THE EFFECTS OF RESTRICTING THORAX MOTION DURING FIXED-SEAT ERGOMETER ROWING

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This study assessed the biomechanical effects of restricted thorax motion during fixed-seat ergometer rowing. Eleven able-bodied participants performed 2 bouts of 4 minutes of submaximal rowing on a custom-made fixed seat. First, the participants were strapped at the waist, allowing thorax motion ("Free thorax"), then strapped around the chest, preventing thorax motion ("Fixed thorax"). Kinematic analysis and force exerted on the ergometer chain were recorded. The "Fixed thorax" setup had lower total power output ($p=0.011$, Cohen's $d=1.61$), total average joint power ($p=0.006$, Cohen's D $d=1.32$) and VO_2 ($p=0.005$, Cohen's $d=2.00$). No differences existed in the elbow and shoulder power between the setups. The results suggest that restricting the thorax has a negative effect on submaximal effort rowing performance, which could have implications for competitions.

KEYWORDS: Para-rowing, impairment, performance, movement constraints.

INTRODUCTION: In Para-rowing, athletes are classified into one of three classes based on the effect of their impairments on rowing performance (Tweedy & Vanlandewijck, 2011). Within these, rowers in the PR1 class have no leg function, little/no thorax function, and poor sitting stability (World Rowing, 2017). Therefore, athletes in the PR1 class use a stationary (fixed) seat in the boat (World Rowing, 2017). Consequently, PR1 rowers rely predominantly on their arms and shoulders to propel the boat, and do not have much contribution form the thorax (World Rowing, 2017). However, by manipulating the angles of the seat and backrest, a PR1 rower increased their performance by 9% during ergometer rowing through increased thorax motion and power generation (Severin et al., 2021). It is clear that the thorax serves an important role in both normal rowing (e.g., Bechard et al., 2009; Li et al., 2023), and fixed-seat rowing (Agius et al., 2023; Cutler et al., 2017). The current rules in Para-rowing requires PR1 rowers to use a strap across their lower thorax for stability (World Rowing, 2017), thus leaving the upper thorax "free" to contribute to the rowing task to the extent that function allows. To date, it is unclear how residual thorax function may contribute to rowing performance and the effects of a completely fixed thorax have not been assessed. As indicated in the study by (Severin et al., 2021), PR1 rowers may have some residual thorax function that indeed may contribute to rowing performance. Since all PR1 rowers compete against each other, understanding how a "free" versus a "fixed" thorax may contribute to rowing performance is important. Therefore, this study aimed at investigating the effect of a "free" versus a "fixed" thorax during fixed-seat ergometer rowing in terms of total power output and joint kinematics, as well as the individual joint power, and the relative contribution of each joint to the produced power.

METHODS: Eleven able-bodied participants volunteered for this study (3 F/9 M, 27.9±6.3 yrs., 78±14kg, 182±7cm) and provided written informed consent prior to data collection. Participants were all physically active and used a rowing ergometer regularly in their training. Following a warmup, participants performed 4 minutes of submaximal-effort rowing in two setups on an indoor rowing ergometer (Care RowPerfect3 Bv., The Netherlands). Oxygen uptake (VO_2) and respiratory exchange ratio [RER] (Oxycon Pro, Jaeger GmbH, Hoechberg, Germany) and heart rate (Polar Electro Inc., Kempele, Finland) were measured continuously. Each participant maintained a power output where they would remain in an aerobic state (RER around 1.0) for the 4 minutes in both setups, and the power outputs were established accordingly during a familiarisation session at least three days before the testing session. During the familiarisation session, each participant rowed in each setup for several minutes to both identify the suitable intensity and to become familiar with rowing under the constrained conditions.

A custom-made fixed ergometer seat with an adjustable backrest was used during the testing, and participants' legs were resting on a step box to prevent them contributing to the rowing task. For the first setup ("Free thorax"), the backrest was folded back so to not interfere with the rowing, and the participants were strapped with a low strap around their waist similar to what PR1 rowers use in competition (World Rowing, 2017). For the second setup ("Fixed thorax"), the backrest was folded up to near vertical and a second strap was attached around the participants' chest.

