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Influence of different seating and crank positions on muscular activity in elite handcycling - a case study

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Abstract

Due to rising public focus scientific analysis of performance parameters is getting more and more important in paralympic sports. Several studies have been performed to investigate different design parameters of handcycles (e.g. crank length) already; however, most of those were done with able-bodied subjects, widely unfamiliar to handcycling. In this study bilateral surface electromyography (sEMG) of several muscles of the upper body and arms of an elite handcyclist (multiple medal-winner in Paralympic Games and World Championships) is performed with different crank lengths, crank positions and backrest positions at power levels of 130, 160 and 190 W resulting in a total of 22 measurements. sEMG data were recorded bilaterally at a recording frequency of 1000Hz using Ag/AgCl electrodes. Concurrently the crank position was acquired with ten Vicon Bonita infrared cameras recording at 100 Hz. EMG data were rectified, smoothed and normalized to crank-cycle duration (0-360 deg) for each single crank-cycle. Phases of activity for each muscle (i.e. EMG amplitude exceeds 30% of maximum amplitude) and integrated EMG (iEMG) as an indicator for net muscular e ort were calculated. Results showed that amplitude and iEMG were higher for higher power output and shorter cranks, crank and backrest position influenced several muscles but results were always similar for similar shoulder-crank-distances. It could be shown, that muscular effort is clearly influenced by the handcycle parameters investigated and that these measurements can be used to individually optimize the position in a handcycle with regard to muscular effort.

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1. Introduction

Handcycling is a fitness sport as well as a paralympic sport where elite-athletes compete in several classes according to their level of impairment according to the rules of the Union Cycliste Internationale (UCI) [1]. In handcycling a bike is used on which the front wheel is driven - similar to a bicycle - via a chain which is set into motion by a set of cranks turned by the athlete with his/her arms. Contrary to the cranks on a bicycle both arms work synchronously, i.e. they are moving forward and backward at the same time.

The position and handcycle are underlying some regulations of the UCI, but within these the handcyclist is free to choose his/her position as long as it is not changed within the race. The main focus of handcyclists, however, lies on aerodynamics and power transmission from arms to the crank.

Research has already been conducted on several parameters of the handcycle and handcyclist. Bohm,¨ Kramer¨ and Senner [2] and Kramer,¨ Klopfer¨ and Senner [3] tried to optimize the drive system mathematically and experimentally, respectively. Zeller and Abel [4] assessed the use of elliptical chain rings, Faupin et al. [5, 6] concentrated on gear transmission ratio, cadence and joint-angles, Arnet [7] on joint-loads and seating-position. Goosey-Tolfrey, Alfano and Fowler [8] and Kramer¨ et al. [9] examined the influence of crank-length on e ciency and Murray, Buchanan and Delp [10], Phillipou et al. [11] and Doheny et al. [12]assessed joint angles. However, although many studies were conducted concerning handcycling a major part of those was done on handcycle ergometers using able-bodied subjects and hobby-athletes widely unfamiliar with handcycling. In the present study an elite athlete is examined on an individually fitted handcycle the subject uses for racing.

The main research question was whether an altered position on the handcycle would change activation pat- terns and whether the most efficient position in terms of muscular work can be identified. It was expected that (1) lower crank height will lead to shorter activation time of the muscles, (2) higher backrest will result in shorter activation time, (3) longer cranks will lead to a decreased EMG-amplitude, (4) iEMG will be smallest for longer cranks, higher crank height and lower backrest and hence indicate the most efficient position.

2. Methods

One male elite-handbiker (class: H3.2, age: 44 yrs., height: 172 cm, weight: 62 kg, multiple medal- winner in Paralympic Games and World Championships) was informed about the goals and methods of the study and gave his consent to participating. All tests were performed on the subject’s own handbike used for racing (EvoJet, Sozio-Sport GmbH, Zeiningen, SUI). Its front wheel (i.e. driven wheel) was fixed on a TACX Cycletrainer (Tacx B.V., Wassenaar, NED) with an adaptable magnetic resistance device.

The athlete was advised to pedal at three different power levels commonly used in different situations during competition (130 W, 160 W and 190 W). Power levels were measured using a crank instrumented with a powermeter (SRM GmbH, Julich,¨ GER) gear and cadence were noted and used later for all measurements done without the instrumented crank.

