatory muscle activity that takes over the roles of paralyzed muscles. Peak mechanical load in the glenohumeral joint during weight-relief lifts in this study was found to be approximately 300 percent higher than that during submaximal wheelchair propulsion. These high loads in itself may be a risk factor for overuse of the upper-extremity joint. If they indeed lead to microtrauma, it is likely that no recovery occurs due to all-day and regular repetitive submaximal loading during wheelchair propulsion and every other ADL. It is likely that neither wheelchair propulsion nor weight-relief lifts alone are responsible for the overuse injuries, but that the combination of both forms of loading pose a combined high-risk factor.
6  START/STOP PUSHRIM FORCES OF MANUAL WHEELCHAIR USERS WITH PARAPLEgia

S. A. Sisto, M. Boninger, M. LaFountain, J. Wilen, T. Dyson-Hudson, G. I. Forrest

Human Performance and Movement Analysis Laboratory, Kessler Medical Rehabilitation Research and Education Corporation, West Orange, New Jersey; Human Engineering Research Laboratories, University of Pittsburgh, Pittsburgh Healthcare System, Pittsburgh, Pennsylvania, USA; Email: ssisto@kmrrec.org

Little research has been conducted on the start/stop forces applied to the pushrim of manual wheelchair users (MWUs) with spinal cord injury (SCI). Daily activities require MWUs to initiate or terminate wheelchair propulsion abruptly, placing undue shoulder stresses on individuals with paraplegia (IWP) that may already be compromised due to overuse. This study seeks to understand the pushrim forces during abrupt start/stop conditions during wheelchair propulsion of IWP. The hypotheses proposed are that there will be a relationship between (1) rate of rise of the resultant force during start/stop conditions and shoulder pathology and wheel acceleration, and (2) impulse (resultant force by time) during start/stop conditions and shoulder pathology and wheel acceleration. The resultant force variables were evaluated statistically accounting for age, body/wheelchair weight and arm length. We tested seven IWP (T3–L1), at least one year post-injury and with a mean age of 36.4, who used a manual wheelchair as their primary means of mobility, with no previous history of upper-limb trauma. Wheelchair wheels were removed and replaced with force-sensitive pushrims that measure the magnitude and direction of forces and moments exerted on the pushrim. Biomechanical testing was performed on a wheelchair dynamometer consisting of a pair of independent bilateral rollers. A software cueing program indicated when to start acceleration from rest to maximal speed for 5 s and when to perform a sudden stop. The average mass of participants was 83 kg and inclusive of wheelchair mass was 101 kg. Average arm length was 63 cm for the left arm. Assuming symmetry in propulsive kinetics, data are reported for the left wheel only. Kinetics data represent the first push phase only for the start of the cycle and the last contact phase for the stop component of the cycle. The average start rate of rise was 1622 N/s and the stop rate of descent was 3194 N/s. Start resultant rate of rise force was not correlated with X-ray abnormalities; however, when we accounted for age, there was a significant effect of X-ray abnormalities on the start resultant rate of rise ($p = 0.041$). Nonsignificant trends toward a linear relationship between start resultant rate of rise and shoulder MRI changes occurred. There was a significant effect of left shoulder MRI changes on stop resultant rate of descent force ($p = 0.05$). This relationship was not significantly influenced by age, body/wheelchair weight, or arm length. Impulse (work per unit time) initially or at the peak of the first push phase was not significantly related to shoulder pathology or wheel acceleration. The most significant impact of initiation of wheelchair propulsion (start) and termination of propulsion from a maximal speed (stop) on shoulder pathology appears to be the rate of rise/descent of the resultant force, particularly when we account for age for the X-ray findings. The radial force component appears to have a greater impact on the resultant rate of rise/descent than the tangential. Training paradigms that educate MWUs to initiate and stop wheelchair propulsion may aid in the prevention of shoulder pathology.
THE EFFECTS OF BACKREST ADJUSTMENTS ON KINEMATIC PARAMETERS PRODUCED DURING HANDCYCLE SPRINTING

A. Faupin, P. Campillo, S. Bouilland, A. Thevenon, P. Gorce, O. Remy-Neris
Laboratoire d’Etudes de la Motricité Humaine, Faculté des Sciences du Sport Et de l’Education Physique, Université de Lille 2, Ronchin, France with the Institut Garches–104, Garches; Centre J. Calve, Groupe Hopale, Berck sur mer; C.H.R.U. de Lille Service Médecine Physique et Réadaptation, Unité d’Analyse du Mouvement 2, Lille Cédex; Université Toulon et du Var, Faculté des Sciences du Sport, La Garde, France; Email: faupin.arnaud@wanadoo.fr

Even if handrim-propelled is the most developed mode of propulsion, it is nevertheless inefficient and very stressful to the musculoskeletal and cardiopulmonary systems. As an alternative mode of propulsion, the handcycle is based on simultaneous arm-crank propulsion. However, in contrast to handrim propulsion, few or no studies have been conducted in the kinematics of this mode of propulsion. In the search for the optimal handcycle regulation, the backrest angle is an important parameter to consider. The purpose of this study was to investigate the propulsion cycle of handbiking according to three backrest adjustments. Participating in the study were 7 able-bodied persons, 4 men and 3 women, (age 24 ± 2 years; weight 72 ± 15 kg; height 178 ± 84 cm). The subject was settled in the handcycle, which was fixed to a home-trainer. All subjects were asked to perform three 8 s maximal sprints in random order, according to the three following backrest adjustments: Pa = backrest tilted at 135°, Pb = backrest tilted at 113°, and Pc = no backrest (back at about 90°). Backrest angles were obtained with regard to the seat. Three-dimensional motion was recorded with the use of a VICON motion analysis system. During handcycle propulsion, this system uses 6 infrared cameras to track 14 retro-reflective markers placed on the right upper extremity and trunk of the subject. The upper part of the human body is considered as an articulated system composed of rigid bodies corresponding to the following body segments: trunk, arm, forearm, and hand. Euler’s angles were chosen to describe the relative movement of the body segments. For each parameter, a repeated measures Wilcoxon test was used to test for the differences between the three backrest adjustments. Kinematic data from all the trials were collected. We only took into account the last three cycles of the 8 s sprints, when the different variables to be calculated had stabilized and reached a plateau. The kinematic variables analyzed were the flexion/extension (F/E, in degrees) joint movement of the trunk (T), the shoulder (S), the elbow (E), and the wrist (W), the cycle of frequency which is the number of cycles per minute (Freq, in c/min.), and the mean velocity (V, in km/h–1). The main results show that V (21.5 ± 3.5, 22.7 ± 4.7, and 24.5 ± 4.6), Freq (120.6 ± 19.5, 127.8 ± 26.4, and 137.4 ± 25.8), and T (5.1 ± 2.3, 5.3 ± 2.3, and 10.0 ± 3.7), respectively, from Pa to Pb to Pc, are significantly more important without the backrest (Pc). These results tend to explain the fact that people with a good stability of the trunk generally do not have a backrest at their handcycle. It allows them to use the trunk during propulsion cycle and improve their performance. This leads us to believe that the use of the trunk is even more important during the start. In addition, during sporting events, the disabled with spinal cord injuries are nearly lying on their backs on their handbikes (backrest tilted at 135°); we suggest that such a position would allow them to have a best stability of the trunk.
WHEELCHAIR USAGE PATTERN: DOES AGE MATTER?
D. Ding, R. A. Cooper, S. G. Fitzgerald, R. Cooper, D. M. Spaeth, A. E. Hoover, M. Dvorznak
Department of Rehabilitation Science and Technology, University of Pittsburgh, and Human Engineering Research Laboratories, VA Pittsburgh Healthcare System, Pittsburgh, Philadelphia, USA;
Email: dad5@pitt.edu

The study examined the average distance traveled by people in wheelchairs and its relationship to age and years of wheelchair use. The research questions were as follows: (1) Does age and years of wheelchair use influence average distance traveled? (2) Is there a difference in wheelchair usage among manual and power wheelchair users? (3) Is there a difference in average distance traveled among power and manual wheelchair users with similar diagnosis? A total of 42 wheelchair users were recruited from Pittsburgh, of which 19 were manual users and 23 were power users. The participants ranged in age from 24 to 64, with a mean age of 41.4 ± 10.4 years for the manual wheelchair users and 44.3 ± 10.5 years for the power wheelchair users. The average years of wheelchair use was 14.5 ± 6.1 years for the manual group and 15.4 ± 9.0 years for the power group. The manual group included 6 subjects with tetraplegia, 12 with paraplegia, and 1 with multiple sclerosis. The diagnosis in the power group included tetraplegia 7, cerebral palsy 7, muscular dystrophy 3, and other 6. Data were collected with a data-logger attached to the participant’s wheelchair for 57 days. Spearman’s rho was calculated to determine correlations between average distance traveled, age, and years of wheelchair use. Mann-Whitney U tests were done on the average distance traveled, age, and years of wheelchair use to determine if there were significant differences between power and manual wheelchair usage. The significance level was a priori at an alpha less than 0.05. Analysis of the data showed a significant relationship ($p = 0.02$) for the average distance traveled. It was found that the manual group (1669.8 m/day) traveled less than the power group (2741.7 m/day). When separating the two groups, a significant difference ($p = 0.004$) was found in the manual wheelchair group for age and the average distance traveled. Data analysis for the power group showed no significant difference between age and years of wheelchair use in the average distance traveled by the group. Tetraplegia was found to be the only diagnosis, similar to both groups, with six subjects in the manual group and seven subjects in the power group. The subject population is similar in age distribution and years of wheelchair use. Subjects with tetraplegia in their manual wheelchairs traveled 1685.6 m/day and the subjects with tetraplegia in the power group traveled 2996.5 m/day. We found that, in the power group, subjects traveled further and that age was not a limiting factor. It appears that age has an effect on the manual wheelchair usage, in that the older subjects traveled less. Age-related symptom—such as pain, lack of endurance, and decreased strength that limits mobility associated with the functional self-propulsion of any type of manual wheelchair—has less effect on mobility when a power wheelchair is used. The study also revealed that the subjects with tetraplegia traveled further when in power wheelchairs than their manual wheelchair counterparts. One possible reason is that power wheelchair users may be more apt to use their chairs to go longer distances using a car.
9 WHEELCHAIR PROPULSION CAPACITY DURING REHABILITATION OF PERSONS WITH SPINAL CORD INJURY


