Sports equipment design impact on athlete performance – The PR1 Paralympic women's indoor rowing world record

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Abstract

This paper presents findings from evaluating different designs by testing with a world-class Paralympic athlete during the development of high-performance Paralympic sports equipment. Seat designs for the paralympic rowing PR1 class developed through a new process focusing on maximizing movements and supporting impairments were tested by a world-class athlete on an indoor rowing ergometer and used in the 2021 indoor world rowing championship. Results show that the most performant design increased the individual athlete's power output by 47.6%, enabling the athlete to set a new world record with a margin of 13 seconds.

Introduction

Paralympic sports equipment geometry can significantly impact individual athlete performance [1–3]. Through an approach that uses prototyping [4] in combination with physical experimentation to measure both subjective and objective data in a stepwise iterative process, seat designs for the paralympic PR1 rowing class have been developed. To assess the performance of these designs, a world-class paralympic rower has used the designs on an indoor rowing ergometer. Paralympic rowing is divided into three classes (PR1, PR2, and PR3), depending on the severity of the athletes' impairment, regulated by The World Rowing Federation (FISA). Athletes competing in the PR1 class use a fixed seat classified with minimal to no trunk function [5] and rely on their arms and shoulders to generate power [9]. Recent PR1 studies show that design of experiments [1] is necessary to identify optimal geometries per individual athlete [2]. Equipment at the Olympic and Paralympic level should fit all individual athletes, resulting in optimal performance, safety, injury prevention, and fair play. For training purposes, many athletes use rowing ergometers for indoor workouts, and each year the indoor world championship uses the Concept2 rowing ergometer (Concept2, Inc., Morrisville, USA) as competitive equipment. The Paralympic athletes in the PR1 class compete without a dedicated manufacturer offering specialized off-the-shelf equipment for their individual movement parameters, force generation capabilities, and motoric abilities. Paralympic equipment can be improved considerably by better understanding the actual barriers (not only the diagnosed capabilities), translated into optimized geometries and equipment design. While there is research on personalized sports equipment to increase performance in able-bodied rowing [6–8], we postulate that Paralympic athletes can benefit even more.

Method

Three different seat designs were tested, selected from a structured data-set [2] through many different 3D printed prototypes by triple-loop learning [11]. These designs consist of a baseline (A), a customized carbon fiber seat from a PR1 race boat (B) adjusted for maximal performance based on previous results [2], and a (new) curved design intended to maximize athlete shoulder range of motion while stabilizing the athlete's trunk (C). The designs were tested by a 32-year-old female athlete, the current PR1 world record holder competing with a spinal cord injury located at the 10th thoracic vertebra. The athlete provided consent prior to the study in accordance with local legislation. The designs were fixed to a Concept 2 - PM5 rowing ergometer– used to measure power, stroke rate, and (virtual) distance. Heart rate was measured with an H10 Polar heart rate monitor (Polar Electro Oy, Kemple, FIN). Subjective rate of exertion (muscular, breathing, and general) were registered using Borg scale 6-20 [10]. The athlete's blood lactate levels were measured on several occasions to track progression and performance.

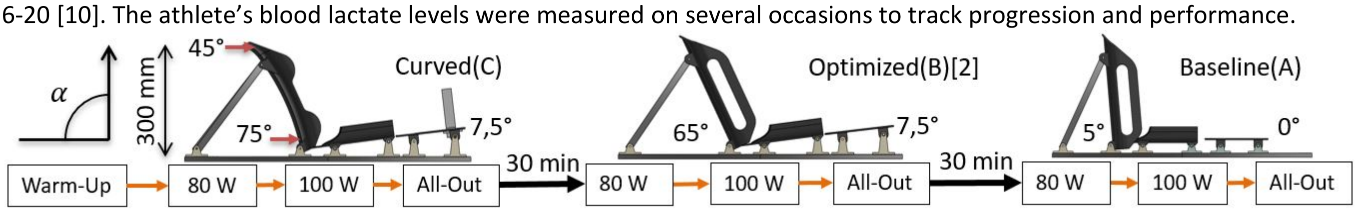

Fig. 1: Experimental design for evaluating and comparing the performance of the three different chair designs.

The three designs were tested according to (Fig. 1). After a 10-minute warm-up, the athlete did three 4minute-long sessions with 80 W target power, 100 W target power, and all-out power, respectively. Each session had a 1-2 minute break with 30 minutes rest between seating positions (Fig. 1), as described in [2].

