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Physiological responses at the anaerobic threshold and at peak performance during arm crank ergometer diagnostics compared to wheelchair propulsion on a treadmill in elite wheelchair basketball players

Ann-Kathrin Otto[1], Rüdiger Reer[1], Birger Holtfreter[2], Helge Riepenhof[2], Jan Schröder[1]
[1]Institute of Human Movement Science, University of Hamburg, Hamburg, Germany
[2]Center of Rehabilitation Medicine, Emergency Hospital Hamburg-Boberg, Hamburg, Germany

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Summary

Background: The aim of this study was to compare arm crank with treadmill wheelchair ergometry by determining metabolic and respiratory outcomes at peak performance and individual anaerobic threshold in order to provide competitive wheelchair basketball players with optimal training prescription recommendations.
Methods: Eight players could be recruited from a first German division team. Oxygen uptake (VO_2), heart rate (HR), energy expenditure (EE), and lactate concentration (LA) was determined at peak performance and at individual anaerobic threshold during two stepwise increasing tests in a randomized order.
Results: Using the arm crank ergometer led to significantly lower results for VO_2 (25.7 ml kg^{-1} min^{-1} vs 50.0 ml kg^{-1} min^{-1}), EE (543 kcal h^{-1} vs 940 kcal h^{-1}) and HR (173 bpm vs 177 bpm) at peak performance and for VO_2, EE and HR at the anaerobic thresholds compared to the wheelchair treadmill procedure ($P = 0.012$), except for the HR at the LA threshold. LA at the anaerobic threshold showed significantly higher concentrations for arm crank ergometry (3.4 mmol l^{-1} vs 2.8 mmol l^{-1}, $P = 0.025$).
Conclusion: We therefore recommend using treadmill testing for wheelchair basketball players as it better mirrors demands of wheelchair basketball motions.

Keywords
Wheelchair basketball – Anaerobic threshold – Performance diagnostics

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Physiologische Belastungsreaktionen an der anaeroben Schwelle und bei der maximalen Leistung während der Armkurbelergometrie im Vergleich zur Laufbandergometrie bei

Introduction

In recent years, wheelchair sports have increasingly gained popularity and acceptance. Wheelchair basketball, especially, is the most popular [10]. According to the International Wheelchair Basketball Federation there are 105 National Organizations for Wheelchair Basketball worldwide including more than 100,000 players [14]. Wheelchair basketball is a team sport which requires skills and knowledge in the use of wheelchairs and basketball. The rules differ slightly from those of regular basketball. A team is made up of twelve players, five of whom are currently entitled to participate in the match on the playing field. The duration of the game is four times ten minutes [12].
Wheelchair basketball includes acceleration and deceleration, sprints and dynamic position changes. The game is characterized by maximum sprint actions and short recovery periods. Players have to activate aerobic as well as anaerobic systems during the game. The aerobic metabolism is the predominant capacity in wheelchair basketball. Furthermore, the anaerobic metabolism is important for short and high intensity actions which are decisive in the game [14]. For a successful game players need to exhibit fundamental skills such as passing, dribbling, shooting, and especially a smooth handling of the wheelchair. Wheelchair basketball players are positioned lower in comparison to basketball players without handicap and the propulsive forces are mainly coming from the arms and upper body strength [5]. To include players within all levels of physical potential and to ensure a fair competition, a Functional Player Classification System was

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Elite-Rollstuhlbasketballspielern

Zusammenfassung

Hintergrund: Das Ziel dieser Studie war es, die Armkurbel mit der Laufbandergometrie anhand von metabolischen und respiratorischen Outcomes während der Höchstleistung und an der individuellen anaeroben Schwelle zu vergleichen, um optimale Trainingsempfehlungen für Rollstuhlbasketballspieler zu geben.
Methode: Acht Spieler aus einer Erstligamannschaft konnten rekrutiert werden. Die Sauerstoffaufnahme(VO_2), die Herzfrequenz (HF), der Energieaufwand (EE) und die Laktatkonzentration (LA) wurden während der Höchstleistung und an der individuellen anaeroben Schwelle während der Durchführung von zwei Stufentests in randomisierter Reihenfolge erfasst.
Ergebnisse: Die Verwendung des Armkurbelergometers zeigte deutlich niedrigere Ergebnisse für VO_2 (25.7 ml kg^{-1} min^{-1} vs 50.0 ml kg^{-1} min^{-1}), EE (543 kcal h^{-1} vs 940 kcal h^{-1}) und HF (173 bpm vs 177 bpm) während der Höchstleistung sowie für VO_2, EE und HF an der anaeroben Schwelle im Vergleich zum Laufbandergometer ($P = 0.012$), mit Ausnahme der HF an der LA-Schwelle. LA an der anaeroben Schwelle zeigte eine signifikant höhere Konzentrationen für die Armkurbelergometrie (3.4 mmol l^{-1} vs 2.8 mmol l^{-1}, $P = 0.025$).
Zusammenfassung: Wir empfehlen die Verwendung des Laufbandergometers, da hier die Anforderungen des Rollstuhlbasketballs berücksichtigt werden.