Institute for Fundamental and Clinical Human Movement Sciences, Vrije Universiteit Amsterdam; Institute for Rehabilitation Research, Hoensbroeck; Rehabilitation Center Amsterdam; Rehabilitation Center De Hoogstraat, Utrecht; Rehabilitation Center Het Roessingh, Enschede, The Netherlands; Email: a.dallmeijer@fbw.vu.nl

Improving physical capacity during rehabilitation of persons with spinal cord injury (SCI) is important for achieving an optimal level of functioning in daily life and independent living. The maximal power output (PO\textsubscript{max}) that can be achieved in a maximal wheelchair exercise test is a functional measure of wheelchair propulsion capacity and a relevant outcome of physical rehabilitation in wheelchair-dependent persons with SCI. The purpose of this presentation is to describe the course of PO\textsubscript{max} during rehabilitation of persons with SCI, and to investigate the relationship of PO\textsubscript{max} with person and injury characteristics. Within the framework of a Dutch multicenter prospective cohort study, 132 subjects with SCI (37 with tetraplegia) were investigated at the start of active rehabilitation (t1), 3 months later (t2) and at the end of clinical rehabilitation (t3). PO\textsubscript{max} was measured in a maximal wheelchair exercise test on a treadmill in subjects who were able to propel a handrim wheelchair. Results were analyzed with the use of generalized estimating equations (GEE) with time of measurement, lesion level, motor completeness of the lesion, age, and sex as independent variables. The GEE method takes into account the dependency of repeated measures within one person and allows a variable number of observations per person, thus increasing statistical power. Significant coefficients of time of measurement indicated that overall mean PO\textsubscript{max} increased from 30.5 W at t1 to 39.5 W and 44.2 W at t2 and t3, respectively. All investigated variables were significant determinants of PO\textsubscript{max} during rehabilitation: persons with paraplegia, incomplete lesions, male persons, and younger persons showed larger values for PO\textsubscript{max}. Age and sex showed significant interaction effects with time, indicating that improvements during rehabilitation were smaller in older persons, as well as in females. Discussion PO\textsubscript{max} is an important outcome measure in wheelchair-dependent persons with SCI during (and after) rehabilitation. In contrast to other fitness parameters, such as the maximal oxygen uptake, PO\textsubscript{max} is a functional measure that gives an indication of the wheelchair performance in daily life. Results suggest that wheelchair training should get more attention in persons with specific characteristics (i.e., older persons and females) in order to reach optimal improvements in wheelchair capacity and avoid a loss of independence. Evaluation of individual improvements in wheelchair capacity during rehabilitation is therefore crucial. Other studies also showed that training and rehabilitation programs could improve physical capacity in persons with SCI. Previous studies also indicated that an improved physical capacity seems to be related to a higher functional ability and a reduction of health-related problems. This study shows the potential for improvements in wheelchair propulsion capacity during rehabilitation, and identifies factors that affect the level (lesion level, completeness, age, sex) and rate of improvement (age, sex) in wheelchair capacity during rehabilitation. These factors should be taken into account when applying wheelchair capacity training in SCI rehabilitation.
10 THE WHEELCHAIR SKILLS PROGRAM: EVOLUTION OF TESTING AND TRAINING PROTOCOLS


Division of Physical Medicine and Rehabilitation, School of Health and Human Performance, School of Occupational Therapy, Department of Engineering Statistics, Dalhousie University; Department of Occupational Therapy, Department of Physiotherapy, and Clinical Locomotor Function Laboratory, Nova Scotia Rehabilitation Centre Site, Queen Elizabeth II Health Sciences Centre, Halifax, Nova Scotia, Canada; Email: kirby@dal.ca

This study was to develop and evaluate a set of testing and training protocols for manual wheelchair skills. Since 1995, we have been developing the Wheelchair Skills Program (WSP), which is comprised of the Wheelchair Skills Test (WST) and the Wheelchair Skills Training Program (WSTP). Development has taken place in an iterative fashion, formally evaluating the measurement properties of the WST and carrying out controlled trials of WSTP efficacy. To date, we have studied 504 people (210 wheelchair users, 25 caregivers, 82 occupational-therapy students, and 187 other able-bodied subjects), many of them on two or more occasions. There have been no serious adverse incidents during WST testing or WSTP training. The reliability of the WST has been excellent and the validity very good to excellent. The WST is a robust tool that can be used in a formal obstacle-course setting or in the community. The total scores of questionnaire versions of the WST (WSTQ) have correlated well with the objective scores. The WSTP has been efficacious in improving the wheelchair skills of wheelchair users, caregivers, occupational therapy students, and able-bodied participants. On the basis of the studies to date, the WSP was upgraded to the 58-skill Version 3.0 in November 2003. These protocols are posted on our website, www.wheelchairskillsprogram.ca. The WSP remains a work in progress. However, the evidence accumulated to date suggests that the WST is a reliable and valid testing tool and that the WSTP is an efficacious intervention.

11 RESTORATION OF THE LEVEL OF EVERYDAY PHYSICAL ACTIVITY DURING SPINAL CORD INJURY REHABILITATION: PRELIMINARY RESULTS


Department of Rehabilitation Medicine, Erasmus Medical Center, Rotterdam, The Netherlands; Rijndam Rehabilitation Center, Rotterdam; Institute for Fundamental & Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam; Rehabilitation Center, Amsterdam, The Netherlands; Email: h.j.g.vandenberg@erasmusmc.nl

Patients with a spinal cord injury (SCI) are at risk of developing a hypothalamic lifestyle, which may have detrimental effects on physical fitness, participation, quality of life, and the development of secondary health problems (coronary heart disease, diabetes). The purpose of this study was to assess the restoration of the level of everyday physical activity during SCI rehabilitation, as measured with an activity monitor (AM). The AM is based on long-term ambulatory monitoring of signals from body-fixed accelerometers during everyday life, aimed at the assessment of mobility-related activities. Measurements with the AM were performed during two consecutive week days at the beginning of the rehabilitation process (T1: measurement in rehabilitation center, the patient can sit in wheelchair for 3 to 4 hours), at discharge from the rehabilitation center.
(T2: measurement in center), and 2 months after discharge (T3: measurement at home). The results in 5 patients (3 men, 2 women) who were completely dependent on a handrim wheelchair will be presented. Mean (±SD) age of the patients was 38 (±17) years; lesion levels ranged from C6 to L2; ASIA impairment scale was A: n = 3, B: n = 1, C: n = 1. Mean (±SD) duration of dynamic activities (composite measure of wheelchair-driving and general movement; calculated as percentage of the duration of the measurement day) tended to increase from 5.1 (±2.0) percent at T1 to 6.7 (±2.5) percent at T2 (ns); corresponding with an increase of 23 min per day. Body motility (intensity of everyday movement) tended to increase from 0.007 (±0.002) g to 0.010 (±0.006) g (p = 0.08), while motility during wheelchair-driving (intensity of wheelchair-driving) significantly increased from 0.027 (±0.008) g to 0.037 (±0.015) g (p = 0.04). In the three patients who also performed measurements in the home situation (T3), there was a strong tendency to decline from T2 (8.0 [±2.5] %) to T3 (3.2 [±1.8] %) (ns). These preliminary results imply that the level of everyday physical activity of patients with SCI improves during their stay in the rehabilitation center. However, the level of everyday physical activity as achieved in the rehabilitation center may decline after discharge. Future analyses in a larger group of patients (n = 40) and after a longer period after discharge (1 year) will have to confirm these preliminary results.

**12 LONGITUDINAL DEVELOPMENT OF MANUAL WHEELCHAIR SKILL PERFORMANCE DURING INPATIENT REHABILITATION OF PERSONS WITH A SPINAL CORD INJURY: ASSOCIATIONS WITH SUBJECT CHARACTERISTICS, LESION CHARACTERISTICS, SECONDARY COMPLICATIONS, AND COMORBIDITY**


Institute for Rehabilitation Research, Hoensbroek; Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam; Rehabilitation Center Amsterdam; Vrije Universiteit Medical Center, Amsterdam, The Netherlands; Email: olga.kilkens@irv.nl

This study measured the development of manual wheelchair skill performance in subjects with spinal cord injury (SCI) during inpatient rehabilitation to determine whether subject characteristics, lesion characteristics, secondary complications, and comorbidity influence the development of wheelchair skill performance during rehabilitation. Within a Dutch multicenter prospective cohort study, subjects with SCI were measured at the start of rehabilitation (T1), three months later (T2), and at the time of discharge (T3). During each measurement they performed the wheelchair circuit: a test consisting of eight different standardized tasks to assess manual wheelchair skill performance. The tasks of the circuit are a figure-eight shape, crossing a doorstep (0.04 m), mounting a platform (0.1 m), 15 m sprint, 3 percent slope, 6 percent slope, 3 min wheelchair propulsion, and a transfer. The performance of the wheelchair circuit leads to three test scores: ability score, performance time score (s), and the physical strain score (%HRR). Subject characteristics (age, gender, and body mass index [BMI]), lesion characteristics (level and completeness), secondary complications (prescribed bed rest and upper extremity pain), and comorbidity were used as independent variables. Multilevel regression analyses with three hierarchical levels (measurement, subjects, rehabilitation
center) were performed. All test scores improved significantly between T1 and T2 ($p < 0.01$). The performance time score was the only score that also showed a significant improvement between T2 and T3 ($p < 0.05$). Age, lesion level and motor completeness of the lesion were significantly related to the ability score. There was a significant interaction between BMI and dummy 1, indicating that between T1 and T2 subjects with a lower BMI improved more than subjects with a higher BMI. The interaction between lesion level and dummy 2 was significant, showing that between T2 and T3, subjects with tetraplegia improved more than subjects with paraplegia. There was a significant interaction between bed rest and dummy 1, demonstrating that between T1 and T2 subjects that had not been prescribed bed rest improved more than subjects that were prescribed bed rest. Age and lesion level were significantly related to the performance time score. There was a significant interaction between lesion level and dummy 2, showing that between T2 and T3, subjects with tetraplegia improved more than subjects with paraplegia. Lesion level and motor completeness of the lesion were significantly related to the physical strain score. There was a significant interaction of BMI and dummy 2, indicating that between T2 and T3, subjects with a higher BMI improved less than subjects with a lower BMI. There was a significant interaction between motor completeness of the lesion and dummy 1, showing that between T1 and T2, subjects with complete lesions improved more than subjects with incomplete lesions. The largest improvements in wheelchair skill performance occurred during the first three months of rehabilitation. The independent variables that had the most influence on the development of wheelchair skill performance over time were age, BMI, lesion level, and completeness of the lesion.

