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Effect of the Air-Pressure Differences of the Wheelchair Tires on User's Upper Extremity Muscle Activities and Acceleration Changes

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Abstract

Although some studies have investigated the effects of tire pressure on the physical load of wheelchair users, the effect of wheelchair tires on the musculoskeletal system of wheelchair users has not been examined. The purpose of the present study was to determine the appropriate specific tire pressure for a manual wheelchair and investigate the disadvantages of maintaining inappropriate tire pressure during manual wheelchair propulsion. The tire air pressures were maintained at 100%, 75%, 50%, 25%, and 0% of the recommended pressure. Normalized wheelchair acceleration and muscle activities from upper extremity were measured in each of tire conditions. A total of 14 healthy, physically active female volunteers asked to drive the wheelchair for 30 m on the pathway at their self-selected speed under different tire air pressure conditions. The tire air pressure condition significantly affected the muscular activities of the ECR, FCU, and TB, which were significantly higher under the deflated conditions compared with the inflated conditions ($p < 0.05$). The ML vector sway of the 100% tire condition was significantly lower than those of the 50%, 25%, and 0% tire conditions ($p < 0.05$). A tire air pressure condition less than 25% of the recommended maximum resulted in significantly elevated ECR, FCU, and TB activities, ML sway, and Borg RPE scores. In addition, tire air pressure less than 25% of the maximum value could affect musculoskeletal load and energy expenditure during wheelchair driving.

Keywords: Wheelchair, air-pressure, accelerometer, propulsion, electromyography

I. INTRODUCTION

A wheelchair is a widely used locomotion-assisting device, particularly for subjects with disabilities of the lower extremities [1-2]. Although the use of the powered form of wheelchairs is increasing annually, manual wheelchairs are the predominant form for gaining mobility [3]. Manual wheelchair users must generate torque to drive the wheels. The magnitude of this propulsion torque is determined by the characteristics of the wheelchair mechanics as well as the kinematics of the user's driving maneuvers [4-5]. The wheelchair user must generate greater force to propel the wheelchair against the frictional resistance, accordance with its speed [6]. Previous studies have reported that this type of accumulated physical load leads to musculoskeletal problems of the upper extremities and increases the potential for injury [6-7].

An epidemiological study reported that 67% of the wheelchair population has a history of shoulder pain, and 59% has experienced hand or elbow pain since becoming a wheelchair user [8]. Wei et al. (2003) reported that seat height affects the temporal parameters of movement and wrist kinematic properties during wheelchair propulsion [9], which could be a factor for the increased incidence of arm and wrist musculoskeletal problems, such as carpal tunnel syndrome. Similarly, deflated wheelchair tires change the seat height and muscle recruitment pattern during wheelchair propulsion. de Groot et al (2013) suggested that tire pressure affects power output, physical strain, and propulsion technique; thus, the importance of maintaining appropriate tire pressure should be emphasized to wheelchair users [4]. It has also been reported that deflated tire pressure increases the energy expenditure as represented by heart rate and oxygen uptake [10]. However, appropriate tire pressure was unclear in that study, so the disadvantages of maintaining inappropriate tire pressure are also unclear. Although some studies have investigated the effects of tire pressure on the physical load of wheelchair users [4,10], the effect of wheelchair tires on the musculoskeletal system of wheelchair users has not been examined.

Previous studies used surface electromyography to investigate muscular recruitment during wheelchair propulsion [9], but the experimental environment was limited to a fixed rig on a rolling surface. However, recent technical developments have allowed collecting data using a wireless system so that the electromyography or accelerometer data can be measured during practical driving conditions. As a wireless measuring device, an accelerometer is used to investigate the magnitude of perturbations of certain movements in previous studies [11,12]. By using these wireless measuring device, therefore, present study is to investigate the mediolateral perturbations and muscular recruitment during practical wheelchair driving.

Various factors influence wheelchair mechanics, including the hand rim tube, seat height, wheelchair mass, and tires [4, 9,13]. Previous studies have reported the advantages of a newly designed propulsion device and seat cushion on reducing physical load and enhancing the comfort of wheelchair users. However, these newly designed devices along with technical improvements might not be an easy adjustment for wheelchair users. On the other hand, the tire air pressure of a wheelchair can be easily modified without purchasing a new one.

The purpose of the present study was to determine the appropriate specific tire pressure for a manual wheelchair and investigate the disadvantages of maintaining inappropriate tire pressure during manual wheelchair propulsion. The present study hypothesized that the magnitude of tire pressure for manual wheelchair propulsion significantly affects upper extremity muscle recruitment and wheelchair perturbations.

