HANDLE REACTION FORCES IN HANDCYCLING ON AN ERGOMETER

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The purpose of this study was to develop a three dimensional sensitive dynamometric handcycling grip and to examine the influence of grip positioning on hand contact forces during low resistance arm cranking. Contact forces of ten male subjects were measured at a neutral grip position, increased crank arm length and increased grip width. The findings suggest a pushdown-pull cranking pattern. Therefore shoulder extensors and elbow flexors may have an important role in force generation. Changes at the grip position have a clear effect on grip contact forces, thus the interaction is complex due to subject specific variations. The data sets the basis for an inverse dynamic model and provides information about involved muscles which is helpful for the training process and injury prevention.

KEY WORDS: sensor technics, hand cycling, crank position, contact forces

INTRODUCTION: Arm crank ergometry covers a wide span of applications, ranging from diagnostics and exercises in rehabilitation (Myers and Bellin, 2000) to specific training with elite level athletes. For the prevention of overuse symptoms and pain or optimization of propulsive mechanics a detailed knowledge of applied forces and the loading of involved structures is essential. Activation of shoulder muscles has been shown to be dependent on external factors as arm posture and applied load (De Groot, Rozendaal, Meskers, Arwert, 2004; MacDonell and Keir, 2005). Besides changed kinematics, different grip positions may also cause alterations in contact forces at the handles and consequently influence force generation at the upper extremities. Therefore the interface between the athlete or patient and its impact on injury prevention or performance enhancement was investigated under various aspects. So far the influence of grip angles (Abel, Burkett, Thees, Schneider, Askew, Strüder, 2015), global grip position (Bressel E., Bressel M., Marquez, Heise, 2001), crank arm length or width (Krämer, Hilker, Böhm, 2009) have been investigated. Inverse dynamic modelling might provide a more detailed knowledge about tissue loading and force generation (Faupin, Gorce, Watelain, Meyer, Thevenon, 2010). To our best knowledge no investigation so far has varied grip alignment, crank width, crank arm length and crank position for ergometer hand cranking and provided three dimensional (3D) contact forces as basis for inverse dynamic modelling for all these conditions. The scope of the study was to develop a 3D sensitive dynamometric handle, provide the data basis for inverse dynamic models and to specify the interaction of handle interface and basic kinetic parameters. This provides information for the training process and especially injury prevention.

METHODS: To investigate the effects of different grip positions on hand contact forces, ten male, healthy subjects with no hand cycling experience (height 180.2 ± 3.0 cm; mass 76.5 ± 6.8 kg) participated in this study. Handle reaction forces were measured using custom built dynamometric handles equipped with two piezoresistive 3D sensitive force sensors each (model 9251A ,Kistler, Winterthur, CH). Handles were calibrated applying uniaxial and combined loadings with a test rig including a material testing machine (Zwick 2020, Zwick/Roell, Ulm, GER) and two force sensor (9251A ,Kistler, Winterthur) equipped actuators. Crosstalk was compensated for each sensor using inverse matrix method. Analog data (1000 Hz, filtering: Butterworth, lowpass, 4th order, cutoff frequency 15 Hz) and kinematic data (100 Hz, filtering: Butterworth, lowpass, 4th order, cutoff frequency 15 Hz)

were collected with an motion capture system (16 infrared cameras, MX F40, Vicon Nexus 2.5, ViconTM Oxford, UK). 52 retro-reflective, spherical markers identified lower extremity reference points and technical landmarks.
The subjects performed in standing position approximately one minute trials at the three grip positions ‘neutral’ (N), ‘long crank arm’ (L), ‘broad grip position’ (B). For all positions the crank axis was at a fixed height, resulting in a position with the arms in approximately 90 degrees ante flexion when the crank was in horizontal position. Grip position was perpendicular to the crank arm. The hand position was controlled with a pronounced ring around the handle, which should be placed between middle- and ring finger. At the ‘neutral’ position, crank length was 200 mm. Previous testing has shown a grip width of 635 mm as habitual, neutral position for this setup. For the ‘long crank arm’ position, crank length was increased to 250 mm, width remained unchanged. Analogous for ‘broad grip position’ grip width was increased to 960 mm, crank length remained unchanged at 200 mm.
During the trials with a target crank rate of 50 rev/min, power was kept constant at 60 Watt by an adapted SRM ergometer (SRM, Jülich, Germany). Out of each trial at least eight consecutive cycles were analyzed. Right handle reaction forces were compared to identify effects of crank arm length and grip width. Starting point for a revolution was defined at vertical, upward crank arm position. Descriptive and inferential statistics were conducted using Matlab (Matlab R2016B, The MathWorks, USA).

