Applied Ergonomics 71 (2018) 38–44

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

The effect of a novel square-profile hand rim on propulsion technique of wheelchair tennis players

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ARTICLE INFO

Keywords:
Wheelchair tennis
Task performance and analysis
Torque
Design
Wheelchair ergonomics

ABSTRACT

The purpose of this study was to investigate the effect of a square-profile hand rim (SPR) on propulsion technique of wheelchair tennis players. Eight experienced wheelchair tennis players performed two sets of three submaximal exercise tests and six sprint tests on a wheelchair ergometer, once with a regular rim (RR) and once with a SPR. Torque and velocity were measured continuously and power output and timing variables were calculated. No significant differences were found in propulsion technique between the RR and SPR during the submaximal tests. When sprinting with the racket, the SPR showed a significantly lower overall speed (9.1 vs. 9.8 m s^{-1}), maximal speed (10.5 vs. 11.4 m s^{-1}), and maximal acceleration (18.6 vs. 10.9 m s^{-2}). The SPR does not seem to improve the propulsion technique when propelling a wheelchair with a tennis racket in the hand. However, the results gave input for new hand rim designs for wheelchair tennis.

1. Introduction

Sports for people with a disability started after World War II when Sir Ludwig Guttmann started to introduce competitive sports as integral part of spinal cord injury rehabilitation. In 1960, the first Paralympic games were held in Rome (Gold and Gold, 2007). Wheelchair tennis was at the Paralympic games for the first time in Barcelona in 1992 (International Tennis Federation, 2017). Since then wheelchair tennis has grown and became more popular and professional.

For professional wheelchair tennis players, it is important to optimize the performance while reducing the risk of injuries (Churton and Keogh, 2013). That can be done by optimizing the athlete himself (e.g. tennis skills, fitness) but also by improving the wheelchair or the wheelchair-user interface (Bascou et al., 2012; Mason, 2011). Wheelchair ergonomics have been studied previously (Van der Woude et al., 1986; Van der Woude et al., 2001) but mainly in daily wheelchair propulsion. Previous wheelchair tennis studies showed that the interface between the player and wheelchair is not optimal when propelling the wheelchair with a racket in the hand (de Groot et al., 2017; Goosey-Tolfrey and Moss, 2005). The speed is lower when propelling with a racket in the hand (Goosey-Tolfrey and Moss, 2005) and this can be explained by the higher power loss that is visible when the racket hand has to (de-)couple to the hand rim compared to propulsion without a racket (de Groot et al., 2017). Subsequently, a higher mean and peak power output is generated during the push phase to overcome these power losses before and after the push phase (de Groot et al., 2017). On the long term, this higher power generation on the racket hand might lead to overuse injuries of the upper extremity. To optimize performance and to prevent overuse injuries, it might be an option to change the ergonomic design of the hand rim to improve the (de-)coupling of the racket hand to the rim.

A previous study with able-bodied participants found no effects of different hand rim designs, i.e., shapes and coating, on propulsion technique and physiological measures under submaximal conditions in a wheelchair ergometer (Van der Woude et al., 2003). In contrast, another hand rim study showed that a larger rim tube diameter yielded slightly but significantly better values for physiological parameters, possibly due to a better grip and therefore less stabilization by the larger muscle groups, while no differences were seen in propulsion technique parameters (Van der Linden et al., 1996). Two studies investigated commercially available hand rims, the NaturalFit (Koontz et al., 2006) and the FlexRim (Richter et al., 2009). The NaturalFit consists of a smooth oval surface for the palm of the hand and a higher-friction contoured slot for the thumb. The FlexRim has a regular rim but consists of a high friction elastic membrane that spans between the hand rim and wheel rim. Biomechanical differences were found when

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https://doi.org/10.1016/j.apergo.2018.04.001
Received 17 October 2017; Received in revised form 3 April 2018; Accepted 4 April 2018
0003-6870/

Fig. 1. The square-profile rim.

these new rims were compared to a regular rim. The NaturalFit showed reduced grip moments during a slow speed test while the peak resultant forces were higher during a fast speed test (Koontz et al., 2006). The FlexRim showed reductions in both peak and total forearm muscle activation (Richter et al., 2006) and oxygen cost (Richter et al., 2009). However, all these studies did not involve holding a tennis racket during propulsion.

