

CHANGES IN THE KINEMATIC AND KINETIC PROFILE OF HANDCYCLING PROPULSION DUE TO INCREASING WORKLOADS

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The aim of this study was to examine changes in handcycling propulsion kinematics and kinetics due to increasing workloads. Twelve non-disabled male triathletes without handcycling experience performed a familiarisation protocol and an incremental step test in a recumbent racing handcycle that was attached to an ergometer. During the incremental test, the tangential crank kinetics, 3D joint kinematics, blood lactate and the rate of perceived exertion (local and global) were identified. The participants showed a significant increase in shoulder internal rotation and abduction and a decrease in elbow flexion and retroversion. Future studies should expand the test spectrum, consider the examination of muscle activation patterns (MAP) and replicate the study with elite handcyclists.

KEY WORDS: handbike, biomechanics, kinematics, kinetics, performance, physiology

INTRODUCTION: Because of the highly individual properties, a huge potential for paralympic athletes is lying in the field of biomechanics (Morrien et al., 2016). In handcycling, studies focussing on biomechanical aspects vary in the use of vehicle (attach-unit vs. racing handcycle) and the type of sample (able-bodied vs. athletes with spinal-cord injury, SCI). Faupin et al. (2010) were the first who measured the upper limb kinematics, 2D crank kinetics and muscle activations patterns (MAP) with respect to crank position of an able-bodied subject in a racing handcycle. Litzenberger et al. (2016) extended this approach by changes in handcycle settings. They examined the influence of backrest position, crank length and crank height on upper body kinematics and MAP of an elite handcycle user performing three different loads. For kinematics, only little changes were observed. Because of the single case design, no conventional statistics could generalize this outcome. Therefore, the aim of this study was (1) to identify the kinematic and kinetic profile of several subjects and (2) examine changes in this profile due to increasing workloads.

METHODS: To improve transferability, twelve non-disabled male competitive triathletes (26.0±4.4 yrs., 1.83±0.06 m, 74.3±3.6 kg) without handcycling experience voluntarily participated in the study. The study was approved by the local ethics committee and complied with the ethical standards of the Helsinki Declaration. Participants were initially familiarized with the handcycle. The incremental test started with an initial load of 20 W and increased every five minutes by 20 W until subjective exhaustion. To quantify the participants effort, rate of perceived exertion (RPE) on a global (cardio-pulmonary) and local (upper extremity) level, capillary blood lactate concentration (La [mmol·l⁻¹]) and heart rate (HR [min⁻¹]) were recorded at the end of every stage. As a performance criterion, the maximal power within the incremental test (P_{max}) was calculated using Equation 1.

Equation 1:
$$P_{max} = (P_L - b_T) + \frac{t_L}{t_T} \cdot b_T$$

where P_{max} is the maximal power output within the incremental test, P_L is the power output of the last step, b_T is the increase in power output with each step, t_L is the duration within the last (unfinished) step and t_T is the prescribed duration of each step.

The tests were performed in a racing handcycle (Shark S, Sopur, Sunrisemedical, Malsch, Germany) that was attached to an ergometer (Cyclus 2, 8 Hz, RBM electronic-automation GmbH, Leipzig, Germany) (Figure 1). In order to ensure comparable conditions between participants and other studies, the backrest of the handcycle was tilted so that (1) the elbow

was slightly flexed in the foremost position and (2) that the axis of the shoulder joint was at the same height as the crank axis (Faupin et al., 2006; Faupin et al., 2010).