Fig. 1. (a) Elevated backrest with the 5 cm foam attached to the original backrest, (b) crank height, in the red triangle the four holes for adjusting the height can be seen (1: lowest, 4: highest).

Additionally to the power levels also seating position, crank height and crank length were varied. For the change of seating position the height of the backrest was changed between the position normally used and a 5 cm elevated backrest (normal: 1, elevated: 2), achieved by using a sti foam pad (Figure 1a). Furthermore three different crank height were used, taking advantage of the four mounting possibilities (from 1: lowest to 4: highest) of the front fork of the hand bike (Figure 1b). Crank length was varied by using cranks with lengths of 160 mm, 165 mm (standard crank used by the athlete (orig)) and 175 mm. Eventually a total of 22 trials with different settings and the aforementioned power levels were performed. However, not all possible combinations were measurable due to constraints of the seating position and freedom of movement of the arms. (Note: in section 3the single trials are named according to these settings [crank-pos]-[backrest-height]-[crank-length]-[power] thus 4-2-160mm-160W indicating a measurement at the highest crank-position (4), elevated backrest (2) with a 160 mm crank at 160 W.)

To capture the athlete's movement 22 retro-reflective spherical markers (diameter: 16 mm) were attached to the athlete's upper body following an adapted VICON upper body protocol. The movement was captured using ten Vicon Bonita infrared cameras (VICON, Ofxord, UK) positioned around the handcycle and recording at a frequency of 100 Hz. Concurrently signals of seven muscles were recorded bilaterally using a Myon 320 wireless EMG system (myon AG, Schwarzenberg, CH) recording at 1000 Hz and two Ag-AgCl surface electrodes with a diameter of 20 mm (Ambu Blue Sensor N, Ambu A/S, Ballerup, DEN) per muscle which were placed with an inter- electrode distance of 20 mm on the longitudinal axis of the muscle-belly following the recommendations of Hermens et al. [13]. The muscles recorded were: m. sternocleidomastoideus (STERNO), m. pectoralis major (PECT), m. deltoideus (DELT), m. biceps brachii (BIC), m. triceps brachii (TRIC), forearm extensors (EXT) and forearm flexors (FLEX).

For the synchronization of the two measurement systems an infrared LED operating at the same frequency as the infrared motion capturing system was used. The optical representation could be observed in the motion capture system and the voltage was recorded on one channel of the EMG system.

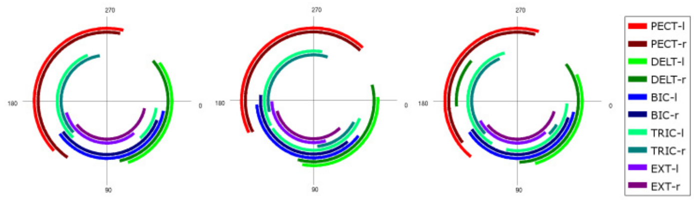
For each measurement the athlete was asked to start pedaling and verbally signaled reaching the desired power level. Both measurement systems where then started, the LED was activated for a short period and 40 s were recorded with both systems. After each measurement the athlete was allowed a break of at least 5 minutes to avoid any fatigue effect. EMG data was rectified and smoothed using forward-reverse moving average filter with a resulting window size of 200 ms. From the motion analysis data the trajectories of the markers positioned on the hand (i.e. near the center of rotation of the pedal-axles) were extracted and their foremost position was defined as 0 deg. Synchronized EMG data was then divided into single crank-cycles using the indices obtained from the motion analysis data and normalized to 360 deg. For each trial and muscle mean amplitude envelope and standard deviation over crank-cycle (0 deg to 360 deg) were calculated.

To assess the activity of the muscles a threshold was set to 30% of the local maximum of a muscle's amplitude. During periods exceeding this threshold the muscle was considered active (on), for periods falling below this threshold it was considered not-active (o). To avoid influence of motion artifacts or single bursts single activity times of less than 15 deg of the crank-cylce where removed. Duration of activation, on- and o -times and occurence of the maximum amplitude in each crank-cycle as well as iEMG values as indicator for net muscular e ort were calculated. iEMG was calculated as percentage of the subject's standard position (=100%), standard crank length at the lowest power level (2-1-orig-130W).

