Exploring different technical solutions of the interface between the hand, racket and the rim in wheelchair tennis

Jorine Koopmana, Monique Bergera, Aldo Hoekstrab, Sonja de Grootc

aHuman Kinetic Technology, The Hague University of Applied Sciences, Johanna Westerdijkplein 75, 2501 EH, the Hague, the Netherlands
bRoyal Dutch Lawn Tennis Association, Koninginneweg 1, 1312 AW, Almere, the Netherlands
cAmsterdam Rehabilitation Research Center | Reade, Overtoom 283, Amsterdam, the Netherlands

Abstract

Purpose

In wheelchair tennis propulsion of the wheelchair is different for both hands, since the athlete has to hold a tennis racket in one hand. Differences in propulsion technique, i.e. forces and timing, have been found between propelling the wheelchair with and without a racket in the hand [1]. Optimizing the coupling of the hand with the racket to the rim is expected to lead to performance improvement Therefore, the purpose of this study was to explore different technical solutions for the interface between the hand, racket and the rim in order to optimize propulsion technique during wheelchair tennis when holding a racket.

Methods

A limited literature study was done on the interface between the hand, racket and the rim. Qualitative interviews were held with (sub)top Dutch tennis players and trainers to gain insight in their technique. Video analysis of training and tennis matches of (sub)top Dutch tennis players were made to acquire knowledge of the hand and racket positions. A list of requirements and several ideas were developed. Different prototypes of (a part of) a rim were 3d printed and tested in laboratory settings.

Results

The literature study showed an increase of effectivity of propulsive force by creating a larger contact area and increased friction; different textures and/or materials can create an increased friction. The video analysis showed a variety of racket positions between players and within players at different speeds. Five different design components and the connections between them were explored: push rim, wheel, the tire, the hand and the racket. Prototypes with a larger contact area and/or different material showed higher isometric peak forces.

Conclusion

This study shows different technical solutions for the interface between the hand, racket and the rim, which will improve propulsion technique during wheelchair tennis. The technical solutions are; different shape of the rim and/or using textures and/or materials with high friction coefficient on the rim and/or hand.

Keywords: wheelchair tennis, propulsion technique, interface, hand, racket, rim

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

* Corresponding author. Tel.: +31 70 4458270
E-mail address: j.koopman@hhs.nl
1. Introduction

Since wheelchair tennis was introduced as a Paralympic Sport in Seoul in 1988, the sport has become more popular and professional. In professional wheelchair tennis players, it is important to optimize the performance. That can be done by optimizing the athlete (e.g. tennis skills, fitness) but also by improving the wheelchair and/or the wheelchair-user interface [3]. In wheelchair tennis propulsion of the wheelchair is different for both hands, since the athlete has to hold a tennis racket in one hand. Previous studies showed that the interface between the wheelchair tennis player and the wheelchair is not optimal when having to propel the wheelchair with a racket in the hand [1,2]. Differences in propulsion technique, i.e. forces and timing, have been found between propelling the wheelchair with and without a racket in the hand [1]. The longer time needed to couple the hand with the racket to the rim leads to higher power losses and subsequently higher power output generation during the shorter push phase, this is clearly shown in figure 1. Optimizing the coupling of the hand with the racket to the rim is expected to lead to performance improvement.

Therefore, the purpose of this study was to explore different technical solutions for the interface between the hand, racket and the rim in order to optimize propulsion technique during wheelchair tennis when holding a racket.

![Figure 1. Typical example of the propulsion technique of the left and right side during a submaximal exercise block on a wheelchair ergometer (upper graph) when propelling without a racket and the second submaximal exercise block (lower graph) when propelling with a racket in the right hand. The longer time needed to couple the hand with the racket to the rim leads to higher power losses and subsequently higher power output generation during the shorter push phase [1].](image-url)
2. Methods

To explore different solutions for the interface between the hand, racket and rim, an overview of the variables of the solution and the context was made; this is called the design space, figure 2. Rectangle A zooms in on the product-hand interface in cross section. The dotted rectangle (B) adds the complete push rim geometry. During pushing the push rim makes a continuous rotational movement and thus time should also be taken into consideration. To complete the model the displacement of the hand and arm during propulsion is added (C). The adaptable variables of the product-hand interface are distance I (the horizontal distance between rim and tire) and distance II (the vertical distance between rim and wheel rim), contact faces, material, texture, cross-section shape and circumference cross-section of the push rim, flatness, continuity and shape of the whole push rim.