One of the French wheelchair tennis players, i.e., Stéphane Houdet – former number 1 of the world, won several Grand Slam tournaments and medals in the Paralympics -, started to play with a hand rim with a square profile. The assumption is that this profile might make it easier to hold the racket against the rim due to the flat and larger surface of the rim (Fig. 1). Due to the possibly easier coupling of the hand with the racket to this square-profile rim, the power loss during coupling seen with the regular rim might decrease and subsequently the peak power output exerted during the push phase might decrease. In the end, this might lead to higher speeds but also to less overuse injuries of the upper extremity. No studies have yet addressed whether this square-profile hand rim is indeed advantageous regarding propulsion technique. Therefore, the objective of our study was to investigate the effect of this square-profile rim on the propulsion technique compared to a regular rim. The hypothesis is that propulsion technique - more specifically the power loss during (de-)coupling of the racket hand to the rim and subsequently the peak power output during the push phase - improves when using such a square-profile rim. To that end, a square-profile rim was developed (Fig. 1) to be able to test this assumption in a group of elite wheelchair tennis players, both during steady-state (constant velocity) and sprint conditions.

2. Methods

2.1. Participants

Eight experienced wheelchair tennis players participated in this study. Participant characteristics are summarized in Table 1. Participant's height and body mass were measured before the exercise tests. All participants were right handed. Test protocols were approved by the ethical committee of the Faculty of Human Movement Sciences, VU University, Amsterdam, the Netherlands. All participants gave informed consent prior to participation.

2.2. Design

In this cross-sectional study, participants performed two sets of three submaximal exercise tests and six sprint tests on a wheelchair ergometer (specifications of this non-commercially available stationary, computer-controlled wheelchair ergometer can be found in Niesing et al. (1990)) with and without holding their own racket twice. One set was performed with the regular rim and the other set was performed with a square-profile rim. Fig. 2 shows the characteristics of the rims. The square-profile rim was made of carbon fiber. The top side of the rim, i.e., where the thumb is located in Fig. 1, has a tennis racket grip texture (Babolat Comfort Pro Team, Lyon, France). The other three sides of the rim were smooth. Order of the sets was randomized among the participants to avoid a possible learning effect. Participants had at least 10 min rest between the sets. Video recordings (Panasonic HC-V770, Osaka, Japan), were made during all tests to be able to observe how athletes coupled their hand and racket to the rims.

Table 1
Participant characteristics.

Personal characteristics	N or mean (SD)
Men/Women (N)	4/4
Age (years)	23.0 (6.4)
Body mass (kg)	63.4 (15.2)
Height (m)	1.72 (0.09)
Body mass index (kg/m^2)	21.3 (4.9)
Wheelchair tennis experience (years)	9.3 (5.1)
Disability	*N*
Paraplegia, incomplete	2
Paraplegia, complete	1
Spina bifida	2
Short femur, hip deviation	1
Hip dysplasia	1
Spastic legs	1
Wheelchair tennis level	*N*
International youth (N)	5
International adults (N)	3

2.3. Wheelchair ergometer

The wheelchair ergometer was fitted on both sides with either a regular hand rim or the newly developed square ones. The wheelchair ergometer measures the torque around the wheel axles and the velocity at each wheel (Niesing et al., 1990). The sample frequency for data collection was set at 100 Hz. Ergometer settings were individually adjusted whereby the adjustments were based as good as possible on the athlete's sitting position in the personal tennis wheelchair. The guidelines for the ergometer settings were: 1) the projection of the center of gravity of the body just lied behind the wheel axle when sitting upright; 2) When the arms were hanging down, the palm of the hand lied on the wheel axle; 3) The position of the seat is horizontal with the back seat in a 90° position with respect to the seat; 4) The height and tilt of the foot support was set like the participant preferred; 5) To keep the body in position, straps on the hips, legs and feet were used. The maximal camber position of the ergometer was used (12°).

2.4. Submaximal exercise test

After a warm-up/familiarization session of 1 min at a velocity of 1.0 m/s and a resistance of 0.15 W/kg (using the mass of the participant and the mass of an average tennis wheelchair (8 kg)) and a rest period of 30s, the submaximal exercise blocks started.

The first 3 min submaximal exercise block was performed <u>without</u> the racket, a speed of 1.5 m/s and a resistance of 0.15 W/kg. The second exercise block was performed <u>with</u> the racket at the same resistance and velocity. The last exercise block was also performed <u>with</u> the racket but now the resistance was set at 0.25 W/kg at a velocity of 1.5 m/s. The participants had 2 min of rest between the submaximal exercise blocks. These blocks were performed with the regular and square-profile hand rims in a counter-balanced order. The square-profile hand rim was placed on both sides to be able to investigate the effect of this rim on propulsion technique in the non-racket hand as well in a future study.

After each set of submaximal exercise tests, i.e., after each rim condition, participants answered two questions, one on their rating perceived exertion (RPE, score 0–10) and one to give an indication about how they experienced the grip (score: 1 (very bad) to 5 (very good)).