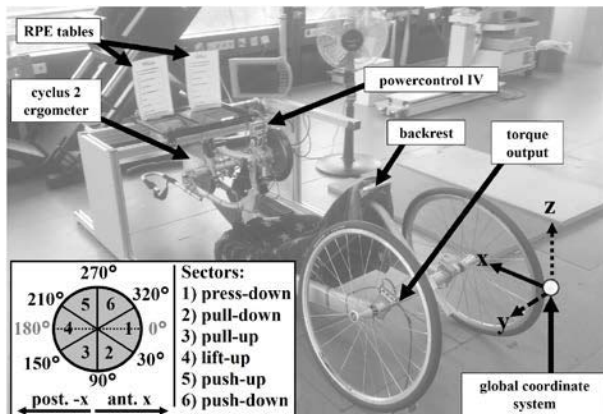


Figure 1: Testing setup. global coordinate definition of the crank position

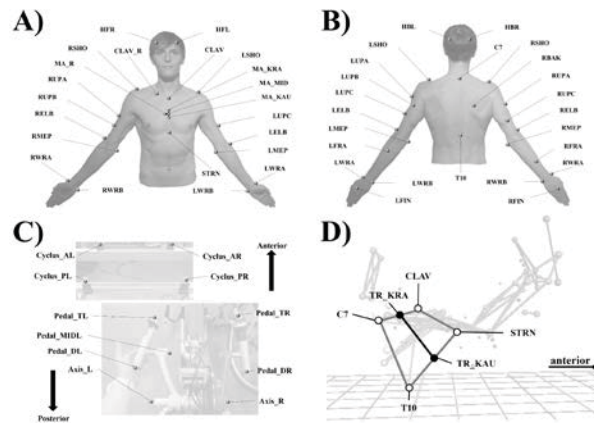


Figure 2: Marker setup and schematic system and trunk vector determination

- A) Body markers from anterior**
- B) Body markers from posterior**
- C) Crank Markers**
- D) Calculation of the trunk angle**

Kinematics and kinetics were collected at the end of the first and beginning of the last minute of each stage for 20 seconds. Seven high speed infrared cameras (100 Hz, MX-F40 and MX-3+, Vicon Nexus 2.3, Vicon Motion Systems Ltd., Oxford, UK) were placed around the handcycle. In all, 44 spherical retro-reflective markers were placed on the crank, the ergometer and anatomical landmarks according to the Upper Limb Model of Vicon Nexus (Figure 2, A-C). The recumbent position in the handcycle inhibited a direct measurement of the 7th cervical vertebra (C7) and the 10th thoracic vertebra (T10) markers during the tests. Therefore, a marker array (MA-KRA, MA_MID, MA_KAU and MA_R) was placed on the sternum in order to reconstruct the required markers from a static trial (Figure 2, A-B).

The joint kinematics of the Upper Limb Model considered the angles and angular velocities of shoulder-flexion (SF), shoulder-abduction (SA), shoulder-internal-rotation (SR), elbow-flexion (EF), palmar-flexion (PF) and radial-duction (RD). To determine trunk-flexion (TF), two new markers (TR_KRA and TR_KAU) were calculated as the midpoints between C7 and the jugular notch (CLAV) as between T10 and the xiphoid process (STRN) (Figure 2, D). The orientation of the trunk vector (between TR_KRA and TR_KAU) to the horizontal plane (x|y) was defined as TF angle.

The tangential crank kinetics based on a powermeter (1000 Hz, Schobener Bike Management System, SRM, Jülich, Germany) installed in the crank. The device is equipped with eight strain gauges, that transferred the tangential deformation of the crank (due to the crank torque) into a voltage signal. To transfer the voltage signals into torque signals, the system was calibrated using free weights (5 to 40 kg) at a crank angle of 0° ($R^2 = 0.998$).

The biomechanical data were filtered (4th-order low-pass Butterworth filter, cut-off frequency 10 Hz), averaged and resampled to a length of 360 frames per cycle using MATLAB (R2016a, MathWorks®, Natick, Massachusetts, USA). Parameters of kinematics and kinetics were maximum and minimum value (MaxV and MinV), range (MaxV-MinV), the crank angle of the maximum and minimum (MaxI and MinI) and the values at maximal and minimal acute power (@MaxP and @MinP). Additionally, the accomplished work within six crank sectors (Figure 1) was calculated using Equation 2 (Krämer et al., 2009).

$$\text{Equation 2: } W_{\text{Rot}} = \int_{t_0}^{t_1} M(\theta) d\theta = \bar{M} \cdot \Delta\theta$$

where W_{Rot} is the rotational work [J], t_0 is the start of the particular sector, t_1 is the end of the particular sector, $M(\theta)$ is the torque with respect of crank angle [Nm rad], \bar{M} is the mean

torque in the particular sector and $\Delta\theta$ is the difference in crank angle for the sectors (60° or 1.0472 rad).

The sectors were combined to two phases in order to compare the amount of work during the pull (press-down, pull-down and pull up) and push (lift-up, push-up and push-down).

Statistical analyses were done using Statistical Package for the Social Sciences software (23, SPSS Inc., Chicago, Ill., USA). To assess changes in the kinematic and kinetic parameters, a one-way ANOVA with repeated measures was performed. In case of missing assumption of normal distribution (Kolmogorov-Smirnov test with Lilliefors-correction), the non-parametric Friedman test was applied. Concrete means were compared using Student's t-Test or Wilcoxon Rank test. The level of significance was set to $\alpha = 0.05$.