Schlüsselwörter
Rollstuhlbasketball – Anaerobe Schwelle – Leistungsdiagnostik

implemented. The classification system consists of four classes with half point classes (1.0–4.5). For definition of each class, the system uses seat balance, trunk stability, trunk mobility in the horizontal, frontal and sagittal planes and wheelchair handling. In addition, the skills of throwing, bouncing, passing and dribbling are taken into account in the classification. Players in class 4.5 have a minimal disability and players in class 1.0 have a significant loss of stability. Due to the variety of functional abilities, which makes an assignment to a class partly impracticable, the subdivision is made in steps of 0.5. This makes it possible to group the players despite the fact that they belong to two classes. In a wheelchair basketball game it is allowed to play with a score of 14 classification points per team [6].

As wheelchair basketball competitions have become more prevalent, the importance for thorough medical care increases. Accordingly, sports medical performance diagnostic procedures should be considered carefully to properly customizing exercise intensities for an optimized improvement of players' endurance [14]. The role of varying individual abilities to use trunk muscle capacities for propulsion should be taken into account, especially. Thus, comparisons of physiological responses during wheelchair propulsion on a treadmill and efforts during an arm cycle ergometer have been investigated in a few studies for various protocols and test devices [1,3,4,10]. Some studies analyzed outcome parameters such as heart rate, maximum oxygen uptake, respiratory quotient, and ventilation [3,10]. Other studies investigated the maximum oxygen uptake and heart rate [4,8,11] during wheelchair driving and arm crank ergometry as well as arm muscle strength. In a review, Baumgart et al. identified maximum oxygen uptake values for Paralympic sitting sports like wheelchair basketball and determined the influence of test-mode on VO_2max, among other things [1]. There was conflicting evidence about differing or correlating outcomes among arm crank or treadmill test devices. While some studies found significant differences between the ergometers [1,3,10,11], others did not [4,8]. So far, the majority of findings refer to peak performance investigations. To date, comparisons of physiological responses during wheelchair propulsion on a treadmill and efforts during an arm crank ergometer with a special emphasis on lactate threshold concepts are missing.

Having in mind that training intensity and volume recommendations are actually often determined by performance capacities at the anaerobic threshold, the purpose of this study was to compare physiological responses like the blood lactate concentration, the heart rate, the energy expenditure and the oxygen uptake during wheelchair propulsion on a treadmill compared to an arm cycle ergometer not only at the peak performance level but also at the individualized anaerobic lactate threshold referring to Dickhuth [2].

We hypothesized significant differences between wheelchair propulsion on a treadmill compared to an arm crank ergometer.

Methods

Participants

Eight elite wheelchair basketball players including national team members could be recruited from a first division team (Table 1). Two players had a traumatic paraplegic lesion (T12, T6), one player suffered a poliomyelitis, another had a bilateral above knee amputee, the fifth

Table 1. Anthropometric parameters (mean ± SD) of the recruited participants.

Subject	Sex	Age (years)	Height (cm)	Mass (kg)	Classification	Disability level
1	F	32	174	66	4.5	Walker
2	F	27	162	64	3.5	Nerves diseases
3	M	26	120	74	3.5	Bilateral above knee amputee
4	M	31	183	98	4.5	Unilateral below knee amputee
5	F	30	175	53	1.5	Traumatic paraplegic lesion (T12)
6	M	31	172	66	2	Traumatic paraplegic lesion (T6)
7	M	32	145	48	1.5	Poliomyelitis
8	M	24	185	75	4	Walker
	Mean	29.1	164.5*	68.0*	3.1	
	SD	±2.9	±20.6	±14.3	±1.2	

Legend: F: female, M: male, T: thoracic level, cm: centimeter, kg: kilogram.
*Average and standard deviation refer to the total sample including both sexes and amputees.

player had a unilateral below knee amputee, the sixth had a nervous system disease, and the last two participants are on walkers. The subjects were informed about the requirements for participating at the investigation one week before the investigation started. The requirements included avoiding physical stress during the last 48 h before testing, a long sleeping time, the introduction for adequate drinking and the retaining of food habits. Subjects were excluded from the study if they had injuries at the upper extremities or if they did not maintain the requirements. Participants were informed about the study procedures and probable discomfort. They signed the written informed consent before the initiation of their study participation.