RESULTS AND DISCUSSION: The data that is presented corresponds to that of the right hand side. Starting point of the cycle is right crank arm positioned vertical, pointing upwards. Cranking direction was clockwise. Handle reaction forces are visualized in Figure 1. Discrete values are presented in Table 1.

Table 1
Peak values and standard deviations of the vertical, anterior-posterior and medio-lateral handle reaction forces, impulse and location of peak force at the crank revolution for the investigated conditions neutral (N), long crank arm (L) and broad crank setting (B)
* =significant difference to neutral position

	Neutral Position			**Long Crank Arms**			**Broad Crank Arms**		
	mean		std	mean		std	mean		std
Impulse [Ns]									
down	23.04	±	12.30	18.54	±	7.47*	20.41	±	9.32
up	-1.20	±	2.15	-0.57	±	1.27	-0.78	±	1.25
posterior	22.17	±	8.61	19.01	±	6.37	16.51	±	5.70*
anterior-posterior	-6.05	±	5.10	-3.16	±	1.89	-4.10	±	2.43
medial	11.04	±	3.99	7.73	±	3.15*	15.10	±	5.63*
lateral	-0.49	±	0.35	-1.15	±	0.79*	-1.72	±	1.05*
Peak Force [N]									
down	41.05	±	16.20	34.59	±	11.3	35.15	±	10.34*
up	1.71	±	12.11	-0.34	±	5.57	0.34	±	8.30
posterior	51.98	±	23.20	43.96	±	16.10	34.84	±	9.39*
anterior-posterior	-20.73	±	13.30	-14.63	±	7.06	-15.43	±	8.14
Medial	23.12	±	8.33	17.90	±	7.51	28.99	±	7.31*
Lateral	-2.89	±	2.13	-5.69	±	3.58	-7.66	±	3.39*
Location of PeakForce [% of revolution]									
Vertical	26.96	±	9.41	31.52	±	17.00	33.12	±	13.60
anterior-posterior	36.50	±	4.65	34.29	±	7.23	44.70	±	4.89*
medio-lateral	33.30	±	3.39	28.52	±	3.85*	42.32	±	6.44*

For the neutral crank position, downwards (41.5 ± 16.2 N), posterior (51.98 ± 23.2 N) and medial (23.12 ± 8.33 N) orientated force was clearly higher, compared to the upwards (1.71 ± 12.1 N), anterior (-20.73 ± 13.3 N) and lateral (-2.89 ± 2.13 N) directed components. Accordingly to this, medial, posterior and downward orientated impulses were dominant. Peak forces were located in a close range of approximately 10 % of crank revolution (%rev). Ranging from 26.96 ± 9.41 %rev (vertical) to 36.5 ± 4.7 %rev (anterior-posterior). This indicates a propulsive mechanism that mainly involves shoulder extensors and elbow flexors. The minimum vertical force of 1.2 ± 2.5 N at the second half of the crank cycle, is similar to that found in cycling (Mornieux, Stapelfeldt, Gollhofer, Belli, 2008). This means, during the upwards movement the weight of the arm can't be entirely compensated.