13 FUNCTIONAL TESTS IN WHEELCHAIR PERFORMED BY PERSONS WITH THORACIC SPINAL CORD INJURY BEFORE AND AFTER A 10-WEEK PERIOD OF KAYAK ERGOMETER TRAINING

A. Bjerkefors, A. Thorstensson
Department of Neuroscience, Karolinska Institutet and Department of Sport and Health Sciences, University College of Physical Education and Sports, Stockholm, Sweden;
Email: anna.bjerkefors@ihs.se

Our purpose was to study the effects of a 10-week period of kayak ergometer training on functional tests performed in the wheelchair by persons with thoracic spinal cord injury. Ten persons with spinal cord injury ranging from T3 to T12 performed 30 sessions, 60 min each, of supervised kayak ergometer training, 3 times per week during a 10-week period. The kayak ergometer was modified with a special seat and an additional balance demand in the mediolateral direction. The balance demand was progressively adjusted to each person's ability to balance the upper body during the paddling movement. Moreover, the resistance and intensity of the sessions were gradually increased during the training period. Before and after the training period, the subjects performed different functional tests in the wheelchair: sit and reach tests, with both unilateral and bilateral arm movements, straightforward and rotated 45° to the side (maximal distance); transferring from the wheelchair to a plank bed (maximal height); propelling the wheelchair 5 m on the rear wheels in forward and backward directions (time); propelling over a curb (maximal height); propelling five laps in a figure eight around two cones placed 3 m apart (time); and propelling 15 m on a level surface (time) and 50 m on a 3° inclined surface (time). In all sit and reach tests, there were significant improvements after training. The average increase was 4.8 cm (14%). There were also significant improvements in height of transferring from the wheelchair to a plank bed (3.3 cm, 4%), propelling over a curb (1 cm, 7%), propelling 15 m on level surface (0.19 s,
and propelling 50 m on inclined surface (1.06 s, 6%). In propelling the wheelchair on the rear wheels in a forward or backward direction and in a figure eight, there were no statistical differences with training. All but two persons improved their ability to reach forward and sideways during the sit and reach test. These two persons had the lowest injury level and the best results from the test before training. In the transferring test and in the wheelchair propelling tests, 8 to 10 persons improved their results. These positive findings are even more conspicuous considering that all persons had several years of experience (226, mean 13) in these activities. Moreover, training on the kayak ergometer did not cause any shoulder pain, and preliminary results from shoulder strength measurements also indicate improvements after training. Kayak ergometer training improved the functional performance of persons with a spinal cord injury in sit and reach, wheelchair propulsion, and transferring tasks. This type of training can therefore be recommended as a suitable activity in rehabilitation and recreation for spinal cord injured persons.

14 DESIGN OF A TEST-AND-TRAINING TRICYCLE FOR PARAPLEGICS

W. Reichenfelser, M. Göhler, T. Angeli
Institute for Machine Elements and Machine Design, Vienna University of Technology, Austria;
Email: wrechenels@www.imel.tuwien.ac.at

Functional electrical stimulation (FES) of the lower limbs is an important supporting therapy for paraplegic persons. Numerous studies indicate the patients’ physiological benefits, ranging from an improvement of the cardiovascular condition and the pulmonary systems [1,2] to an increase of the lower limb circulation, a reduction of muscle atrophy, and a rise of bone density [3]. This study aims to increase the attraction of FES exercise for paraplegics with cycling ergometers [4] and specially designed cycles for outdoor use [5–8]. The instrumented tricycle for paraplegics described herein is adjustable to individual subjects and can be used as a stationary test bed as well as a training devise for outdoor use. The basic frame of the vehicle is that of a commercially available tricycle. To guarantee its functionality as a test bed for cycling, a main requirement was the easy adjustability of the essential geometric parameters, which was realized by several adaptations. To adjust the crank position in relation to the hip, the crank axis can be easily varied in its vertical (due to a spindle construction) and horizontal positions. The inclination of both the seat—in a range of 20°—and the backrest—in a range of 28°—can be adjusted as well. A motor installed in the hub of the back wheel serves as a pace-keeping or braking element during the isokinetic tests and enables a passive pedaling mode. For paraplegic cycling, specially designed orthoses are mounted on the pedals, which keeps the legs of the paraplegic in the sagittal plane. The hinge joints of the orthosis allow plantar and dorsal flexion of the foot. An implemented potentiometer works as an angle encoder, indicating the ankle angle during cycling. If needed, the ankle can easily be fixed at a given angle position. The control of the FES is done by a program written in LabView 6.1, which is communicating via serial port with the measurement devices and a 10-channel current-controlled stimulator [9]. The control panel offers the possibility to choose the range, the current ramp, and the amplitude of the stimulation for each muscle. Also, general parameters such as stimulation frequency, pulse length, and the motor mode can be varied via the control screen. After a test run, the data of pedal forces and power output are automatically processed and shown as graphs for analyzing. With this tricycle and the stimulation control, we have prepared a compact system that can be used for individual optimization of stimulation patterns for pedaling and that is also equipment for regular outdoor FES cycling. A test series is planned in a rehabilitation center where the optimum stimulation and the best geometric settings for several paraplegics are investigated.

References

2. Janssen TWJ, Glaser RM, Shuster DB. Clinical efficacy of electrical stimulation exercise...


15 MOBILE CYCLING FOR PEOPLE WITH SPINAL CORD INJURY USING FUNCTIONAL ELECTRICAL STIMULATION: A CASE STUDY

K. J. Hunt, B. A. Saunders, R. Sutherland, S. Grant, A. N. McLean, M. H. Fraser
Centre for Rehabilitation Engineering, University of Glasgow, Centre for Exercise Science and Medicine, University of Glasgow, and Queen Elizabeth National Spinal Injuries Unit, Southern General Hospital, Glasgow, UK; Email: k.hunt@mech.gla.ac.uk

We describe a system for mobile, recreational cycling for people with spinal cord injury (SCI), powered by functional electrical stimulation (FES) of the paralyzed lower-limb muscles. The approach has been used with many subjects, but is described here in the form of a case study, which describes the progression of one SCI subject from initial recruitment and assessment, baseline health measurements, to a muscle conditioning regime, and then to a progressive program of cycle training. A commercially available recumbent tricycle is adapted for FES-induced lower-limb cycling. Pairs of surface electrodes are attached to each of six muscle groups, i.e., the left and right quadriceps, hamstring, and gluteal muscles, which are activated appropriately. The stimulation intensity can be varied by the cyclist with the use of a “throttle” integrated in the handgrip, and in this way the cycle cadence is controlled. This self-contained FES system can be used for mobile cycling, but can also be mounted on a cycle trainer for indoor exercise and training sessions. An initial cycle test revealed that the subject was able to do unloaded cycling on the trainer for approximately 5 min, but he was unable to propel the cycle for mobility. He then carried out a program of muscle strengthening at home, during which the quadriceps and hamstring muscle groups were stimulated with the subject in a seated position. This was done every second day for up to 1 h per session. After three months, the subject underwent a cycling test and was able to cycle for 20 min at an initial power output of 15 W, which decreased to 11 W at the end of the session. At this time he began a program of cycle training. An FES tricycle system was installed at his home, and he initially cycled for 20 min, three times per week, at a power output of up to 15 W. The training stimulus was then progressively increased, by increasing both the duration of exercise and the exercise intensity. We will report on the progression in power output for this subject, and the speed and distance he is able to cover during mobile cycling. The metabolic efficiency of FES cycling is significantly lower than that for normal subjects. We note that (1) cycle exercise induces useful cardiopulmonary responses, and corresponding fitness improvements, so that, for static cycle ergometry and fitness training, low efficiency is not a limitation; and (2) the power output achieved by a typical SCI cyclist is sufficient to provide propulsion for mobile cycling, but efficiency optimization remains an important goal. Mobile cycling with FES is an attainable goal.
for people with SCI who carry out regular training sessions. We have reached an agreement with our City Council for access to safe cycling areas within local public parks and a recreation hall at a leisure center. We will report on our subject’s experience in using these facilities for FES cycling. We believe that this provides a good model for encouraging the use of FES cycling within the general SCI population.

16 SMOOTH PEDALING OF THE PARAPLEGIC CYCLIST—A NATURAL OPTIMALITY PRINCIPLE FOR ADAPTATION OF TRICYCLE AND STIMULATION TO THE RIDER

J. Szecsi, M. Fiegel, S. Krafczyk, A. Straube
Department of Neurology, LMU–Munich, Munich, Germany;
Email: JSzecsi@nefo.med.uni-muenchen.de

