行政院國家科學委員會專題研究計畫 成果報告

以生物力學的觀點評估輪椅網球運動員之關節負荷及功能
性表現

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Abstract

Athletes usually tilt the wheels of their racing wheelchair a camber angle to increase the stability when propelling the wheelchair. However, there are few studies examine the effect of the camber on wheelchair propulsion from the biomechanical point of view. The purpose of this study was to investigate the effects of camber angle on pushrim forces and joint kinematics of upper extremity. Three experienced wheelchair users with spinal cord injuries (age 34.7±2.5 years, weight 57±3.6kg, and height 157.7±2.1cm) participated in this study. A six-camera Expert Vision™ motion analysis system (Motion Analysis Corp, CA, USA) was used to collect the three-dimensional trajectory data of the markers. Five reflective markers were attached on the right wheels to collect the trajectory data during wheelchair propulsion. A basketball type manual wheelchair with an instrumented wheel was used in the study. The wheel was equipped with a 6-component load cell to collect the forces and moments applied on the hand-rim by users. Each subject was asked to propel the wheelchair in three different cambers, 8 degrees, 16 degrees, and 24 degrees, at the speed of 0.9 m/s on the motorized treadmill at a zero grade. The test order was randomized. The maximal pushrim force significantly increased with the increased camber angle, but the fraction effective force, tangential pushrim force divided by resultant pushrim force, decreased with increased camber. The camber angle may affect tire distortion and the human power stroke. As the camber angle increased, the less effective diameter of the wheels would require more revolutions to run the same distance. The increased camber increased the friction in the bearings as well as tire wear. We therefore concluded that the camber significantly affected the handling and performance of the user in wheelchair propulsion.

Keywords: wheelchair, disabilities, biomechanics, camber, upper extremity

INTRODUCTION

Wheelchair athletes usually suffer from the shoulder injury, especially those who specialize in the races that need speeding up (Curtis & Dillion, 1985; Ferrara & Davis, 1990). Once the injury occurs, the athlete’s performance will also suffer. In addition, the injury will affect the athlete’s will of doing certain exercise and may prevent the athlete from exercising hereafter eventually. So it is very important to understand the interaction between wheelchair athletes and wheelchairs. Among all, the camber of the rear wheel is one of the most important factors in wheelchair propulsion. Yet, from the biomechanical point of view, the most appropriate camber angle still remains unknown. In fact, many athletes slightly tilt wheels of the racing wheelchairs a camber angle to improve the stability while propelling the wheelchair. However, few
biomechanical studies have concerned the effect of the camber on wheelchair propulsion so far. Therefore, the purpose of this study was to study the required pushrim forces and kinematics of the wrist, elbow and shoulder joints at different wheel camber angles using the motion capture system and an instrumented wheel. We expected that the outcome will furthermore help wheelchair users to improve the wheelchair propulsion performance and to avoid injuries.

METHODS

Three SCI (Spinal Cord Injuries) experienced wheelchair users (age 34.7±2.5 years, weight 57±3.6kg, and height 157.7±2.1cm) participated in this study. A six-camera Expert Vision™ motion analysis system (Motion Analysis Corp, CA, USA) was used to collect the three-dimensional trajectory data from the markers placed on the user-wheelchair system. Fourteen reflective markers were attached on the right upper extremity and trunks of subjects to collect the trajectory data during wheelchair propulsion. The other five reflective markers were attached on the right wheel of the wheelchair to define its coordinate system (Su, et al., 1993). From known camera positions, ExpertVision software was able to reconstruct and calculate three-dimensional positions and related kinematic data for the markers. A basketball type manual wheelchair with an instrumented wheel was used in the study (Wu, et al., 1998). The wheel was equipped with a 6-component load cell to collect the forces and moments applied on the hand-rim by users. The fraction effective force (FEF), the tangential force divided by resultant force, is usually used to indicate the propulsion efficiency. This could be expressed as:

\[
FEF = \frac{F_t}{\sqrt{F_x^2 + F_y^2 + F_z^2}}
\]

A special designed device on the center of the wheel was used to adjust the angle of the wheel camber. To have a consistent configuration of the seating of the wheelchair users, the seat position of each subject was adjusted to align the shoulder just above the wheel axle with 60 degrees of forearm flexion angle while the hand was at the top dead center. Each subject was asked to propel the wheelchair at three wheel camber angles (8, 16 and 24 degrees) at the constant speed of 0.9 m/sec on the motorized treadmill (Fig 1). At least ten trials were sampled for each camber setting. Each trial lasted for 10 seconds with 3 minutes rest between trials. Euler angles were used to describe the three-dimensional joint movements of trunk and upper extremity with respect to their neutral posture. The test order was randomized. Differences between the biomechanical variables across three conditions were investigated using repeated measures one-way ANOVA.