3. Results

All measured data were used for the calculation of the values mentioned. However, EMG data of FLEX and STERN could not be used because a steady activation did not allow any analysis, hence these muscles were excluded from the results. In this paper only exemplary results can be shown, however these are representative for all similar trials. For different crank heights it could be seen that there was a shift in the activation timing. For a lower crank height both the on and o event for all measured muscles occurred later in the crank-cycle (Figure 2b) than for a higher crank height (Figure 2c). Table 1 reveals that all muscles show similar activation duration, only DELT was clearly activated longer and TRIC shorter for the lower crank height. Similar results could be observed for all measured positions.

Similar to the changes for different crank heights it can be observed that a change in backrest also changes the activation pattern, i.e. with a higher backrest (Figure 2a) the muscles display a later onset and a later o set time than for the same configuration with a higher backrest (Figure 2b). The total duration of activation, however, does not differ greatly between the two conditions for most of the muscles observed. Only one muscle (TRIC) has a longer activation for a higher backrest (Table 2).



(a) 2-1-orig-190W (b) 2-2-orig-190W (c) 4-2-orig-190W (d) legend

Fig. 2. Activation times of all measured muscles (red: PECT, green: DELT, blue: BIC, turqoise: TRIC, purple: EXT, l: left, r: right) for different crank heights at 190 with an elevated backrest, (b) low crank (position 2), (c) high crank (position 4).

EMG amplitude plots are shown in Figure 3 for different trials with different crank lengths and power levels. It is interesting to note that for most of the trials the shortest crank (160 mm, red) yields the highest EMG amplitude, however the medium length crank (standard crank, 165 mm, blue) and the longest crank (175 mm, green) often show similar behavior with the standard crank even displaying lowest amplitudes for some muscles (especially TRIC, BIC, EXT).

Table 1. on and o in degree of crank-cycle time of activation in deg (act) the maximum amplitude for each muscle (l: left, r: right, 2-2: low crank, 2-4: high crank).

	2-Feb			4-Feb		
	on	o	act	on	o	act
PECT l	154	313	159	130	287	157
PECT r	153	313	160	143	285	142
DELT l	357	100	103	336	74	138
DELT r	345	105	120	175	221	46
				323	88	165
BIC l	38	176	138	11	147	136
BIC r	50	186	136	18	148	130
TRIC l	21	146	125	3	103	100
	150	280	130	121	255	134
TRIC r	28	85	57	31	46	15
	166	288	122	135	247	112
EXT l	73	179	106	48	152	104
EXT r	46	164	124	16	141	125

Table 2. on and o in degree of crank-cycle time of activation in deg (act) the maximum amplitude for each muscle (l: left, r: right,2-1: low backrest, 2-2: high backrest).

	2-Jan			2-Feb		
	on	o	act	on	o	act
PECT l	137	283	146	154	313	159
PECT r	125	281	156	153	313	160
DELT l	324	71	107	357	100	103
DELT r	319	78	119	345	105	120
BIC l	10	145	135	38	176	138
BIC r	21	145	124	50	186	136
TRIC l	8	48	40	21	146	125
	133	247	116	150	280	130
TRIC r	137	261	124	28	85	57
				166	288	122
EXT l	50	164	114	73	179	106
EXT r	11	142	131	46	164	124