For paraplegic FES cycling to achieve both the known medical benefits and useful outdoor distances, training must be intensified and extended from clinics to the home environment. Questions arise as to how to achieve the best match between the individual patient and the technically very diverse devices, including finding out whether a patient can drive a certain available cycle, and, if not, which muscle(s) could be responsible; and, further, which cycle would be the optimal one for the patient, or what would be the best geometrical setup and stimulation pattern. To tackle these problems, we propose a practical (i.e., reasonably simple) and physiologically meaningful model based on the presumption of uniform angular speed of the crank (smooth pedal stroke). To cover a broad range of geometries, three commercially available tricycles (OVG, Rowedder, Speedy) and a MotomedViva Ergometer were provided with shaft encoders for crank-angle measuring, handle-bar throttles for stimulation intensity control, and orthoses for leg fixation. We stimulated the muscle group’s quadriceps, gluteus, and hamstrings. Six completely paraplegic subjects with spastic lesions (Th5–Th10) volunteered for the measurement and cycling session. After removing the front wheel of the OVG tricycle, we coupled the crank to an ATI six-component sensor by means of a chain, thus converting the tricycle into a torque-measuring test bed. In this way, isometric moment/angle characteristics were obtained for each muscle group. By subtracting the bias in each angle position, the active isometric moment/angle characteristics of every muscle group due to pure stimulation were obtained (drive profile). The bias itself represents the isometric torque caused by gravitational and joint-elastic effects. Computing the gravitational component isolates the elasticity. Regarding the highly nonlinear rider/tricycle system particularly as a one-degree-of-freedom, closed-loop linkage with fixed trajectory (uniform crank rotation), we have a linear relationship analogous to the obviously isometric summation rule of the muscle torques. The muscle coefficients can be regarded as load profiles of the respective muscles, and each cycle can be described by a set of such coefficients. These coefficients merge at 40 rpm giving a unique load profile. Comparing the load profiles with the isometric sum of active muscle torques (drive profiles) clearly shows the drive possibilities in a given situation. Amplitude deviation and phase shift from the load profile lead to non uniform pedaling (beating). Cycling experiments on the ergometer against constant load (1, 2, and 3 Nm) show that aside from the load and drive profiles, the (rotation) speed of the crank and beating of the speed can be reasonably well predicted. Cycling experiments on three tricycles demonstrate that starting from load/drive profiles, it is a possible to select an optimal tricycle from the viewpoint of smoothness of pedal stroke. We clearly established a physiologically based matching system starting from load and drive-profile considerations. To predict distance covered or power, further investigations should include fatigue models.
EFFECT OF RELEASING THE ANKLE JOINT ON FES CYCLING

M. Gföhler, A. J. van Soest, L. J. R. Casius

Institute of Machine Elements, Vienna University of Technology, Austria; Institute for Fundamental and Clinical Human Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands; Email: margit.gfoehler@tuwien.ac.at

Cycling by means of functional electrical stimulation (FES) is an attractive training method for individuals with paraplegia. The physiological benefits of FES [1] are combined with the psychological incentive of independent locomotion. Usually the ankle joint is locked by an orthosis for paraplegic cycling. Alternatively, the ankle joint can be released and controlled by stimulation of the ankle plantar and dorsiflexors. Compared to cycling with a fixed ankle, a 25 percent higher muscle mass is activated for a free ankle, and improvement of blood circulation and reduction of atrophy of the muscles, bones, and passive cartilages in the lower legs are likely. However, by the additional degree of freedom, the control problem is aggravated [2]. In this study, the effects of releasing the ankle joint on drive power output and overcoming the dead center is addressed. Additionally, the influence of muscle strength of the ankle plantar and dorsiflexors and the position of the pedal axis with respect to the ankle joint is investigated. A model for healthy cycling [3] was adapted for paraplegic cycling on a recumbent cycle [4]. Simulations with locked and released ankles were performed. For the released ankle, the effective foot length (distance ankle joint-pedal axis) was varied. In the simulations with locked ankle, quadriceps, glutaeus maximus, and hamstrings were stimulated; for the released ankle, also the triceps surae and tibialis anterior. Maximum isometric muscle forces were scaled and time constants for activation and deactivation adjusted to measured values [5]. Stimulation patterns were optimized for maximum power output for isokinetic cycling, with the use of a parallel genetic algorithm [6]. The results show that for 45 rpm cycling, the average drive power output for fixed ankle is 90 W. For a released ankle and standard foot length of 0.165 m, power output dramatically decreases to 40 W. For a foot length of 0.11 m, power output is 86 W, which increases to 103 W for 0.055 m. The lowest total drive torque at the dead center is 2.8 Nm for the fixed ankle, which increases to 3.3 Nm for free ankle and foot length 0.055 m. The simulation results indicate that besides expected physiological advantages, releasing the ankle joint in FES cycling combined with adaptation of geometrical parameters may lead to a slight increase of drive power output and may slightly facilitate overcoming the dead center. In order to profit from release of the ankle joint, the effective foot length has to be fine-tuned to the strength of the ankle plantar and dorsiflexors.

References
2. [CD-ROM.] Soest AJK, Ruina A. Maximal cycling power can be slightly increased by constraining leg kinematics. Proc 4th World Congress on Biomechanics, Calgary 2002.
18 EFFECTS OF 4 WEEKS TRAINING WITH A HYBRID FES CYCLE ERGOMETER IN SPINAL CORD INJURED INDIVIDUALS

D. Thijssen, P. Heesterbeek, J. Duysens, M. Hopman
Department of Physiology, University Medical Center Nijmegen, Nijmegen, Sint Maartenskliniek Research, Nijmegen, The Netherlands; Email:d.thijssen@fysiol.umcn.nl

Previous studies reported that vascular adaptations in the legs of spinal cord injured (SCI) individuals are reversible by functional electrical stimulation (FES) training. Training with a hybrid system (the BerkelBike), exercising both arms and legs, may even be more advantageous for vascular remodeling. This study assessed adaptations in vascular function in SCI individuals after 4 weeks of hybrid FES training. In 10 SCI individuals (age 39 ± 9 years), forearm, calf and thigh blood flow (BF), reactive hyperemia (RH), and vascular resistance (VR) were measured by venous occlusion plethysmography at baseline and after 4 weeks of hybrid FES training. SCI individuals trained 8 to 10 times in 4 weeks with the BerkelBike. This is a mobile FES cycle and arm ergometer that can be used by SCI subjects at home and outdoors. BF and RH were measured 5 min before and immediately after 13 min of ischemia (with supra-systolic pressure of 220 mmHg), respectively. VR was calculated as mean arterial pressure (MAP) divided by leg blood flow. Mean and minimal VR were calculated from auscultatory and Finapres MAPdata, respectively. Thigh and forearm BF increased from 2.3 ± 0.9 to 3.3 ± 1.2 ml/100 ml tissue/min and 2.1 ± 0.9 to 2.7 ± 1.3 ml/100 ml tissue/min, respectively (paired t-test, $p < 0.01$ and $p < 0.05$). Calf BF remained unchanged (3.2 ± 1.7 vs. 3.5 ± 1.5 ml/100 ml tissue/min). Thigh RH increased from 14.6 ± 2.2 to 16.6 ± 3.9 ml/100 ml tissue/min after training ($p < 0.05$). Calf and forearm RH did not change after training. Thigh mean VR showed a significant decrease from 44 ± 27 to 30 ± 12 units of resistance (UR) (mmHg/ml/100 ml tissue/min) ($p < 0.01$). Forearm and calf mean VR showed no change (37 ± 17 to 29 ± 11 UR and 50 ± 25 to 38 ± 18 UR, respectively). Forearm, calf, and thigh minimal VR did not change. The absence of calf vascular adaptations after 4 weeks of hybrid FES ergometry may be explained by the fact that calf muscles were not directly stimulated during the training. In contrast, the thigh muscles, which were highly deconditioned before training and stimulated during training, showed the most pronounced vascular adaptations. The forearm, although not deconditioned before training, did demonstrate an enhanced basal BF as a result of training on the BerkelBike. We found vascular adaptations after 4 weeks (9 ± 1 session) of hybrid FES cycling that were only slightly less from vascular remodeling after 6 weeks (18 sessions) FES leg cycling exercise, maybe as a result of increased intensity of hybrid training when exercising both arms and legs. The results of this study indicate that 4 weeks of training with a hybrid system already leads to pronounced vascular readjustments, mainly in the exercising muscles, i.e., the thigh and arms.

19 FUTURE TREATMENT STRATEGIES IN SCI REHABILITATION: RECOVERY OUTCOME, MECHANISMS, AND MEASURES

J. F. Ditunno
Regional Spinal Cord Injury Center of Delaware Valley, Jefferson Medical College, Rehabilitation Medicine, Philadelphia, Pennsylvania, USA; Email: John.Ditunno@Jefferson.edu

This study demonstrates that future treatment strategies in spinal cord injury (SCI) rehabilitation to restore function should be based on success of rigorous clinical trials with demonstrated effective interventions. To appreciate the knowledge of the course of neurological recovery, their mechanism and measures will be essential to the design and execution of these trials. The study reviewed selected recovery outcomes and measures from multicenter studies and a large SCI data base. The accuracy of baseline examinations in the first days following injury is critical to the demonstration of changes in neurological recovery. Recovery of one neurologic level in subjects with tetraplegia depends on severity, initial level of the injury, and the strength of muscles below the level of injury. Motor recovery of the upper extremities typically correlates with self-care function.
Neurological recovery following SCI often correlates with increased function and walking, in addition to self-care. In subjects with paraplegia, prediction of recovery of walking is possible based on the initial one-week sensory and motor examination. Although initial neurological findings correlate with neurological and functional recovery outcomes in large populations of 3,500 subjects reported by the Model SCI Center in the U.S., improved outcome measures for walking are needed. The Walking Index for Spinal Cord Injury (WISCI) has recently demonstrated criterion validity and increased sensitivity and responsiveness to change in neurological/walking function in subjects with SCI. The Randomized Clinical Trial on Body Weight Support training reported on several measures for use to determine improved walking function and the WISCI scale correlated well with walking speed, lower extremity motor scores, and other measures [1]. Early intervention strategies should be based on ideal timing to maximize neural plasticity. The demonstration of improved neurologic and functional outcomes following SCI requires accurate neurologic and sensitive functional measures.