Design

The study was conducted as a repeated-measure design with two repetitive measurements in a randomized order. The randomization was assigned by lot without putting back. This study followed the ethical standards of the declaration of Helsinki.

Test devices and procedures

The participants were tested in two graded maximal exercise tests which were separated by seven days rest. Tests took place at the same laboratory and at the same time of the day to minimize circadian variations. Subjects were tested on a treadmill (HP Cosmos Saturn 300/100r, H/P/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany) and on an arm crank ergometer (Motion 800 med, Emotion Fitness GmbH & Co. KG, Hochspeyer, Germany). For the tests on the arm crank ergometer, players used their own wheelchair (Fig. 1). The arm cycle was adjusted to the tune of their sternum. On the treadmill, participants were tested in their own basketball wheelchair (Fig. 2).

The following outcomes were assessed at the peak performance level and at the individual anaerobic lactate threshold (1.5 mmol l^{-1} above the minimum lactate equivalent) reported by Dickhuth (1): capillary blood lactate (LA, mmol l^{-1}), heart rate (HR, bpm), energy expenditure (EE, kcals h^{-1}), and oxygen uptake (VO_2, ml kg^{-1} min^{-1}).

Ramp test protocol

The arm crank ergometer test began with 50 watts as a starting load which was increased by 20 W every three minutes. The participants turned the crank by 60 revolutions per minute. The test on the treadmill started with 6 km/h and 1% elevation. The speed was increased by 1.5 km/h every three minutes. The test protocols were developed on the basis of the literature and adapted after previous tests [11]. Both tests continued until the subjects gave up due to physical exhaustion. In-between each grade, a thirty-second break was implemented to take the peripheral lactate blood sample from the earlobe and the heart rate values directly at the end of the stage. Respiratory parameters were taken continuously and documented directly after each stage like the heart rate.

Statistical analyses

The results were presented as median (MED) and quartile range (Q75–Q25). Group differences

Figure 1
Test situation at the arm crank ergometer.

between devices were tested using the non-parametric Wilcoxon-test and correlations were determined using the Spearman's concept (SPSS, IBM, Armonk; NY, USA). Significance was accepted at the 5% level ($P \leq 0.05$).

Results

The total of the eight subjects completed both maximal exercise tests. In Table 2, the outcome for LA (mmol l^{-1}), HR (bpm), EE (kcals h^{-1}) and oxygen uptake (VO_2 ml kg^{-1} min) are given for the peak performance level and the lactate threshold concept (Dickhuth) comparing arm crank and treadmill results.

At the peak performance level, the athletes showed significantly higher values for VO_2max at the treadmill condition compared to the arm crank ($Z = 2.52$, $P = 0.012$), which were almost two-fold higher (50.0 ml kg^{-1} min^{-1} vs 25.7 ml kg^{-1} min^{-1}) (Fig. 3). Furthermore, the maximum HR was about 4 bpm higher under the treadmill condition ($Z = 2.53$, $P = 0.011$), and the EE was almost two-fold higher, too ($Z = 2.52$, $P = 0.012$). Only, the maximum LA values did not differ significantly ($Z = 0.00$, $P = 1.000$). HR and LA showed meaningful and significant correlations ($r_s > 0.80$, $P < 0.05$), while VO_2max showed no correlation ($r_s < 0.01$, $P = 0.98$).

At the individual anaerobic lactate threshold (Dickhuth), we found significantly lower LA concentrations at the threshold for the treadmill compared to the arm crank condition (2.8 mmol l^{-1} vs 3.4 mmol l^{-1}, $Z = 2.24$, $P = 0.025$) (Fig. 3). For VO_2 and HR, as well as for EE, we found the same relations like in peak performance: a non-significant difference of 4 bpm more for the treadmill ($Z = 1.68$, $P = 0.093$), and almost two-fold higher values for VO_2 and EE ($Z = 2.52$, $P = 0.012$) (Fig. 3). Correlations between treadmill and arm crank were high only for EE ($r_s = 0.81$, $P = 0.015$), while the other correlations remained non-significant ($r_s < 0.67$, $P > 0.05$).