II. METHODS

II.I Participant

Fourteen asymptomatic subjects participated in the present study. The sample size was calculated using G-power 3.1.3 software. The study was a one-way repeated-measures design, with a significance level of 0.05 and an effect size of 0.6. The criteria for selecting participants were as follows: no musculoskeletal disorder during the past 6 months and no history of surgery on the upper or lower extremities. Fourteen males finally participated in this study. All patients read and signed informed consent following the ethical standards (Kaya IRB – 275).

II. II Instrumentation

A standard lightweight manual wheelchair was used in this study. The specifications of the manual wheelchair were 50 cm seat width, 22 cm backrest height, and 80 cm total height. The tire air pressures were maintained at 100%, 75%, 50%, 25%, and 0% of the recommended pressure. The experimental condition was randomly determined using the card method. The air pressure of the wheelchair tire was controlled by a digital air pressure gauge. The roadway was 30 m long and was an artificial marble surface.

Surface electromyography (sEMG) data were collected using a wireless surface EMG system (Wireless EMG System 1000, BTS, Milan, Italy). The sEMG signals were sampled at a 1,000 Hz frequency. The data were computerized using EMG acquisition software. Band-pass (50–450 Hz) and notch filters (60 Hz) were used. Four channels of surface electrodes were attached on the dominant right side of each subject parallel to the muscle fibers. The electrodes were attached to the extensor carpi radialis (ECR) muscle approximately 5 cm distal from the lateral side of the elbow, to the flexor carpi ulnaris (FCU) approximately 2% of the distance from the elbow to the wrist on the medial side, to the biceps brachii 3 cm above the myotendinous junction of the elbow, and to the triceps brachii (TB) muscle at 50 % on the line between the posterior crista of the acromion and the olecranon at 2 finger widths medial to the line [14]. The skin surface was shaved if covered with hair, and the skin was cleaned with alcohol.

Normalized wheelchair acceleration was measured in each of the three directions during wheelchair propulsion (sensor range: −2 to +2 G, sampling rate of 32 Hz) using a tri-axial accelerometer (Fit Dot Life, Suwon, Korea). The device was 35 mm in length × 35 mm in width × 13 mm in height and weighed approximately 13.7 g. It was firmly taped to the third metacarpal bone. A sensor was fixed with double-sided tape over the posterior side of the backrest. The tri-axial accelerometer data were extracted using Fitmeter Manager 2 software (Fit Dot Life). Normalized anterior–posterior (AP), medial–lateral (ML), and vertical (VT) acceleration values were calculated using the following formulas (Shin et al., 2016):

$$\mathrm{AP} = \left(\sum_{i=1}^{n}\sqrt{z_i^2} \Big/ \sum_{i=1}^{n}\sqrt{x_i^2+y_i^2+z_i^2}\right) * 100$$

$$\mathrm{ML} = \left(\sum_{i=1}^{n}\sqrt{x_i^2} \Big/ \sum_{i=1}^{n}\sqrt{x_i^2+y_i^2+z_i^2}\right) * 100$$

$$\mathrm{VT} = \left(\sum_{i=1}^{n}\sqrt{y_i^2} \Big/ \sum_{i=1}^{n}\sqrt{x_i^2+y_i^2+z_i^2}\right) * 100$$

The Borg perceived exertion score rating (Borg RPE score 6–20) was recorded after performing each exercise to identify the subjective difficulties of each exercise. Borg (1970) designed the RPE scale, which is one of the best indicators of the degree of physical strain [15].

II. III Procedures

Subjects were asked to wear gloves to eliminate friction between the hands and the push-rim. Each subject was allowed to become familiar with propelling a manual wheelchair for 5 min. During the practice time, each subject's comfortable speed was measured by a researcher. Before performing the experimental trials, each subject performed two trials at maximal voluntary muscle contraction for the muscles against manual resistance. The maximal manual resistance for each muscle was applied using specific protocols that followed the clinical literature for muscle testing [16]. The highest sEMG value of each muscle was used for the subsequent normalization procedure.

After practice, participants performed five randomly selected measurement trials. Each subject was asked to drive the wheelchair for 30 m on the pathway at their self-selected speed under different tire air pressure conditions. To avoid the effects of acceleration and deceleration on the measurements, the 2 m at the beginning and end of each trial were excluded.

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II. ⅣStatistical analysis

The PASW Statistics (version 18.0; SPSS Inc., Chicago, IL, USA) program was used to reveal significant differences in the percentage maximal voluntary muscle contraction, normalized acceleration, and Borg RPE scores among the exercise conditions. The Kolmogorov–Smirnov test was performed to test the data distribution for normality before the parametric statistical analyses. One-way repeated-measures analysis of variance was used to test for differences after adopting one factor (tire air pressure) in the study design. Bonferroni post-hoc correction was used for pair-wise comparisons. A statistical significant level was set as 0.05.