Reference

**WEDNESDAY 21 APRIL**

1 PARTICIPATION AND MOBILITY: WHAT ARE THEIR ACTUAL RELATIONSHIPS THROUGHOUT THE DISABLEMENT PROCESS?

L. Noreau

Rehabilitation Department, Laval University, Center for Interdisciplinary Research in Rehabilitation and Social Integration Québec, Canada;

Email: Luc.Noreau@rea.ulaval.ca

Over the last decades, some components of the disablement process have achieved a good level of clinimetric properties based on solid constructs. However, participation has not reached such a level of measurement, and it deserves much more attention in order to clarify its underlying constructs. An appropriate conceptualization of participation remains essential, a prerequisite to the understanding of the associations with the other components of the disablement process. It is even more crucial as participation is becoming a central outcome of a successful rehabilitation, and it is the factor that seems to have the greatest contribution to the subjective quality of life compared to body function and structure or activities. The literature reports various ways to measure participation that essentially refer to a society-perceived vs. a person-perceived approach of participation (formerly called handicap). The former is mostly based on a quantitative measure (number of times, hours, etc.), while the latter further refers to the quality of a person’s involvement in life situations (perceived difficulty, possibility of carrying out activities). These recent advances in the conceptualization of participation have brought about some questions about the availability of measurement tools that have a good fit with the International Classification of Functioning and Disability (ICF) definition of participation and a majority of its related domains. These advances require the development or refinement of tools that properly address the concept of participation. Actually, a tool that assessed the concept of handicap may not be valid anymore based on the new conceptualization and, not surprisingly, two instruments developed a decade apart to assess similar concepts may have a low level of association (convergent validity) in many of their subdimensions. Mobility, which appears to be used as an umbrella term, may be defined as the ability to physically move about, especially to do work or take exercise. Such a term is difficult to operationally define (or to state clearly), particularly as it is used in all components of the ICF: body function (mobility of joint and bone functions) and activity participation (general domain of mobility). In terms of measurement and construct, the latter is particularly confusing, as it can include, under the same appellation, elements such as maintaining a body position, transferring oneself, walking, and using transportation or driving,
which basically are issued from distinct constructs and therefore may be measured by totally different instruments. A scientifically sound approach of measurement requires that concepts be mutually exclusive, belonging to precise and distinctive domains. A recent study suggests that there exists two "dimensions" into the activity-participation domain. The preceding pieces of information show that the determination of the actual associations between the restoration of mobility and participation should be made with caution and the first issue is to establish what domains of participation, measured from a quantitative or a qualitative approach, are likely be influenced by the enhancement of mobility. Over the last three decades, many studies reported a potential association between exercise, physical activity, training, and some ICF components (body structures and functions) following spinal cord injury. Several of these reports led to conclusive findings. However, only a few attempts were made to determine the association with the other dimensions of the disablement process (activity participation) and, despite significant studies since the early 1990s, there is a paucity of authoritative reports on this topic. In the presence of complex interaction between personal (intrinsic) and environmental (extrinsic) factors, the determination of actual associations between the enhancement of mobility and participation after spinal cord injury may require the use of complex statistical models, taking into account the other dimensions of the disablement process.

2 PARTICIPATION AFTER SPINAL CORD INJURY: RESULTS OF A VOCATIONAL AND LEISURE OUTCOME STUDY


Center for Rehabilitation, University Hospital Groningen, Northern Centre for Health Care Research, University of Groningen, The Netherlands; Email: m.c.schonherr@beatrixoord.nl

This study seeks to gain insight into the changes in participation in vocational and leisure activities of people with spinal cord injury (SCI) after reintegration in society. The study design was a descriptive analysis of data gathered by a mailed questionnaire, which was returned by 57 individuals (response 83%) with traumatic SCI, aged 18 to 60 years, admitted to a Dutch rehabilitation center with a special department for patients with spinal cord injuries, from 1990 to 1998. Participation, expressed in terms of hours spent on vocational and leisure activities, changed to a great extent after the SCI. This was mainly determined by a large reduction of hours spent on paid work. While 60 percent of the respondents currently have a paid job, many changes took place in the type and extent of the job. Loss of work was partially compensated with domestic and leisure activities. Sports activities were reduced substantially. The change in participation level and compensation for the lost working hours was not significantly associated with the level of work-related disabilities or SCI specific health problems. As was found in other studies, most respondents were satisfied with their lives. Reduced quality of life was particularly related to unsatisfactory work and leisure situations. Changes in participation after SCI are mainly explained by reduction of working hours. Focus on the vocational and leisure situation after the rehabilitation period might enhance a satisfactory participation. Information about the unmet needs during the reintegration process can help professionals to guide people with SCI through the complex reintegration procedure.
Rehabilitation of immigrants after spinal cord injury (SCI) is hampered by specific problems [1]. This study seeks to gain insight into the backgrounds of these problems during SCI rehabilitation. Immigrants are people who are born (or were at least one of their parents) in Turkey, Asia (Indonesia and Japan excluded), Africa, or Latin America (definition from the Dutch central statistical institute, CBS). Specific interest goes to immigrants from Turkey and Morocco. The purpose of the study was to (1) gain insight in characteristics of immigrants with SCI in The Netherlands, (2) increase the scientific understanding of the rehabilitation process after SCI for immigrants compared to Dutch patients and for patients compared to professionals, and (3) gain insight in significance of independence and societal integration as experienced by immigrants compared to Dutch patients with SCI. A search was conducted of the medical files of immigrant patients with SCI in all rehabilitation centers in The Netherlands with a specialized SCI unit. In-depth interviews were conducted with immigrants and Dutch patients with SCI about experiences with rehabilitation, experiences with their disability, and their views on the significance of independence and societal integration. In-depth interviews were also conducted with professionals about their views on rehabilitation and their experiences with immigrant patients. Analyses of these interviews was conducted with computer-assisted qualitative data analysis software (Atlas.ti). Patients and professionals have different views (explanations) on injury, appropriate treatments, and treatment aims. Failing to notice and discuss these differences leads to bottlenecks in the rehabilitation process [2]. Bottlenecks are ascribed to cultural aspects in the case of ethnic differences between the patient and the professional, which makes them difficult to resolve. So far, phase 1 of this study is complete, and phases 2 and 3 are ongoing. In three years time, 81 patients with SCI with a non-Dutch background were discharged from rehabilitation. This is 6.8 percent of the population in all participating rehabilitation centers, compared to 9.9 percent of immigrants in the Dutch population as a whole. Most immigrants come from Turkey, Morocco, Suriname, and the Dutch Antilles (traditional groups of immigrants for The Netherlands). Demographic and injury related characteristics are similar to figures of the general SCI population [3]. In 75 percent of the cases, communication in Dutch or English was sufficiently possible during rehabilitation. After rehabilitation 53.2 percent lived independently and 27.8 percent lived with their families. Professionals had low expectations about reintegration to a labor situation for immigrant patients. In 55.7 percent of the cases, no return to work was expected; for women, this figure was even higher, 88.2 percent. Discussion from the medical files give some preliminary information about rehabilitation of immigrants with SCI. The group is similar with respect to demographic and injury-related characteristics. Language problems are prominent in only a minority of the cases. However, integration into a labor setting is seen by professionals as a problem. Current interviews must give insight into the rehabilitation process for immigrants with SCI.

References
To date, the duration of initial clinical rehabilitation of persons with SCI in The Netherlands is mainly determined by medical considerations, and financial reasons are of minor importance. Maybe for this reason, the duration of initial inpatient rehabilitation in The Netherlands, despite a considerable reduction in recent years, appears long compared to international figures. The aim of the current study was to describe the duration of initial clinical rehabilitation and the functional gains during this period. This study is part of a research program: Physical strain, work capacity and mechanisms of restoration of mobility in the rehabilitation of individuals with spinal cord injuries. The “umbrella project” within this program is a prospective cohort study in which persons with SCI are included who are in initial clinical rehabilitation, are between 18 and 65 years old, and are expected to remain at least partly wheelchair-dependent. Measurements are at the start of functional rehabilitation when the person is just able to sit in a wheelchair for 3–4 hours (T1), three months after T1 (T2) and at discharge (T3). Measures used in this study are level and completeness of injury as determined by American Spinal Injury Association (ASIA) criteria, demographic characteristics (age and gender), and functional ability as measured with the use of the Functional Independence Measure (FIM). Data of 134 persons from 8 specialized rehabilitation centers were available. 71.6 percent were male and mean age was 40.2 years. The majority (69.9%) had a motor-complete injury (ASIA A or B), and 38.6 percent had tetraplegia. Etiology of injury was traumatic for 73.1 percent. Median duration of functional rehabilitation (T1–T3) was nearly 6 months (178 days), and the period between the date of injury and the start of functional rehabilitation was 74 days. The median duration of rehabilitation was strongly dependent on the type of injury with 301 days for persons with complete tetraplegia, down to 138 days for persons with incomplete paraplegia. Median functional gain varied from 23.9 points in persons with complete paraplegia to 33.4 points in persons with incomplete tetraplegia. Median FIM discharge scores were 40.0 in persons with complete tetraplegia, 84.0 in persons with incomplete tetraplegia, 76.0 in persons with complete paraplegia and 76.5 in persons with incomplete paraplegia. Compared to American figures [1], length of stay in The Netherlands is still considerably longer than in the U.S., but discharge scores were somewhat higher for persons with complete paraplegia (mean FIM 71.2 against 69.4) and considerably higher for persons with complete tetraplegia (mean FIM 46.3 against 32.4). SCI rehabilitation in The Netherlands takes longer than in the U.S., but appears to show better results, especially in persons with complete tetraplegia. Comparisons with other countries are needed to facilitate interpretation of these differences.

Reference
5 FOLLOW-UP CARE TO SPINAL CORD INJURED PATIENTS LIVING IN THE COMMUNITY: A SYSTEMATIC REVIEW OF INTERVENTIONS AND A COMPARISON OF FOLLOW-UP CARE PROGRAMS IN THE NETHERLANDS AND THE U.S.