A limited literature study was done on the interface between the hand, racket and the rim, i.e. rectangle A and B in figure 2. Qualitative interviews were held with (sub)top Dutch tennis players and trainers to gain insight in their technique (which parts of the hands were used) and possible solutions like grip and wearing gloves. Video analysis of training and tennis matches of (sub)top Dutch tennis players were made to acquire knowledge of the hand and racket positions. The videos were placed at the back and the side of the wheelchair during training. During matches the video was placed on the side of the field. A list of requirements based on literature study, interviews and video analysis were formulated and several ideas and concepts were developed to gain insight in the optimal cross-section shape, material, the texture and the place of the texture. Different prototypes of (a part of) a rim were 3d printed and tested with students in laboratory settings. The test set-up displayed in figure 3 was used. Participants pushed on a part of the rim and the force was measured with a dynamometer that was connected to an external frame. The different prototypes were compared with the original push rim.

Fig. 3. Test set-up; wheelchair on a frame, prototype mounted on the wheel, connected to a dynamometer.
3. Results

Based on the literature study, the interviews and the video analysis the following variables of figure 2 were excluded from the design space; the flatness (because the movement of the hand is executed parallel to the rim), continuity (x,z plane) and shape (y,z plane) of the whole push rim (because it is needed that the hand can always make contact at any point on the push rim to optimize the propulsion) and distance I and II (based on interviews this was not the focus);

Other findings based on literature and interviews were:

- Using a racket decreases the contact surface between the hand and the rim (variables: contact faces, cross-section shape, circumference cross-section push rim);
- Effectivity of propulsive force can be increased by creating a larger contact area and increased friction (variables: contact faces, cross-section shape, material and texture);
- Different textures and/or materials can create an increased friction [4] (variables: material and texture);
- Some athletes used gloves to cover their hands when the push rim is too slippery, the influence of the effectivity of gloves is never tested (variable: material and texture).
- When redesigning the rim the focus should be on optimizing the propulsion technique of the user (less power loss when coupling and lower peak forces during the push).

The video analysis showed a variety of racket positions between players and within players at different speeds (see figure 4). In figure 5 the use of the hand without a racket during propulsion of the wheelchair at different speeds is shown. Braking occurs by letting the push rim slip through the hands

![Fig. 4. Several racket positions (relative to the push rim (PR)) that were found in videos of wheelchair tennis players.](image)

![Fig. 5. Use of hands during propulsion without a racket of the wheelchair at different speed (fast and slow).](image)

The most important requirements, which are used to develop and select different solutions for the interface between the hand, racket and the rim, based on literature, interviews and video analysis, are:

The solution

- provides friction in the direction of propulsion and is smooth for braking
- provides more contact surface between the hand and the push rim.
- prevents loss of power when coupling to the push rim/ wheel during propulsion, and subsequently the high peak forces during the push.
- allows the racket to be held in a position ready to hit a ball.
- may not cause any injuries to the user.

Based on the system boundary A of the design space, 5 different components were distinguished, the push rim, wheel, the tire, the hand and the racket (figure 6).
The idea generation and concept development is based on these components and the interaction between them. Idea generation resulted in 4 different concepts. Concept 1, based on friction on the rim in one direction and smooth in other direction (variables: material and texture); Concept 2, based on a stable racket support by the rim at the ideal angle of the racket (variables: cross-section shape); Concept 3, based on increasing contact area with the thenar and thumb (variables: cross-section shape); Concept 4, based on a hand cover that provides additional grip (variables: material and texture).

A final concept is made based on concept 1, 2 and 3. The racket is supported by one plane surface, the hand is supported by two surfaces, to create a larger contact area for racket and hand. Rough material and texture is placed on different surfaces.

Prototypes of the final concept were made. On different surfaces rough material was placed. Some prototypes showed higher isometric peak forces. Texture with friction in one direction is not tested. A squared profile (used by one of the French players) is tested, the placement of the racket is not optimal and seems not to optimize the propulsion technique of the user (less power loss when coupling and lower peak forces during the push).

Due to confidentiality in relation to the Paralympics in 2016 in Rio, we cannot give more specification of the design and results of testing the prototypes.

4. Discussion and conclusion

This study showed different technical solutions for the interface between the hand, racket and the rim, which will improve propulsion technique during wheelchair tennis. The technical solutions were: different cross-section shape of the rim and/or using textures and/or materials with high friction coefficient on the rim and/or hand.

Various positions of the racket were possible on the original rim. The new cross-section shape, where the racket is supported by a plane surface, suggests one position of the racket. Further investigation is needed to study whether this is the best position for propulsion.

The concept has to be optimized. A study on the material of the whole rim, the material and texture (on different places) on the rim, and the size of the profile in relation to the anthropometric of the hand is needed.

In further exploration of other technical solutions, the variables flatness, continuity and shape of the whole push rim, distance I (the horizontal distance between rim and tire) and distance II (the vertical distance between rim and wheel rim) can be included.

For evaluation of the new shape, it is needed to make whole prototypes of the rim and testing these rims in laboratory settings and under realistic conditions with wheelchair tennis players.

Acknowledgements

A special thanks goes to Bas van der Ham, graduate student from Industrial Design Engineering at TU Delft.

5. References