Results

The results show that design C significantly increases performance compared to design A and design B. In addition, the athlete's blood lactate showed a reduction at 100W target power from 8.2mmol/L in the baseline to 2.3 mmol/L in the optimized position and 1.1mmol/L using the curved design C. At 80W target power, the stroke rate was similar when comparing C and B but reduced 7spm compared with A. At 100W target power, the stroke rate(C) got reduced by 12spm(A), 4spm(B). At all all-out, the stroke rate(C) got reduced by 14spm compared to(A) and 5spm(B)(Fig. 2a). Heart rate (Fig. 2b) was reduced by 10/9bpm(B) at 80/100W and 16/13bpm(A), compared to C. When measuring rowing distance at All-Out testing, the length

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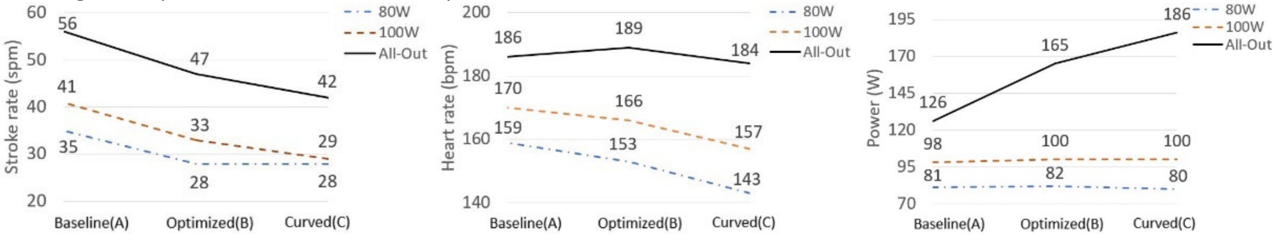
increased by 13.3% and 4.1%, respectively, compared with A and B. In Fig. 2c, the power output at all-out testing increased by 47.6% using C compared to A and 12.7% compared to B.



(a) (b) (c)

Fig. 2: Performance of Baseline(A), Optimized(B), and Curved(C) in terms of (a) Stroke rate, (b) Heart rate, and (c) all-out power.

Table 1: Subjective feedback from the athlete using BORG scale

Position	Curved(C)			Optimized(B)			Baseline(A)		
Power (W)	80	100	All-out	80	100	All-out	80	100	All-out
Muscular	8	12	19	8	12	18	10	15	17
Breathing	8	15	20	10	14	19	10	15	19
General	8	14	20	9	13	19	10	15	18

The subjective feedback from the athlete (Table 1) shows that in sub-max testing, the athlete felt less strain on her body using C and could go all-out, whereas she felt restricted from the A and B.

Discussion

The results clearly indicate that design C is more performant than A and B. In the new curved design (C), the athlete was able to generate much more power. As seating positions found in designs A and B were also tested in [2] by the same athlete, it is relevant to investigate differences in power output between experiments. The power output from the athlete was close to identical in the two experiments for the seating positions found in designs A and B, respectively. Design C was also the best performing position, observing the subjective Borg scale, similar to the physiological data. Two days after the experiment presented in this article, the same athlete set a world record using design C. The authors believe the approach showcased in this paper to be highly relevant for designing high-performing Paralympic sports equipment, which can be used in other sports and with individual athletes to increase performance and efficiency. The authors argue that better performing Paralympic sports equipment would also result in higher participation within para-sports, both on a professional and recreational level, as it increases the athlete's performance, joy, and comfort. While observing the athlete, physiotherapists stated that design C has injury prevention capabilities, enabling the whole core. With this design, the athlete is capable of training in longer sessions or at higher intensity. After the results shown in this paper were recorded, the athlete has adapted more to this new design and is training healthier with increasing power output.

Conclusion

This paper has presented results from evaluating different designs developed through a new approach for designing high-performance Paralympic sports equipment. The approach implemented in this article consists of 1) combing experiments to find the right basic biomechanics fit followed by 2) human-centered design iterations to optimize said fit. Results strongly indicate that the most performant design increased the athlete's performance in terms of work ergonomics, showing a performance increase in power by a total of 47.6%. Furthermore, the optimized design (C) was used two days after the experiment to set a new indoor women's PR1 world record, with 8.18,5s, 13s faster than the previous world record.

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