J. H. A. Bloemen-Vrencken, L. P. de Witte, M. W. M. Post
Rehabilitation Center Hoensbroeck, The Netherlands; Institute for Rehabilitation Research, iRv, Hoensbroeck, The Netherlands; University of Maastricht, The Netherlands; Email: j.bloemen@irv.nl

This study provides information of the content of follow-up care programs performed by rehabilitation centers to spinal cord injured (SCI) patients after their initial in- and outpatient rehabilitation. In this study only medical and nursing follow-up care is studied, since SCI patients experience many problems that are in the scope of the medical and nursing profession. The study also describes whether these follow-up care programs have been evaluated regarding the effects on the occurrence of secondary impairments, well-being, and the quality and costs of care. A systematic literature search was conducted in MEDLINE (1972–2003) and CINAHL (1982–2003). A publication was selected when it described medical and/or nursing follow-up care to SCI patients living in the community after their initial in- and outpatient rehabilitation performed by or with rehabilitation facilities for SCI patients. Furthermore, 13 specialized SCI rehabilitation facilities in the U.S. and The Netherlands were visited to study their follow-up programs. In The Netherlands the following rehabilitation centers were visited: Het Roessingh, Rijndam, Beatrixoord, Heliomare, Revalidatiecentrum Amsterdam, Sint Maartenskliniek and Hoensbroeck. In the U.S. were Mount Sinai in New York, Magee in Philadelphia, Shepherd in Atlanta, The Institute for Rehabilitation and Research in Houston, and Santa Clara Valley Medical Center in San Jose. The search resulted in 24 papers. Six papers reported on experiences with telemedicine, of which 5 were performed in the same rehabilitation center. In 6 follow-up care programs, the most important method were clinics, consisting of periodical checkups. In 3 programs, home visits were the most important method. Nine programs combined several methods for their after care, i.e., visits to home, community facilities and work place; clinics; educational sessions; peer support; phone calls; and providing expertise and support to community health resources. Most follow-up care programs, however, have not been properly evaluated. Until several years ago, follow-up care provided by the rehabilitation centers in The Netherlands mainly consisted of periodically medical reviews, performed by a physiatrist. Since 2002, in 5 rehabilitation centers, the nursing profession has taken on a more important role in the support to patients after discharge. In the U.S., most rehabilitation centers’ follow-up care also consists of periodic medical reviews. Furthermore, most centers have programs that support the re-entry of patients to daily life and the community. The content of these programs differs in each center, but in general much attention is paid to the education of patients, their families and community health care providers; practicing all kinds of activities at home, at school, or at work; organizing outings; and peer contact. The content of most of these programs were not included in the results of the literature search. The literature search provided only a small number of descriptions of follow-up programs. Most of them have not been properly evaluated. The fact that several existing follow-up care programs have not been described in the literature showed the presence of publication bias. There is a need for the development, communication, and well-designed evaluation of follow-up care to SCI patients.
6 DEVELOPMENT OF MECHANICAL EFFICIENCY OF WHEELCHAIR PROPULSION DURING REHABILITATION IN PERSONS WITH A SPINAL CORD INJURY

S. de Groot, A. Dallmeijer, O. Kilkens, E. Angenot, F. van Asbeck, A. Nene, M. Post, L. van der Woude
Institute for Fundamental and Clinical Human Movement Sciences, Vrije Universiteit Amsterdam; Institute for Rehabilitation Research, Hoensbroeck; Rehabilitation Center Amsterdam; Rehabilitation Center De Hoogstraat Utrecht; Rehabilitation Center Het Roessingh; The Netherlands
Email: s.de.groot@fbw.vu.nl

The purpose of the study was to investigate the development in gross mechanical efficiency (ME) of handrim wheelchair propulsion during the rehabilitation of persons with a spinal cord injury (SCI). The hypothesis was that ME improves during rehabilitation. Within a Dutch multicenter prospective cohort study, SCI patients were tested at the beginning of their clinical rehabilitation (T1), 3 months later (T2), and at time of discharge from rehabilitation (T3). If subjects were able to, they performed two blocks of 3 min submaximal steady-state treadmill exercise in a standardized handrim wheelchair. ME values were calculated for both exercise blocks during the last 30 s. Measurement time (T1–T3, defined as dummy variables with T2 as reference), lesion level and completeness (motor), and power output (PO) were used as independent variables in a multilevel regression analysis with 4 hierarchical levels (exercise block, time, subject, center) \((p < 0.05)\). This method considers dependency of repeated measures within the same person, and dependency of subjects within rehabilitation centers. Subjects were only included when they performed a test two or more times. Subjects with incomplete data sets could be included in this procedure, which led to \(n = 4659\) subjects with paraplegia (PP) and \(n = 1524\) subjects with tetraplegia (TP) per block and time. All exercise blocks and measurement times were included in one model. Model 1: To investigate whether ME changed over time, time was included as the only independent variable. ME was 5.59 percent at T2 and showed a small but significant increase (0.67%) during rehabilitation between T1 and T2, but not between T2 and T3. Model 2: To study the effect of lesion level and completeness on ME, these variables and their interactions with both time dummies were added to model 1. Thereafter, a backward selection was performed (removing the variable with the highest \(p\)-value step by step). In model 2, the intercept of ME at T2 was 4.55 percent and ME showed a significant increase (0.63%) compared to T1, but no increase between T2 and T3. A significant difference in ME (1.45%) between PP and TP was found. Completeness was not significantly related to ME. No significant interactions with time were found for lesion level and completeness. Model 3: Because PO has an effect on ME and was different between PP and TP, PO was added to model 2 and a backward selection was performed. PO showed a significant influence on ME with a 0.26-percent increase per watt \((p = 0.02)\). Lesion level was removed from the model, while a smaller but significant increase (0.38%) in ME between T1 and T2 remained. Results showed a small improvement in ME during the first three months of active rehabilitation and a larger value for PP compared to TP. When correcting for the differences in PO between individuals, the change in ME between T1 and T2 showed a smaller improvement (though significant), and ME was similar for PP and TP.

7 ENERGY EXPENDITURE IN INDIVIDUALS WITH A SPINAL CORD INJURY IN A 40 MIN ENDURANCE TEST

T. Abel, M. Kröner, I. Bleicher, S. Rojas, A. Kupfer, Ch. Peters, P. Platen
Institute of Cardiology and Sports Medicine; German Sport University Cologne; Institute of Morphology and Tumour Research, Cologne, Germany; Email: abel@dshs-koeln.de

Wheelchair sports such as wheelchair racing (WR) and handbiking (HB) have increased in popularity in Germany. This is of great importance because of the inability of wheelchair-dependent people to maintain cardiovascular...
Abstracts of Oral Presentations

Health and fitness by daily activities. The energy expenditure (EE) (kcal/h) is one of the most important values concerning the prevention of cardiovascular diseases. The purpose of this study was to evaluate the EE of spinal cord injured individuals in HB and WR. After giving their written consent to participate in the examination, 10 wheelchair racers (WR) (age: 32.5 years; height: 171.5 cm; weight: 59.2 kg) and 17 handbikers (HB) (age: 36.5 years; height: 176.1 cm; weight: 71.1 kg) completed a basal metabolism evaluation, an incremental exercise test until exhaustion (HB: ergometer; WR: treadmill) and an endurance test (both groups: treadmill). The intensities for HB and WR during the endurance test on the treadmill were determined with the heart rate, corresponding to 2 mmol/l (first 20 min) and 4 mmol/l (second 20 min) lactate concentration in a preceding incremental work load test. During the endurance test, the lactate concentrations were measured to compare them with the predicted values. Oxygen uptake (O₂) and carbon dioxide production (CO₂) (ml/min), arterialized capillary blood lactate concentration (LA) (mmol/l), and heart rate (HR) (bpm) were recorded during each test. EE was calculated by indirect calorimetry. In the basal metabolism test EE in HB was 65.4 ± 14.1 kcal/h and, in WR 60.3 ± 9.1 kcal/h. For the endurance test the values of O₂, CO₂, LA, HR, and EE at the intensities corresponding to 2 and 4 mmol/l lactate are shown in the table below, which represents the physiological responses during the endurance test corresponding to intensities of 2 and 4 mmol/l lactate, values are given as mean ± SD:

<table>
<thead>
<tr>
<th></th>
<th>HB (SD)</th>
<th>WR (SD)</th>
<th>HB (SD)</th>
<th>WR (SD)</th>
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<tbody>
<tr>
<td>O₂</td>
<td>1332 (368)</td>
<td>1175 (285)</td>
<td>1792 (408)</td>
<td>1505 (210)</td>
</tr>
<tr>
<td>CO₂</td>
<td>1178 (303)</td>
<td>1145 (258)</td>
<td>1666 (326)</td>
<td>1427 (188)</td>
</tr>
<tr>
<td>LA</td>
<td>2.2 (0.8)</td>
<td>2.65 (0.36)</td>
<td>4.27 (1.4)</td>
<td>3.31 (1.0)</td>
</tr>
<tr>
<td>HR</td>
<td>117 (19)</td>
<td>142 (28)</td>
<td>146 (23)</td>
<td>165 (23)</td>
</tr>
<tr>
<td>EE</td>
<td>389 (105)</td>
<td>342 (84)</td>
<td>530 (115)</td>
<td>445 (71)</td>
</tr>
</tbody>
</table>

The lactate concentration during the endurance test showed no significant differences to the predicted values of 2 and 4 mmol/l, respectively. The variability, however, was very high, especially for the more intensive last 20 min. Altogether, the results showed that the energy expenditure either in handbiking or in wheelchair racing was high enough to maintain fitness and to probably prevent cardiovascular diseases even with a moderate intensity: However, longitudinal studies are needed to investigate whether recommendations for able-bodied persons are also effective for spinal cord injured individuals.

8 PREVALENCE OF SHOULDER PAIN IN ADULT VERSUS CHILDHOOD ONSET WHEELCHAIR USE
B. J. Sawatzky, G. Slobogean, C. Reilly
Department of Orthopaedics, University of British Columbia, Vancouver, Canada;
Email: bsawatzky@cw.bc.ca

Those who begin wheelchair use before skeletal maturity have greater propensity for remodeling, thus potentially decreasing the prevalence of shoulder problems in this population. The purpose of this study was to see if there was a difference in shoulder pain related to the age that one began with the use of a wheelchair. This study compared two groups of individuals, childhood and adult traumatic or congenital spinal cord injured. The primary outcome variables shoulder pain with the use of the Wheelchair User Shoulder Pain Index (WUSPI) and the Brief Pain Inventory (Short Form) (BPI). The age of onset of wheelchair use is the primary variable and covariates include length of wheelchair use, type of wheelchair, activity level, and lesion level. Forty five subjects were included in this analysis, 19 adult onset wheelchair users with traumatic paraplegia and 26 childhood onset wheelchair users (6 traumatic paraplegia, 20 spina bifida). Mean age was 41 years (±10.3 years) and 21 years (±7.9 years) for the adult group and childhood group, respectively. The mean number of years in a wheelchair were not significantly different: 10.7 versus 14.7 years for adult and childhood groups, respectively. The mean age of wheelchair onset was 6.7 versus 29.9 years for the childhood and adult groups, respectively. There was a significant increase in shoulder pain as measured by WUSPI for the adults (21.9) as compared to the childhood onset users (8.1) (p < 0.001). Similarly, general pain measured by the BPI was greater in the adult onset wheelchair users.
(\( p < 0.001 \)). There was no difference in level or frequency of activity between the two groups, however those who daily participated in wheelchair sports had more pain than those who were not involved in wheelchair sports. Individuals with pain required more assistance wheeling up hills than those with less pain. The BPI correlated with the WUSPI score \((r^2 = 0.48)\), implying a large degree of the pain suffered by paraplegic wheelchair users can be attributed to shoulder pain. The WUSPI scores for the adult onset wheelchair users were significantly higher compared to the childhood onset group. This indicates that the differences in shoulder pain between the two populations is related to the age at which participants began wheeling, and does not appear to be related to any other obvious behavioral or demographic factors. Several explanations may be responsible for this, the most probable being the ability of the immature skeleton to remodel in response to the abnormal force experienced while wheeling. Preliminary data indicates that those who began with the use of wheelchairs as children may have an opportunity to remodel their shoulder joint to accommodate the extra strain that wheeling causes, thus reducing shoulder symptoms as adults seen in these results. This hypothesis needs to be tested by examining the osseous and soft tissue structures of childhood onset wheelchair users.