III. RESULTS

The mean values of the normalized EMG and acceleration data and Borg RPE score data are shown in Tables 1 and 2. The tire air pressure condition significantly affected the muscular activities of the ECR, FCU, and TB, which were significantly higher under the deflated conditions compared with the inflated conditions ($p < 0.05$) (Figure 1). The 100% air pressure condition resulted in significantly lower activities of the ECR and TB than did the 0% and 25% air pressure conditions ($p < 0.05$) (Figure 1).

The measured variables of the ML vector sway and Borg RPE score were significantly different among the tire conditions (Table 2) ($p < 0.05$). Similar to the ECR results, the ML vector sway of the 100% tire condition was significantly lower than those of the 50%, 25%, and 0% tire conditions ($p < 0.05$) (Figure 2). No significant differences in the AP or VT vector sway were observed for the different tire conditions ($p > 0.05$).

The 100% and 75% tire air pressure conditions resulted in a significantly lower Borg RPE score compared with the 25% and 0% deflated tire conditions ($p < 0.05$) (Figure 2).

Table 1. Comparison of muscular activities with different tire conditions during wheelchair propulsion (n = 14, unit: %MVC)

	Air pressure of the wheelchair tire conditions					p-value
	100%	75%	50%	25%	0%	
ECR(%MVC)	45.57±10.33	50.64±12.58	53.36±12.01	55.38±12.88	61.81±13.81	.00*
FCU(%MVC)	33.85±6.67	38.03±8.21	38.39±8.41	42.07±11.30	50.42±12.71	.01*
BB(%MVC)	16.02±8.67	17.86±11.24	17.91±10.61	17.88±9.46	17.59±9.50	.88
TB(%MVC)	36.85±12.05	39.90±12.14	42.23±15.22	45.96±15.14	51.67±16.82	.00*

ECR: Extensor carpi radialis, FCU: Flexor carpi ulnaris, BB: Biceps brachii, TB: Tricpes brachii, %MVC: % Maximum voluntary contraction, *: p<.05

Table 2. Comparison of acceleration vector sway, and perceived subjective difficulties with different tire conditions during wheelchair propulsion (n = 14)

	Air pressure of the wheelchair tire conditions					p-value
	100%	75%	50%	25%	0%	
Vertical sway	40.86±7.49	37.90±8.40	35.69±7.20	35.62±7.10	35.55±5.10	.05
AP sway	36.65±6.65	39.93±6.92	39.65±5.25	38.44±5.55	34.74±3.44	.05
ML sway	59.92±4.16	61.61±3.49	63.79±4.01	65.33±1.82	66.71±3.59	.00*
Borg RPE score	7.64±1.55	8.21±2.01	9.43±2.17	9.93±1.98	11.43±2.28	.00*

AP sway: anterior-posterior sway, ML sway: Mediolateral sway, Borg RPE score: Borg ratings for perceived exertion score, *: p<.05

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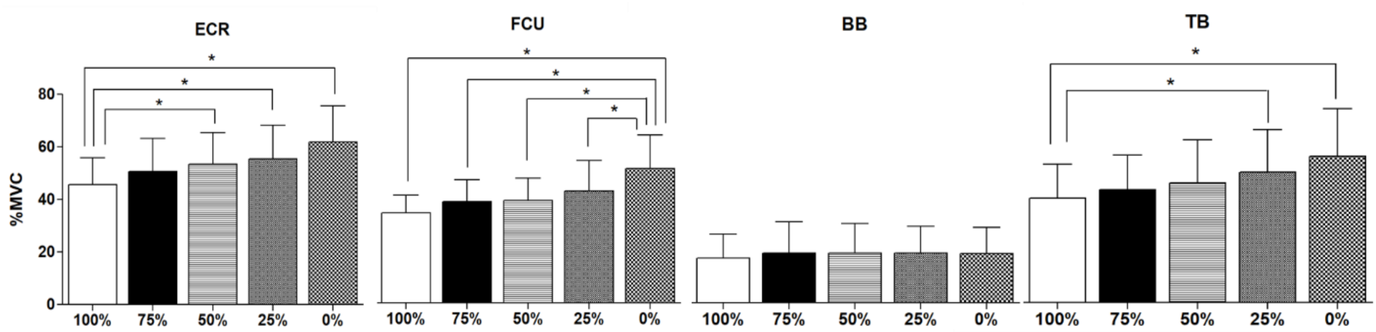

Figure 1. Comparison of muscular activities with different tire conditions during wheelchair propulsion. *: p<.05