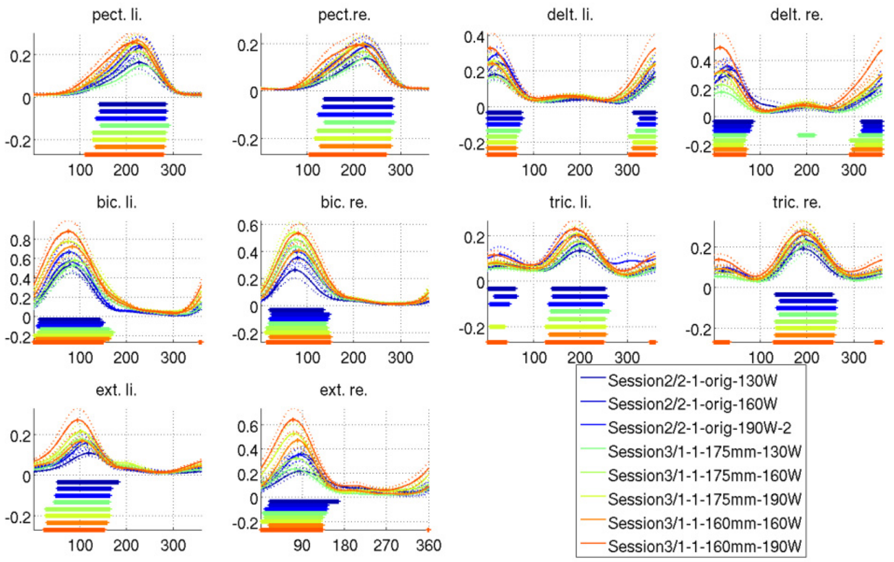


Fig. 3. Mean amplitudes (solid) over the crank-cycle standard deviation (dotted) of all muscles using different crank lengths (red: 160 mm, blue: 165 mm (orig) and green: 175 mm) at 130, 160 und 190 W.

Table 3. iEMG values in percent referred to the original settings at 130 W (=100%) for all muscles (l: left, r: right), values lower than 100 are marked bold.

	PECT		DELT		BIC		TRIC		EXT	
trial	l	r	l	r	l	r	l	r	l	r
2-1-orig-130W	100	100	100	100	100	100	100	100	100	100
2-1-orig-160W	134	135	118	91	111	138	113	114	137	117
2-1-orig-190W	146	152	143	102	131	162	170	134	153	119
2-2-orig-130W	111	115	129	99	117	125	153	121	135	139
2-2-orig-160W	136	112	125	100	124	131	155	120	142	142
2-2-orig-190W	154	133	152	125	139	129	129	130	165	151
4-1-orig-130W	145	131	88	70	117	150	195	113	129	99
4-1-orig-160W	114	123	115	82	116	167	200	116	152	128
4-2-orig-130W	121	109	97	63	116	137	107	91	126	138
4-2-orig-160W	131	105	118	77	125	145	114	98	132	143
4-2-orig-190W	147	130	145	102	131	159	124	107	158	170
1-1-175mm-130W	92	107	99	61	113	170	103	97	148	82
1-1-175mm-160W	136	128	139	80	136	205	122	115	176	122
1-1-175mm-190W	158	157	141	100	190	233	144	141	204	176
1-2-175mm-130W	112	112	115	87	141	131	110	109	168	116
1-2-175mm-160W	131	128	139	112	144	143	126	126	159	130
1-2-175mm-190W	159	155	133	121	170	197	134	143	192	192
1-1-160mm-160W	160	146	129	104	168	169	134	132	153	142
1-1-160mm-190W	173	160	176	147	198	228	172	161	238	231
1-2-160mm-130W	115	131	153	108	152	134	123	114	133	198
1-2-160mm-160W-2	151	145	165	130	149	158	131	125	153	209
1-2-160mm-190W	186	161	185	175	186	195	156	166	227	303

The iEMG values for all trials conducted are given in Table 3 where the athlete's standard position at 130 W is taken as reference equaling 100% and all other values are given relative to this reference. It can be ob- served that there are only few trials and few muscles falling below the 100% values of the original settings. Furthermore a comparison of the different power levels reveals that iEMG values for the standard configuration still are lowest and hence can be assumed more efficient than the others.

4. Discussion

In this project it could be clearly shown, that different seating positions in a handcycle change the muscle activation pattern. It could be observed that activation times tend to change due to the distance of the crank (crank height) in relation to the athlete's shoulders (backrest height). Although the activation patterns changed, the activation times did not, which disagrees with our expectations (1) and (2).

EMG amplitude showed changes due to crank length and although the shortest crank yielded the highest amplitude the results for the standard crank and the longest crank were not as unambiguous as expected because amplitude for several muscles was lowest with the standard crank, which is again not in accordance with our expectation (3) .

As for the iEMG - which can be regarded as an indicator for net muscular e ort - it can be stated that results clearly showed that the standard settings - independent of power level - permanently showed the lowest values. Values for the high crank height, low backrest and long crank show tendencies towards smaller iEMG values, but not for all muscles, hence the results are not meeting our expectation (4).

Summing up the outcome of this study it can be stated that according to the present data the results are indicating that the actual position suits the athlete well and no need for immediate change is obvious. The athlete's already established motion and activation pattern seems to fit his position on the bike and vice- versa. Small potential for improvement concerning iEMG can be detected for the longest crank but for confirmation a longer training period with the unfamiliar crank would be required.

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