9 QUALITY OF LIFE OF INDIVIDUALS WITH SPINAL CORD INJURY: MEASUREMENT APPROACHES AND RESEARCH FINDINGS

M. Dijkers
Mount Sinai School of Medicine,
New York, New York, USA;
Email: marcel.dijkers@mssm.edu

Quality of life (QOL) has no uniformly agreed-upon meaning. However, three conceptualizations of individual QOL can be distinguished, and there are measures of QOL corresponding to each: (1) QOL-as-utility, reflecting the value attached by “society” to (health) states as distinguished on the basis of sensory abilities, mobility, cognitive competencies, symptoms, etc. Typical examples of this approach are the Quality of Well-Being scale (QWB) and the Health Utilities Index (HUI). (2) QOL-as-achievement, in which very similar items are used to differentiate individuals, with the use of a total score or profile. The prototype in this category is the SF-36, but the Nottingham Health Profile (NHP), the Craig Hospital Assessment and Reporting Technique (CHART), and most other measures designed as or used as QOL instruments belong in this group. (3) QOL-as-subjective well-being, which focuses on the satisfaction and wellbeing feelings engendered by objective statuses. The Flanagan QOL measure and other life satisfaction instruments, and various measures of (nonpathological) mood such as the Affect Balance Scale (ABS) are examples. No research has utilized QOL-as-utility to evaluate the QOL of individuals with spinal cord injury (SCI); however, application to hypothetical cases indicates that having SCI by definition results in diminished QOL, a finding certainly at variance with the experience of many individuals with SCI. There are many applications of QOL-as-achievement measures to SCI; they often indicate much lower QOL than for nondisabled persons, because the focus is on impairments and activities, rather than participation. However, even the ones that are more “fair” tend to show QOL decrements after SCI. There also are quite a few studies of QOL-as-subjective well-being, generally showing that the subjective well-being of people with SCI is on average somewhat lower than that of nondisabled persons. The data indicate that SCI impairments (level and completeness of injury) affect well-being minimally if at all, activity limitations play a minor role, but that the most significant impact is that of participation restrictions. There is a need for research to incorporate individual goals, expectations, desires, etc., in QOL measurement, in order to obtain a more complete assessment of experienced QOL. Without that component, societal values or researcher values are imposed, and the QOL of individuals with SCI is by definition devalued. Instruments that allow this necessary individualization in QOL measurement (prioritization of domains of life and/or subjective evaluation of one’s status in each) are highlighted.
Support from family members, especially partners, is crucial for maintaining independent living for many persons with spinal cord injuries (SCI). However, little is known about the amount and types of support given by partners of persons with SCI and of their perceived burden of support. The aim of this study was (1) to describe the support given to persons with SCI by their partners and (2) the perceived burden of support by partners and (3) to examine predictors of perceived burden of support. A cross-sectional survey was administered, inviting all members of the Dutch patients organization DON (n = 1004) and their caregivers, if applicable, to participate. Physical disability of the person with SCI was measured with the use of the Barthel Index (BI), a 10-item measure of independence in self-care, continence, and mobility (Cronbach’s alpha 0.85). The number of secondary conditions, other practical problems, and psychosocial problems were recorded. Partner support was described with the use of a list of activities of daily living (ADL) support (14 items; alpha 0.91), other practical support (9 items; alpha 0.84), and emotional support (2 items; alpha 0.87). Burden of support was measured by a 6-item measure (alpha 0.92). Nonparametric descriptive statistics and correlations were used to describe types of support and relationships between support, burden of support and patient and caregiver characteristics. Linear regression was used to identify predictors of caregiver burden. Responses were obtained from 461 persons with SCI. Of 265 couples, patient as well as partner data were available. Mean age of the partners was 49.4 years (SD ±12.2) and 69.8 percent were women. Mean BI of the persons with SCI was 12.3 (SD ±4.7) on a 0–20 scale, and 60.4 percent were seriously disabled (BI < 15). Most partners provided various kinds of support. ADL support and other practical support was given much more often by partner of persons with serious disability, but less difference was seen regarding emotional support. Professional (paid) support was obtained by 45.3 percent of all couples. Perceived burden of support was high in 34.1 percent of partners of persons with serious disabilities, compared to 4.5 percent of partners of persons with minor disabilities. Significant predictors of caregiver burden were, in order of importance, the amount of ADL support given, psychological problems of the patient, partner age, partner gender, BI score, and time after injury (total explained variance 47%). A substantial proportion of partners of persons with SCI suffer from a serious burden of support. Prevention of caregiver burnout should be part of the lifelong care for persons with SCI.

For the persons with spinal cord injury (SCI), physical training is a major part of the rehabilitation program in the acute phase after the injury. When the persons with SCI leave the hospital, they are recommended to continue with regular physical activity to stay healthy. The aim of this study was to gain more knowledge about the differences according to perceptions of life satisfaction as experienced by physically active as opposed to physically inactive persons with longstanding incomplete SCI. A descriptive study to determine and quantify the type and amount of training, self-reported health, use of wheelchair, employment, and life satisfaction was carried out at Sunnaas Rehabilitation Hospital for persons with longstanding incomplete SCI. A survey was conducted by mailing questionnaires to 100 persons with SCI (>8 years post injury) classified as Frankel D, age at injury <60 years. The response rate was 72 percent. The median age of respondents was 47.5 (29–76) years, and the median time following the...
injury was 17.5 (8–39) years. In total 72.5 percent of the response group performed some kind of physical activity regularly. As many as 86 percent reported health problems related to their SCI, but there was no correlation between self-reported health and whether the persons were physically active or inactive. Physically active persons were more socially active with respect to the frequency of meeting friends \((p = 0.034)\), and a positive relationship between physical activity and global and domain specific life satisfaction was observed. Only 7 persons (10\%) of the total present study group were able to walk 7 m or less, and no differences were detected between the groups regarding walking distances. On a regular basis, 28 percent of the physically active group of the present study used a wheelchair outdoors as opposed to only 5 percent of the physically inactive group. From these results, it could be questioned why the persons that are with the use of wheelchair were more physically active. Do daily life activities require so much effort in persons with walking limitations that they were less capable of more physical strain on a daily basis? Might the consequence have been a negative circle with overuse of muscular-skeletal strength, endurance and decreasing capacity? The results indicated that persons with longstanding incomplete SCI had similar exercise habits as the general Norwegian population regarding the frequency and method of exercise. No correlations between exercise habits and health problems were detected. Persons with longstanding incomplete SCI who were physically active had more frequent contact with friends, experienced a greater level of life satisfaction and were more frequent users of wheelchair as mobility aid then those who had a sedentary lifestyle. Further studies are recommended in the field.

12 SECONDARY DISABILITY RISK FOR UNINSURED AND UNDERINSURED FEMALE WHEELCHAIR USERS DUE TO WHEELCHAIR CLASS


A. Kostov Assistive Technology Research Laboratories, Glenrose Rehabilitation Hospital & Faculty of Rehabilitation Medicine; University of Alberta; Edmonton, Alberta, Canada; School of Nursing and Department of Kinesiology and Health Education; University of Texas at Austin, Austin, Texas, USA; Email: brian.fay@ualberta.ca

Previous research of manual wheelchair users has demonstrated correlation between weight and secondary disability pathologies at the shoulder and wrist [1]. Additional work has found female wheelchair users to have smaller normalized upper extremities than male wheelchair users, as well as requiring a greater percentage of maximum effort to propel a wheelchair at typical propulsion speeds [2,3]. A common intervention to address these concerns is to provide wheelchair users with light or ultralight wheelchairs. This pilot study assessed the relationship between wheelchair weight and factors such as functional ability, activity level, presence and duration of pain in the upper extremity, and insurance status. Nine women were recruited via a metropolitan population in the U.S. and were divided into groups based on wheelchair weight: heavy-weight (HW) (>14 kg, \(n = 5\)) and lightweight (LW) (<14 kg, \(n = 4\)). Subjects completed questionnaires quantifying variables. Common functional abilities included transferring, eating, turning hand motions, writing, grooming, toileting, and dressing both the upper and lower body. Secondary disability was assessed via questions concerning pain, duration of pain, pain after wheelchair propulsion, and symptoms that prevent participation in activities. Activity level was assessed relative to participation in activities of daily living. Insurance status was assessed via classifying insurance as government-supported, private, HMO, or PPO. Questions inquired on insurer restrictions on wheelchair choice. The duration of
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wheelchair use, hours used per day, and activity levels were not significantly different between groups. The HW group reported a higher incidence of difficulty with functional ability tasks such as writing, grooming, toileting, and dressing the lower body. The HW group reported a higher incidence of shoulder, elbow, and wrist pain and hand numbness. Symptoms of pain and numbness occurred for a longer duration in subjects demonstrating symptoms in the HW than the LW group. A greater proportion of HW than LW group subjects had chosen to purchase a powered mobility device such as a scooter or power wheelchair. Insurance held by the HW group more often restricted the class of wheelchair options. This pilot study indicates that while female wheelchair users who use HW chairs are similarly active as women in LW wheelchairs, they experience a greater incidence of pain, suggestive of secondary disability. This is further suggested by a higher incidence of pain after propulsion, and pain that may prevent other activities. Given these findings, women wheelchair users may wish to insist on provision of a wheelchair weighing <14 kg. Choice of wheelchairs available is of concern since government and/or insurer policies may restrict users to the HW class. The added financial cost of a LW wheelchair may be outweighed by the human costs of future secondary disability and the associated financial costs of this pilot study tend to confirm previous research, which has expressed concern over the role of wheelchair weight and physical demands placed on the female wheelchair user. Given the small sample size of this study, further research is required to demonstrate whether the trends shown here form strong statistical relationships.