RESULTS: The mean P_{\max} , La_{\max} , and HR_{\max} were 131.3 ± 14.9 W, 9.6 ± 2.2 $\text{mmol} \cdot \text{l}^{-1}$ and 167.2 ± 14.9 min^{-1} . At exhaustion, RPE_{local} (19.8 ± 0.6) was significantly higher than RPE_{global} (18.0 ± 1.1 ; $P = 0.003$). The maximal torque was found within the pull-down and push-up sector, whereas the lowest torque and cadence occurred during the lift-up (Figure 3).

During the incremental test, a significant decrease in shoulder-retroversion ($P < 0.0005$), adduction ($P < 0.0005$), elbow-flexion ($P < 0.0005$) and elbow-extension ($P < 0.0005$) was observed (Figure 3). Maximal abduction ($P < 0.0005$) and internal-rotation ($P = 0.031$) showed an increase. The MaxV-MinV of the SF ($P = 0.069$), EF ($P < 0.0005$) and RD ($P < 0.0005$) rather decreased, whereas a rather increase in MaxV-MinV for SA ($P = 0.003$), SR ($P = 0.069$) and RF ($P = 0.009$) was found. The maximal elbow-flexion ($P = 0.002$), elbow-extension ($P = 0.006$) and dorsal-flexion ($P < 0.0005$) occurred significantly later in crank cycle. At the 180° position, a significantly higher abduction ($P < 0.0005$) and lower elbow-flexion ($P = 0.001$) was measured. The maximal angular velocity of anteversion ($P = 0.004$), abduction ($P = 0.009$), dorsal-flexion ($P = 0.053$), ulnar-duction ($P = 0.037$) and trunk-flexion ($P = 0.006$) occurred later in crank cycle. The lift-up was performed with a significantly higher anteversion velocity ($P < 0.0005$), internal-rotation velocity ($P = 0.006$) and dorsal-flexion velocity ($P = 0.024$). The highest W_{Rot} was observed during the pull-down and pull-up sector, whereas the lift-up and press-down accounted for the lowest proportion of work. For higher workloads, the difference between push and pull phase increased in favour of pulling.

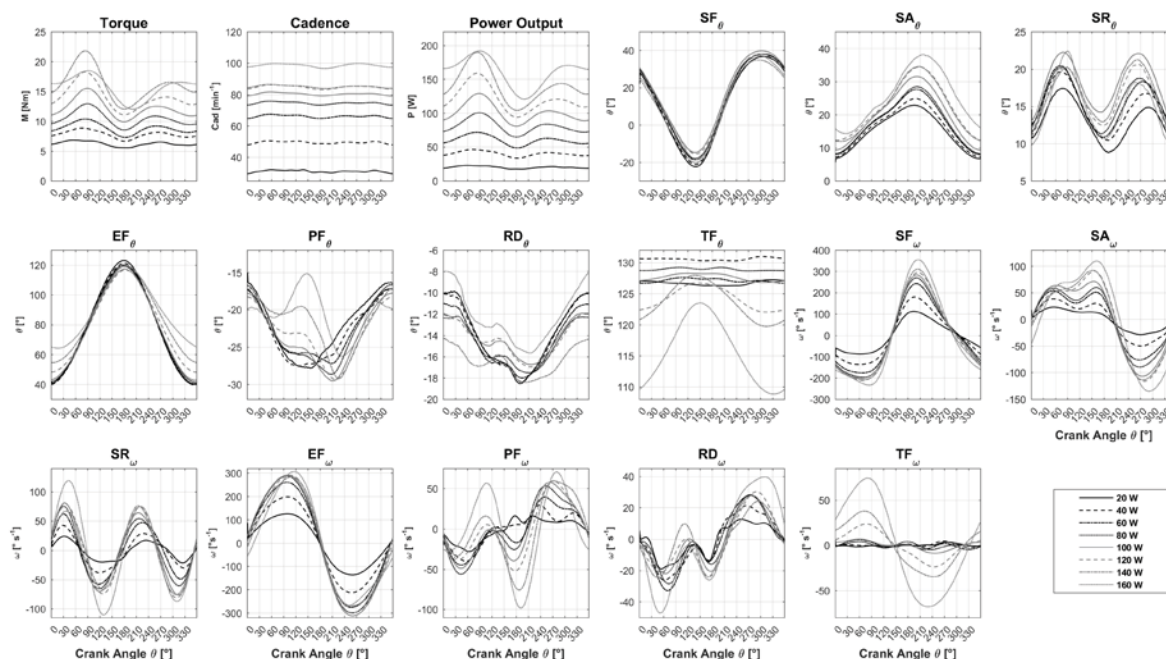


Figure 3: Changes in the kinematic and kinetic profile due to increasing workloads