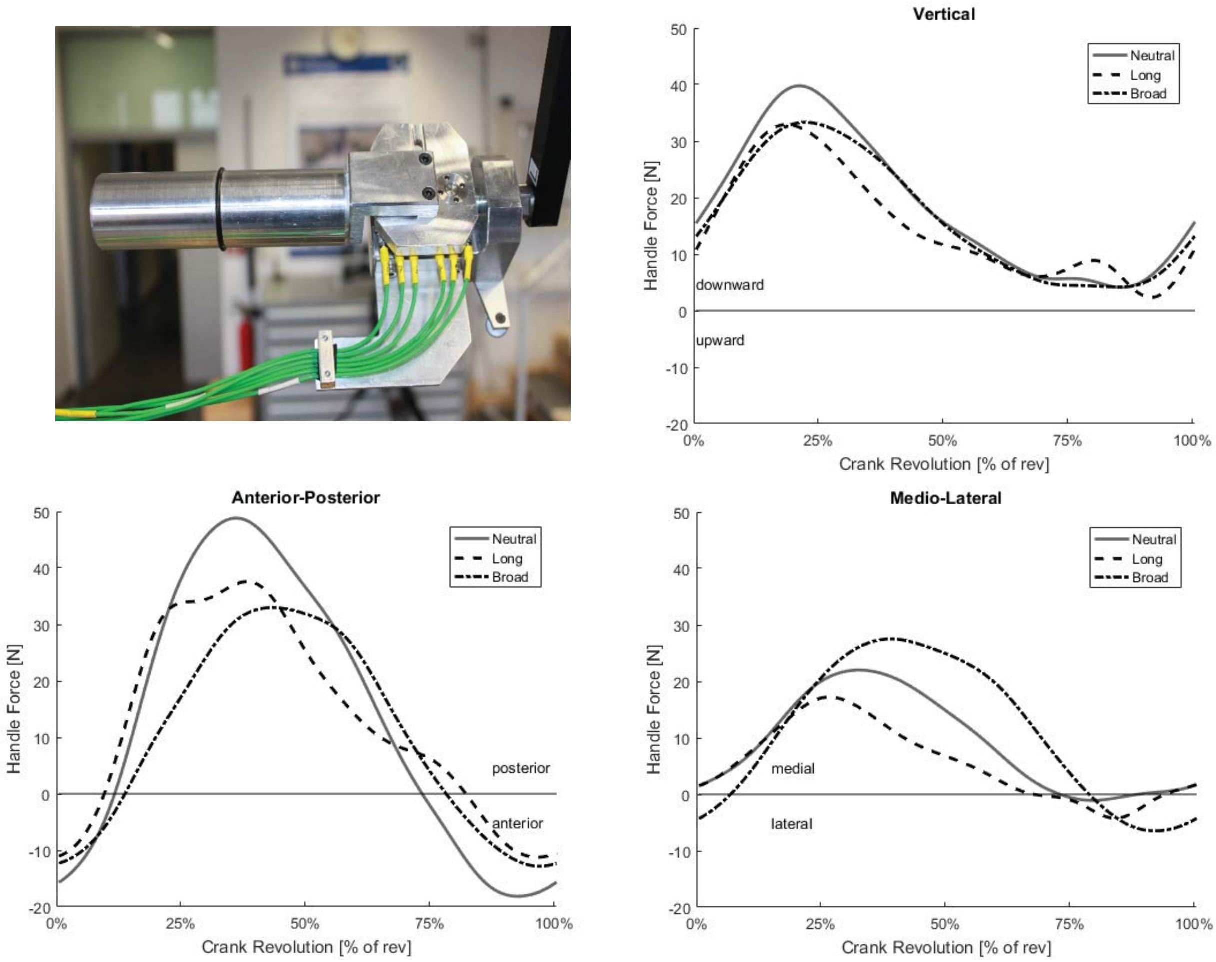

Figure 1: Dynamometric handle with two force sensors and time histories of the handle reaction forces under the three investigated conditions: neutral (grey line), long crank arms (black dashed line) and broad grip position (black dash-point line)

In comparison to the neutral crank setting, the long crank arms reduced the downwards and medial orientated impulse significantly, the posterior component was not affected. This might be reasoned by the unchanged location of the posterior peak force around 35 % revolution, close to the 90° crank arm position. Expressed in a crank cycle specific reference system, a posterior force at this point in time this results in an ineffective radial force component. This counteracts the effects of a prolonged lever arm.

In comparison to the neutral position, increasing grip width results in significantly reduced downward and posterior impulses and peak forces. The posterior peak force is located at a later point in time of the cranking movement. Opposite to this, medial peak force and impulse were increased significantly.

The present study uses a global reference system for illustrating the hand forces. As mentioned before, further information regarding crank pattern effectiveness might be provided by expressing the sagittal plane kinetics in a crank arm centered coordinate system. Scope of the present study was a rehabilitative application, therefore ergometer resistance of 60 W was very low. An increased cranking resistance may cause the usage of additional muscle groups and therefore influence the observed push-down / pull cranking pattern.
The long crank arm setting was expected to decrease peak forces in the propulsive sagittal plane effectively. This cannot be confirmed for the peak forces and only partially for the force impulse. Even though arm cranking is a guided movement, degrees of freedom at shoulder, elbow and wrist generate a subject specific movement variability, illustrated by high standard deviations for almost all values. Nevertheless changes at the hand position showed a direct impact on the handle reaction forces. For a better understanding of cranking mechanics further investigation of parameters as crank adjustments in grip position, width, crank arm length, height or resistance should be taken into consideration. One main rationale of this investigation was to establish a workflow for measuring grip contact forces and thereby provide the basis for an inverse dynamic model. Hereby especially the combination of different crank arm settings, as width and length and grip position might provide further insight.

Conclusion: The present study established a workflow for measuring contact forces during arm cranking. For low resistance cranking a force generation pattern which can be described as pushing-down and pulling was observed. Shoulder extensors and elbow flexors as m. latissimus dorsi, m. brachialis or m. biceps brachii are therefore possible contributors to force generation. Interaction between geometric changes at the crank and hand forces are complex. Further investigation of parameters related to ergometer configuration, such as crank adjustments in grip position, width, crank arm length, height or resistance should be taken into consideration. An inverse dynamic approach might provide a better understanding of tissue loading and propulsive mechanics and therefore improve training and rehabilitation strategies.

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