References

13 THE EFFECT OF A SPECIALIST SEATING ASSESSMENT CLINIC ON THE SKIN MANAGEMENT OF INDIVIDUALS WITH SPINAL CORD INJURY

P. Kennedy, C. Berry, M. J. Coggrave, L. S. Rose, L. Hamilton

National Spinal Injuries Centre, Stoke Mandeville Hospital, Aylesbury, Bucks, UK;
Email: lone.rose@smh.nhs.uk

This study evaluated the specialist seating clinic’s effectiveness in improving skin management knowledge and independence, represented by the Needs Assessment Checklist (NAC). The study was of longitudinal, between-subjects design, with two intervention groups and one control. All subjects were inpatients at the National Spinal injuries Centre undergoing their first rehabilitation since injury. Group 1 consisted of individuals who had attended a specialist seating assessment (SSA) before their first needs assessment. Group 2 had attended SSA between their first and second needs assessment. Group 3 (control) had not attended SSA at all. Patient skin management ability was assessed with the use of the skin management subscale of the NAC, a measure of rehabilitation outcome, at two time points. Significant differences were identified between group 3 and group 1 at both the first ($p < 0.05$) and second ($p < 0.01$) needs assessment. Significant improvements were also observed within each group between the first and the second needs assessment time point in all seating assessment categories. Skin management achievement scores were significantly higher for patients who had attended a SSA clinic before their first NAC (group 1) at both time points, supporting the use of SSA as a proactive intervention to improve patient independence, knowledge and awareness, and potentially reduce pressure ulcer incidence.
14 EFFECTIVENESS OF AUTOMATED LOCOMOTOR TRAINING IN PATIENTS WITH CHRONIC INCOMPLETE SPINAL CORD INJURY: A MULTICENTER TRIAL

M. Wirz, G. Colombo, V. Dietz, G. Hornby

*University Hospital Balgrist, Zürich, Switzerland; Email: markus.wirz@balgrist.ch*

The purpose of this study was to investigate whether automated locomotor training with a driven gait orthosis (DGO) can enhance over-ground walking capabilities and improve functional performance in individuals with a chronic, motor-incomplete spinal cord injury (SCI). Twenty patients with a chronic (>2 years) motor-incomplete SCI, classified as American Spinal Injury Association (ASIA) C \((n = 9)\) and D \((n = 11)\), performed robotic-assisted, body-weight-supported treadmill training. They trained 35 times per week over a period of 8 weeks. Single training sessions consisted of up to 45 min of walking time, with a gait speed between 0.42 and 0.69 m/s, and a body weight support as low as possible. The participants were measured pre-, mid-, and post-training with the 10 m walk (10 m), the 6 min walk (6 min), the Timed Up and Go (TUG), and the Walking Index for Spinal Cord Injury II (WISCI II) tests. In a subgroup of patients \((n = 10)\), lower-extremity motor scores and spastic motor behaviors were also assessed to investigate changes in these measures due to the DGO treadmill training. Improvements in the subjects’ gait velocity, endurance, and performance of functional tasks, measured with the use of the 10 m, 6 min, and TUG, were observed during and after the robotic-assisted locomotor training. Those subjects whose locomotor and functional ability was most impaired experienced the greatest benefit from the training. There were no significant changes in the WISCI II, i.e., the requirement of walking aids, orthoses or external physical assistance did not change. No correlations between improvements in walking speed and muscle strength or spastic motor behaviors were found. Intensive locomotor training on a treadmill with the assistance of a DGO results in an improved over-ground walking function, even in a chronic stage after acquired SCI. The long-lasting and task-specific training program seems to be the main issue responsible for the observed improvements. The combination of body-weight-supported treadmill training with the assistance of a robotic device allowed longer trainings with a regular and consistent gait pattern and reasonable workload of the involved physiotherapists. The improvements were not associated with a gain in voluntary muscle force. The assessment of walking function solely based on lower-extremity muscle scoring is limited. A comprehensive assessment should include tests that address the functional performance, i.e., walking tests as used in this study.

15 METABOLIC FACTORS IN THE GOVERNING OF PREFERRED RATES OF MOVEMENT

R. Herman, W. Willis, A. Thompson

*Banner Good Samaritan Medical Center, Phoenix, Arizona; Department of Kinesiology, Arizona State University, Tempe, Arizona, USA; Email: richard.herman@bannerhealth.com*

The time-honored concept regarding the coincidence between minimization of energy cost (e.g., \(O_2\) cost of transport) and preferred rates of walking is not generalizable to all forms of locomotion, indeed to other forms of stereotyped movements. Under various conditions of locomotion, there is a profound disassociation between the preferred rate of movement and minimum energy expenditure. In fact, preferred rates of movement often occur at the expense of an increase in energy expenditure. The degree of minimization of aerobic demand at the preferred rate of movement and minimum energy expenditure. In fact, preferred rates of movement often occur at the expense of an increase in energy expenditure. The degree of minimization of aerobic demand at the preferred rate of movement during over-ground walking and wheelchair propulsion when compared to aerobic demand at higher/lower rates can be as low as 10 percent. Can such a limited decrease in aerobic demand describe such a global influence on motor control? What possible sensory-motor mechanism(s) would be used to control data of the degree of aerobic demand? Is \(O_2\) enough to describe energy consumption, given that both \(O_2\) and fuel consumption...
pathways are necessary components for aerobic metabolism? In a previous abstract, we concluded that when Epidural Spinal Cord Stimulation was used to facilitate locomotion in subjects with spinal cord injury, there was a shift from carbohydrate (CBO) to fat oxidation that was correlated with a lower sense of effort, a higher preferred walking rate, and greater endurance and distances of walking. This outcome triggered a research agenda in able-bodied humans in which we observed O₂ and fuel cost of transport during treadmill and overground walking at various rates and walking conditions. Under normal locomotion conditions, while O₂ cost at 2 mph (53.6 m/min) and 4 mph (107.3 m/min) was always <10 percent higher than the nadir of the O₂ cost of transport at the preferred speed at 3 mph (80.5 m/min), the CBO oxidation rates were more than tenfold over this range of speeds. Minimizing effort correlated with minimizing CBO oxidation (i.e., to the level of gluconeogenesis) under all conditions with/disassociation between preferred rates of walking and minimum O₂ cost of transport. The inflection point of the exponential curve between CBO oxidation and speed was always at the level of preferred speed. The literature reports that the O₂ cost of locomotion is not different for able-bodied subjects walking compared to wheelchair propulsion across a range of speeds from 1.5 to 2.75 mph. This focus on O₂ cost of transport obscures the fact that wheelchair propulsion across the speed range demands over six times greater CBO oxidation than does able-bodied walking. At higher rates of walking (>3 mph), when increasing sense of effort correlates robustly with increasing CBO oxidation and poorly with fat oxidation, afferent signals related to metabolic fuel selection in skeletal muscle provide important inputs into the central nervous system during walking. The latter signals ensure that the central nervous system selects a walking speed with minimal CBO demand, thus maximizing metabolic range of motor activity as well as sparing CBO fuel for emergency burst activity. Thus humans self-select (prefer) a walking speed that can supported almost exclusively by fat combustion. Apparently, the motor control system attempts to control CBO oxidation to gain economical advantage.

16 VALIDITY AND RELIABILITY OF TIMED WALKING TESTS IN SUBJECTS WITH A SPINAL CORD INJURY

H. J. A. van Hedel, M. Wirz, V. Dietz
Spinal Cord Injury Center, University Hospital Balgrist, Zürich, Switzerland;
Email: hvanhede@balgrist.unizh.ch

This study assessed the validity and reliability of three timed walking tests, the Timed Up and Go (TUG), the 10 m walk (10MW) and the 6 minute walk test (6Min) in subjects with a spinal cord injury (SCI). The study was performed at the Spinal Cord Injury Center of Balgrist University Hospital in Zürich, Switzerland. Validity was assessed with the data of 75 SCI patients. All patients performed the three timed tests and the Walking Index for Spinal Cord Injury II (WISCI II) on the same day. Validity was assessed by calculating correlation coefficients (r) between the WISCI II and the three timed walking tests, as well as between the three timed tests themselves. This was done for all patients and for subgroups of SCI patients with good and poor walking ability. Subgroups were defined as “poor” (WISCI II categories < 11) and “good” (WISCI II categories 11–20) or “dependent” (WISCI II categories 0–8, 10, 11, 14 and 17) and “independent” (WISCI II categories 9, 12, 13, 15, 16 and 18–20). Reliability was determined in 22 SCI patients. Three measurements within seven days were performed to assess intra- and inter-rater reliability. We assessed the reliability by means of correlation coefficients and the Bland-Altman method. The three timed walking tests correlated moderately with the WISCI II (|r| > 0.60) and excellently with each other (|r| > 0.88). For patients with poor walking ability (poor and dependent), the correlation between the timed tests remained high (|r| > 0.70), but decreased between WISCI II and the tests (|r| < 0.35). Patients with a WISCI II score less than 11 showed a positive correlation between the WISCI II and the TUG and a negative correlation between the WISCI II and the 6Min. For dependent patients, this did not occur. High correlation coefficients (r > 0.97) were found for intra- and inter-rater reliability.
However, when tested by the same therapist, the Bland-Altman method showed that SCI patients performed the TUG and 6Min significantly better on the second test occasion. Furthermore, scatter plots showed that the TUG and 10MW inter-rater reliability were negatively influenced by very poor walking ability (>40 s needed to walk 10 m). In general, the three timed tests appear to be valid and reliable measures to assess walking function in SCI patients with good and poor walking ability. However, the reliability of the 10 MW and the TUG must be interpreted with caution in patients with very poor walking function. Furthermore, the better performance of the TUG and 6Min on the second test occasion by the same therapist might be caused by a “learning effect.” Indeed, these tests assess a more complex task, i.e., balance for the TUG and cardiovascular exercise for the 6Min, compared to the 10MW.