DISCUSSION: In comparison to Faupin et al. (2008), the ranges of motion (RoM) were lower in the current study although a similar standardisation was applied. Litzenberger et al. (2016)

described an increase in elbow RoM for higher workloads, whereas a significant decrease was found in the current study. They even showed a reduction in palmar-flexion, that was contrary to the current study (Litzenberger et al., 2016). The maximal and minimal elbow flexion appeared later during the crank cycle for the examined participants compared with data of an elite handcyclist in a lower position. Hence, the propulsion strategies for increasing workloads seem to be different between novice and elite athletes. In comparison to Krämer et al. (2009), differences in W_{Rot} were found that are probably based on the use of an attach-unit with a wider crank width (58.0 cm) compared to this study (38.5 cm).

The participants faced higher mechanical and metabolic demands with changes in propulsion kinematics and kinetics. Initially, the participants tried to cope increasing workloads by lowering the wrists range of motions. An increase in wrist stiffness could improve the distal force transmission for higher workloads. Furthermore, the participants increased shoulder abduction and internal rotation, especially during the lift-up. For higher loads, the shoulder experienced a fast anteversion movement during the 180° position. It is likely, that the aim of this strategy is to quickly overcome the lift-up by an increasing inclusion of large muscle groups (e. g. M. pectoralis major) (Madsen et al., 1984; van Drongelen, 2011). It seems, that participants tried to emphasize the pull phase in order to minimize the loss in cadence during the push phase. From the 120 W step on, a trunk supported push phase was observed that was accompanied with a lower elbow extension.

The higher increase in cadence (than the increase in torque) and the higher RPE_{local} values are consistent with international literature, assuming that high muscle forces and concomitant limitations in local blood flow are responsible for exhaustion in arm cranking exercises (Price et al., 2007). The low acute power values during the lift-up indicate that the maintenance of high power level is probably limited by the inefficient transition between pull and push phase.

CONCLUSION: At increasing workloads, changes of propulsion kinematics and kinetics could be observed for several subjects. At maximal intensities, a reinforced pull phase could narrow the loss in crank angular velocity during the lift-up and thus delay fatigue. Because of the work distribution, the pull phase seems to be of more importance, which should be considered in sport specific strength and endurance training. To validate the current findings, future studies should replicate and expand the study with several elite handcyclists.

REFERENCES:

- Faupin, A., Gorce, P., Meyer, C. & Thevenon, A. (2008). Effects of backrest positioning and gear ratio on nondisabled subjects' handcycling sprinting performance and kinematics. *JRRD*, 45(1), 109-116. doi:10.1682/JRRD.2006.10.0139.
- Faupin, A., Gorce, P., Watelain, E., Meyer, C. & Thevenon A. (2010). A biomechanical analysis of handcycling: a case study. *Journal of Applied Biomechanics*, 26(2), 240-245. <https://www.ncbi.nlm.nih.gov/pubmed/20498497>
- Krämer, C., Schneider, G., Bohm, H., Klopfer-Kramer, I. & Senner, V. (2009). Effect of different handgrip angles on work distribution during hand cycling at submaximal power levels. *Ergonomics*, 52(10), 1276-1286. doi:10.1080/00140130902971916
- Litzenberger, S., Mally, F. & Sabo, A. (2016). Biomechanics of elite recumbent handcycling: A case study. *Sports Eng*, 19(3), 201-211. doi:10.1007/s12283-016-0206-x.
- Madsen, N. & McLaughlin, T. (1984). Kinematic factors influencing performance and injury risk in the bench press exercise. *Med Sci Sports Exerc*, 16(4), 376-381. <https://www.ncbi.nlm.nih.gov/pubmed/6493018>
- Morrien, F., Taylor, M. J. D. & Hettinga, F. J. (2016). Biomechanics in Paralympics: Implications for Performance. *Int J Sports Physiol Perform*, 1-34. doi: 10.1123/ijsp.2016-0199
- Price, M. J., Collins, L., Smith, P. M. & Goss-Sampson, M. (2007). The effects of cadence and power output upon physiological and biomechanical responses to incremental arm-crank ergometry. *Appl Physiol Nutr Metab*, 32(4), 686-692. doi:10.1139/H07-052
- van Drongelen, S., van den Berg, J., Arnet, U., Veeger, D. J. H. E. J. & van der Woude, L. H. V. (2011). Development and validity of an instrumented handbike: initial results of propulsion kinetics. *Med Eng Phys*, 33(9), 1167-1173. doi:10.1016/j.medengphy.2011.04.018

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