RESULTS AND DISCUSSION

Temporal characteristics consist of cycle time, propulsion and recovery phase. The increased camber angle increased the time to propel with reduced recovery time (Table 1). However, there is no significant difference in the cycle time among 3 camber angles.
Table 1: Temporal characteristics vs. camber angle

<table>
<thead>
<tr>
<th></th>
<th>8 deg</th>
<th>16 deg</th>
<th>24 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propelling Phase</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>(%)</td>
<td>50.33%</td>
<td>2%</td>
<td>54.01%</td>
</tr>
<tr>
<td>Recovery Phase</td>
<td>49.67%</td>
<td>2%</td>
<td>45.99%</td>
</tr>
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</table>

In general, increased camber angle not only significantly (p<.05) increased the ROM (range of motion) of the flexion/extension and the radial/ulnar deviation in wrist joint, but also the ROM of forearm pronation/supination and that of elbow flexion and of shoulder flexion/extension. In constrast, the ROM of the internal/external rotation and abduction/adduction in the shoulder joint had no obvious changes while the camber angle was increased.

The maximum pushrim force increased while the camber angle increased (Fig. 2). The increased camber angle not only resulted in the lower seat position and changed the user-wheelchair interface but also increased the tire-floor contact area. The peak tangential force did not significantly altered with different cambers, but the peak axial force increased as wheel camber became greater and greater. The peak centripetal radial force decreased with the increased camber angle although there was no significant difference. The maximal centrifugal radial force appeared in the end of the pushing phase.

Greater cambers decreased the FEF (Table 2). Although tangential forces among three cambers were similar at the same speed on the treadmill, the increased camber increased resultant force applying on the hand-rim. When the angle of camber changed, the interface between the tire and the ground would change as well. Excessive camber in a wheelchair can make the wheelchair more difficult to propel the wheelchair. Since the camber angles changed along wheel axle in this study, the greater the angle, the lower the seat height. According to the relevant literature available, as the height of the wheelchair seat becomes lower, both the propelling forces and the joint loads increased.

Though the maximal tangential fraction force didn’t alter obviously when tilting, the axial force and shoulder extensions angle changed as the camber angles increased. The axial force also changed significantly in both the pushing and propelling phases. Although the radial fraction force didn’t increase because of the tilting statistically, the maximal centrifugal force of the radial force decreased in the late propelling phase due to the great propelling angle. Besides, the wrist endured greater forces in radial-ulnar direction while the camber angle was small whereas the shear force of wrist applied by the pushrim contact force was smaller when the wheelchair was tilted greatly. Meanwhile, the ulnar force of the wrist suffered greater pressure at the late
propelling phase because of the bigger propelling angle. Bigger camber angle significantly cause more pressure to the joints, especially on the frontal plane. It must be paid attention to avoid the wrist injuries. In athletic field, sport wheelchairs adopt bigger camber angles to avoid overturns in speedy turning.

<table>
<thead>
<tr>
<th>Camber Angle</th>
<th>FEF (%)</th>
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<tbody>
<tr>
<td>8 deg</td>
<td>90.05</td>
</tr>
<tr>
<td>16 deg</td>
<td>82.45</td>
</tr>
<tr>
<td>24 deg</td>
<td>75.24</td>
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CONCLUSION

This study investigated the influences of the pushrim camber angle on the kinematic and kinetic features of the shoulder, elbow and wrist joints for wheelchair athletes. Some important findings were as follows:
1. The camber change affected upper extremity kinematics three-dimensionally and influenced the contact force of pushrim mainly in coronal plane, rather than in tangential component.
2. Push force increased with the increased camber angle of pushrim at the same speed.
3. The increased camber angle of pushrim had greater influences on the fraction effective force.

We concluded that the camber significantly affected the handling and performance of the user in wheelchair propulsion.

REFERENCES