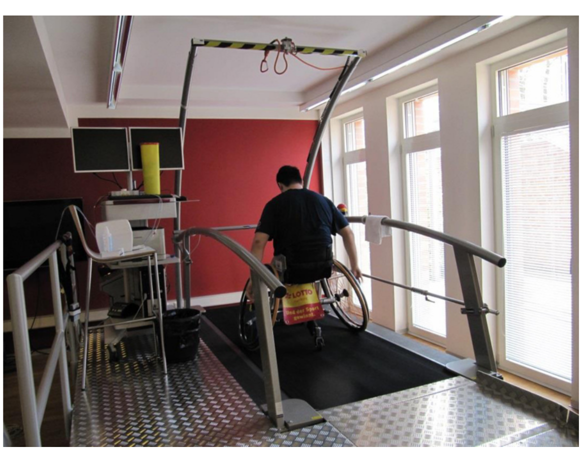

Figure 2
Test situation on a treadmill.

Discussion

The purpose of this study was to compare the physiological responses during wheelchair propulsion on a treadmill compared to an arm crank ergometer with a special emphasis on the lactate threshold, because training intensity and volume recommendations are actually often determined by performance capacities at the anaerobic threshold. Comparable investigations are lacking, so far. Significant differences between the two test devices were hypothesized and could be confirmed. VO_2, HR and EE at peak performance and at the anaerobic lactate threshold showed significantly higher values, while LA was significantly lower using the

Table 2. Performance outcome parameters corresponding to arm crank ergometry and treadmill wheelchair propulsion ergometry at peak performance and at the individual anaerobic lactate accumulation threshold (referring to Dickhuth) given as median with quartile range (75%/25%).

		VO_2 (ml min^{-1} kg^{-1})	Z (P)	r_s (P)	HR (bpm)	Z (P)	r_s (P)	EE (kcal h^{-1})	Z (P)	r_s (P)	LA (mmol l^{-1})	Z (P)	r_s (P)
Peak performance													
Arm crank	Median	25.7			173			543			5.9		
	(Q75–Q25)	(29.3–22.7)	2.52	0.006	(180–161)	2.53	0.826	(627–460)	2.52	0.692	(8.4–5.5)	0.000	0.857
Treadmill	Median	50.0	(0.012)	(0.988)	177	(0.011)	(0.011)	940	(0.012)	(0.057)	6.8	(1.000)	(0.007)
	(Q75–Q25)	(51.2–45.0)			(188–170)			(1225–756)			(8.7–5.7)		
Individual anaerobic threshold													
Arm crank	Median	19.1			145			368			3.4		
	(Q75–Q25)	(21.1–18.1)	2.52	−0.571	(158–138)	1.68	0.667	(458–348)	2.52	0.810	(4.1–3.1)	2.24	0.524
Treadmill	Median	39.2	(0.012)	(0.139)	149	(0.093)	(0.071)	787	(0.012)	(0.015)	2.8	(0.025)	(0.183)
	(Q75–Q25)	(40.9–36.7)			(161–146)			(880–670)			(2.9–2.5)		

Legend: VO_2: oxygen uptake, HR: heart rate, EE: energy expenditure, LA: lactate concentration, Wilcoxon test *Z*-value (*P*-value), Spearman correlation coefficient r_s (*P*-value).

treadmill compared to the arm crank. These results suggest that less muscle mass is involved leading to the pronounced lactate concentration increases.

Our peak performance results were in line with several studies also reporting significant differences between wheelchair propulsion on a treadmill compared to arm crank ergometry [1,3,10,11], but were contradictory to other studies that did not report significant differences [4,8]. Gass et al. [4] did neither find differences between arm crank exercise and wheelchair propulsion on a treadmill in the maximum oxygen uptake nor in the maximum heart rate, while McConnell et al. [8] found no VO_2max differences either but the maximum heart rate was reported to be significantly greater for the treadmill. Higher values during treadmill wheelchair propulsion could be explained due to a greater muscle mass activation that appear more specific to everyday ambulation [1,11]. In relation to another often used test form, Baumgart et al. [1] investigated in a review the differences between treadmill ergometer, wheelchair ergometer and arm crank ergometer and found higher VO_2max values for treadmill ergometer and wheelchair ergometer.