An eleven-camera motion capture system (Oqus, Qualisys AB, Stockholm, Sweden, 100Hz) tracked markers allocated to the left upper extremity and thorax (C7 to T8 vertebrae) in accordance with ISB standards (Wu et al., 2005). A load cell (N-DTS-FS5, Noraxon USA Inc., Scottsdale, Arizona, 1500Hz) recorded the force exerted on the chain of the ergometer (Severin et al., 2021). The data was imported to Matlab R2022b (MathWorks inc., Nantick, MA, USA) and filtered using a 4^{th} order Butterworth lowpass filter at 5Hz.

The angles of the forearm to humerus (elbow), humerus to thorax (shoulder) and thorax to the global coordinate system (thorax) were calculated using an ZXY sequence (equivalent to sagittal plane, frontal plane, and transverse plane). The elbow and thorax were considered 1 degree of freedom (DOF) joints with only sagittal plane motions, while the shoulder was considered a 3 DOF joint. The joint moments were calculated according to Dumas et al. (2007), and were multiplied with angular velocities to calculate the joint powers. The sum of the average joint powers in each plane (total average joint power, P_{tot}), one DOF for the elbow and thorax and 3 DOF for the shoulder, was calculated. The average joint power produced at each joint was then divided by P_{tot} to calculate the relative contribution of each joint.

Paired t-tests were used to compare the setups in terms of joint range of motion (ROM), average joint power, and relative joint power. Effect sizes were calculated using Cohen's D and the alpha level was set to $p<0.05$. All statistical analyses were performed using the "*rstatix"* package in RStudio 2023.09.1 (R Core Team, 2023).

RESULTS:

The P_{tot} (sum of the elbow, shoulder, and thorax powers), power output, and VO_2 were all significantly lower during the "Fixed thorax" setup than during the "Free thorax" setup (Figure 1, Table 1).

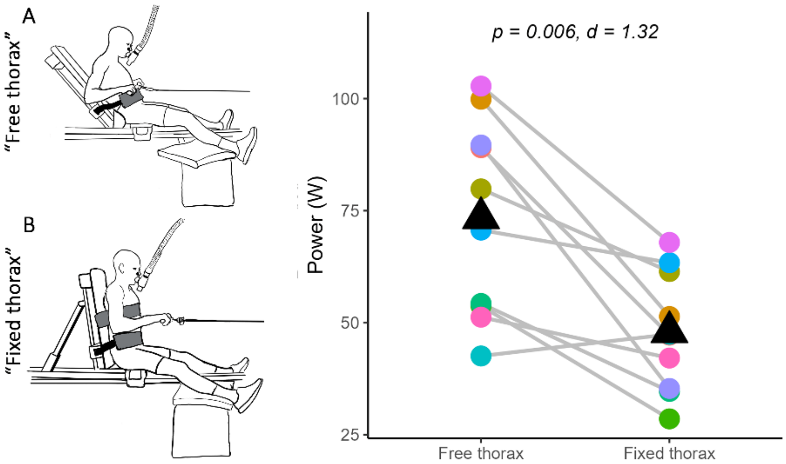

Figure 1: A: schematic of the "Free thorax" setup. B: schematic of the "Fixed thorax" setup. C:The average total joint power produced by the elbow, shoulder, and thorax in both setups. The points show the participants and their individual change while the black triangles indicate the mean power at each setup.

The lower P_{tot} in the “Free thorax” setup was predominantly a consequence of reduced thorax flexion/extension power with no changes in the power produced at the shoulder and elbow at a group level. The relative contribution of power was increased at both the shoulder and elbow, as a result of the reduced contribution of the thorax. RER and heart rate were not significantly different between the setups. The restricted thorax also reduced the ROM of the shoulder in the sagittal and frontal planes.

Table 1: Effects of “Free” and “Fixed” thorax during ergometer rowing.

		Free thorax	Fixed thorax	p	ES
	Power output (W)	75±28	47±15	0.011	1.61
	P_{tot} (W)	73±22	48±13	0.006	1.32
	RER (VCO2/VO2)	1.0±0.1	1.0±0.1	0.141	-0.53
	VO2 ($L·kg·min^{-1}$)	25.3±5.2	17±3.6	0.005	2.00
	Heart rate (bpm)	137±20	133±22	0.678	0.19
	Stroke rate (spm)	40±2	50±3	<0.001	4.33
	Stroke length (m)	0.8±0.02	0.5±0.01	<0.001	1.16
Joint ROM (°)	Elbow flexion/extension	96±7	96±5	0.954	-0.02
	Shoulder flexion/extension	115±14	93±9	0.001	1.82
	Shoulder abduction/adduction	61±14	51±13	0.096	1.18
	Shoulder internal/external rotation	17±6	21±4	0.074	-0.81
	Thorax flexion/extension	51±15	6±3	0.000	3.22
Joint power (W)	Elbow flexion/extension	12±5	12±6	0.974	-0.02
	Shoulder flexion/extension	20±7	24±9	0.243	-0.46
	Shoulder abduction/adduction	8±7	9±3	0.929	-0.04
	Shoulder internal/external rotation	0±1	0±1	0.155	0.58
	Thorax flexion/extension	33±11	3±3	0.000	2.97
Joint power (%)	Elbow flexion/extension	17±6	26±11	0.031	-1.11
	Shoulder flexion/extension	27±4	50±12	0.000	-1.88
	Shoulder abduction/adduction	11±7	18±5	0.017	-1.45
	Shoulder internal/external rotation	0±1	-1±2	0.174	0.51
	Thorax flexion/extension	45±7	7±5	0.000	5.41

P_{tot}: total average joint power; VCO_2: Volume carbon dioxide; VO_2: Volume oxygen ;bpm: beats per minute; spm; strokes per minute; ROM: range of motion.

DISCUSSION: This study showed that fully restricting the thorax during ergometer rowing reduced the power output and P_{tot} produced while altering the relative joint power contribution and kinematics of the upper body.

The constraint we applied was successful in restricting the thorax as indicated by its low ROM. Further, to maintain predominantly aerobic conditions in both setups, our participants used a lower power output during the “Fixed thorax” setup, which is in line with previous research (Cutler et al., 2017).

It is important to note that the average joint powers produced at both the elbow and shoulder joints did not show a significant group effect as a result to the added constraint (Table 1). This suggests that there were no compensatory mechanisms present as a response to restricting the thorax, and importantly, no increased demands on the arms. However, it should be noted that a closer assessment of the individual responses showed that the participants used different strategies to adapt to the different setups. For example, during the ”Fixed thorax” setup, one participant had 11W higher average shoulder extension power, while another had 19W lower average shoulder extension power compared to the “Free thorax” setup. Further, the lower VO_2 during the “Fixed thorax” setup was unsurprising, despite similar heart rate at both setups since it is directly dependent on power output, while heart rate is not.

In this study, we assessed able-bodied individuals that were not competitive rowers, and thus only highlight the potential effects of thorax involvement in Para-rowing; actual PR1 athletes may respond differently than our participants. Any differences between the “Free thorax” and “Fixed thorax” setups on competitive Para-rowers should be investigated further. Athletes competing in the PR1 class are likely to have varying degrees of thorax function depending on the nature of their impairment but still compete against each other. Therefore, understanding both the effects of various degrees of residual thorax function, and various methods for strapping the thorax, on performance in Para-rowing is important.

CONCLUSION: This study showed that performing fixed-seat ergometer rowing with a “Fixed thorax”, rather than a “Free thorax” reduced the performance in terms of power output, joint power, and oxygen consumption. Taken together, the findings from study suggests that restricting the thorax during rowing has a negative effect on submaximal effort rowing performance. This could have implications for competitions in which athletes with various degrees of thorax function compete against each other.

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