These partly contradictory findings may be due to several methodological confounders. We examined elite competitive wheelchair basketball players with varying disorders and differing trunk stability, and we found almost two-fold higher VO_2max results using the treadmill compared to the use of the arm crank. Maximum heart rate was slightly but significantly higher during the treadmill propulsion task (Table 2). Rotstein et al. [10] examined mixed performance level wheelchair drivers with a low competition level demonstrating low correlation for peak VO_2 during

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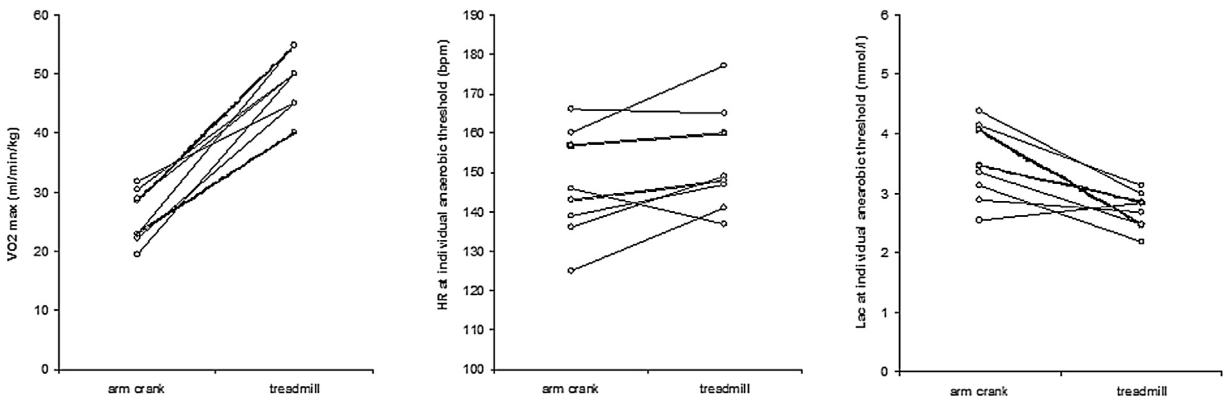

Figure 3
Results of the individuals of the arm crank and treadmill (the two walkers are highlighted).

wheelchair driving on a treadmill compared to arm crank ergometry ($r = 0.57$). Baumgart et al. [1] included studies with wheelchair basketball players with varying disorders and varying training status demonstrating VO_2max results ranging between 30.9 and 38.1 ml min^{-1} kg^{-1} for treadmill, arm crank ergometry and wheelchair ergometry. Gass et al. [4], Gass and Camp [3] and McConnell et al. [8] included exclusively quadriplegic athletes demonstrating VO_2max results ranging between 25 and 35 ml min^{-1} kg^{-1} for treadmill and 24 ml min^{-1} kg to 30.0 ml min^{-1} kg for arm crank ergometers, respectively.

Additionally, technical and instrumentation aspects should be considered. In our investigation, the arm crank ergometer could be positioned individually for each participant, providing an optimized height of the arm crank in relation to shoulder height and trunk stabilization properties, while earlier studies used a fixed arm crank ergometer, which could not be adjusted to shoulder height, in order to enable maximal efficiency for all subjects [4,10,11]. On the other hand, the fixed revolutions per minute used in our investigation could have influenced the aerobic performance. This is due to the fact that the anaerobic metabolism is more required with a higher resistance at higher workloads with constant cadence. Furthermore, the used wheelchair could have led to different results, as well [13]. In our study, participants used their own sport wheelchair with a differing architecture from a daily wheelchair. High stabilization in trunk may be needed to avoid low, lateral steering movements [7]. Consequential extra energy will be required [1,10,11]. This could be a reason for the high energy consumption measured in our study for the treadmill condition in comparison with daily used [4,10,11] or especially designed wheelchairs [8].

The study design itself could have influenced the differing results, too. While we used a randomized order of the repeated measures, others did not and ignored associated confounders like motivation, learning or fatigue effects [9]. Rotstein et al. [10] and Tropp et al. [11] did not specify these aspects.

Conclusion

Our results revealed meaningful differences in oxygen uptake, energy expenditure and heart rate, as well as in the lactate concentration at the individual anaerobic threshold between measures generated from arm crank or wheelchair treadmill ergometry. The knowledge of those meaningful differences between the compared test devices will help to avoid device dependent underestimations that could lead to serious consequences for the management of training intensities, probably leading to an accidental over-reaching or time-loss due to inefficient intensities. We therefore recommend using treadmill testing for elite wheelchair basketball players as it better mirrors demands of wheelchair basketball motions. A standardized protocol for wheelchair ramp tests is lacking so far, and should be defined to ensure a valid and comparable performance diagnosis for wheelchair athletes.

Conflicts of interest

The authors declare no conflict of interest.

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Corresponding author:
Ann-Kathrin Otto, Mollerstraße 10, 20148 Hamburg, Germany.
E-Mail: ann-kathrin.otto@uni-hamburg.de