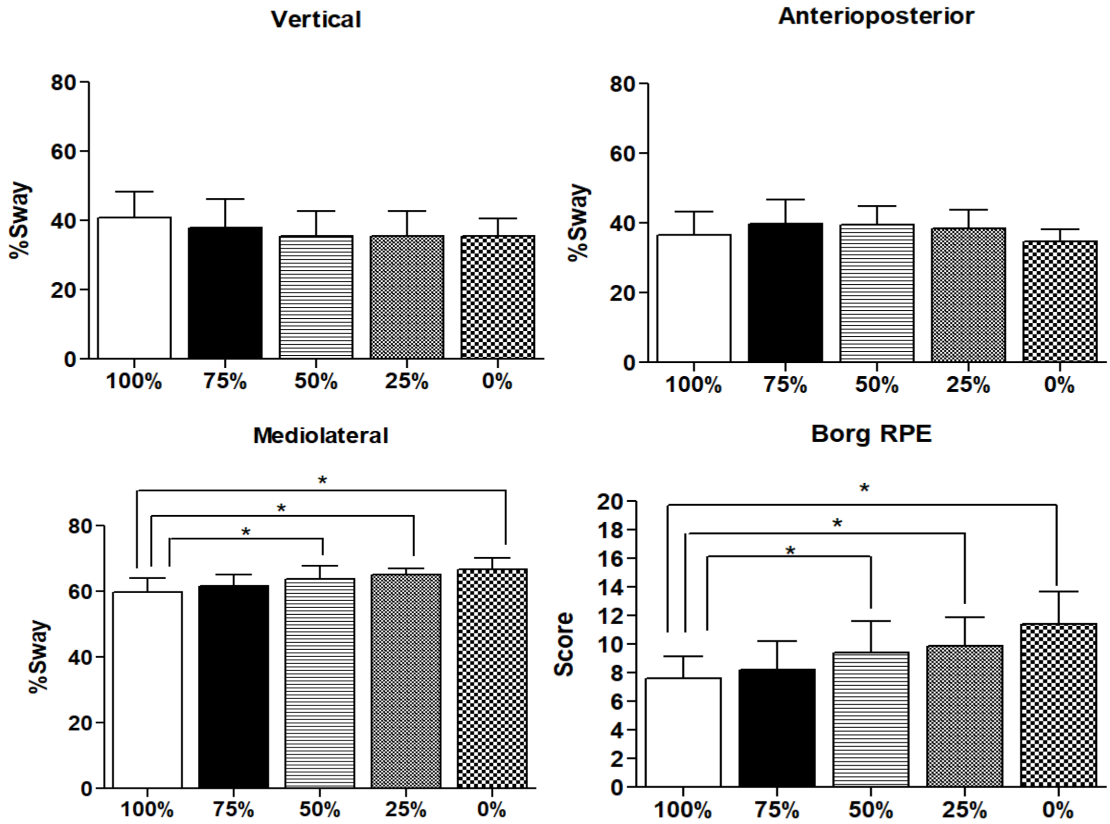

Figure 2. Comparison of acceleration vector sway, and perceived subjective difficulties with different tire conditions during wheelchair propulsion. *: p<.05

IV. DISCUSSION

The use of a manual wheelchair, which requires repetitive propulsive movement, is often associated with upper extremity musculoskeletal problems [2,7]. The objective of the present study was to investigate the musculoskeletal load and acceleration sway under five different wheelchair tire conditions during driving movements by measuring muscular activities, subjective difficulties, and vector sway. In the present results, wrist muscle activities increased with the decrease in tire air pressure. The surface electromyography data could not confirm that a high level of activity was positive or that a low level of activity was negative. Previous studies demonstrated that excessive activation of the upper trapezius is a risk for musculoskeletal disorders [17]. Among the muscles investigated here, the FCU and ECR were significantly more activated under the deflated tire conditions than under the inflated tire conditions. The FCU and ECR are the main actors of wrist flexion and extension [18]. Wei et al. (2003) reported that the increased wrist movement during wheelchair maneuvering may be associated with the incidence of carpal tunnel syndrome [9]. Although increased wrist muscular activities under a deflated tire condition was not directly associated with increased wrist movement, the deflated air tire condition might contribute to the incidence of wrist musculoskeletal problems by increasing wrist flexor and extensor activities.

The present study used a tri-axial accelerometer to measure changes in velocity during wheelchair driving. The demonstrated variables, including VT sway, AP sway, and ML sway, are not displacement values but rather normalized values of the velocity changes. Increased acceleration is manifested by the variance in the kinetic energy, and linear momentum also increases [19]. Despite the experimental conditions requiring the wheelchair to drive in an anterior direction, the normalized tri-axial accelerometer values revealed a significant difference in the mediolateral direction. Previous studies that used tri-axial accelerometers suggested that the increased normalized accelerometer value in an unintended direction is interpreted as an unnecessary energy expenditure [11,12].

The major finding in this study was that a tire air pressure condition less than 25% of the recommended maximum resulted in significantly elevated ECR, FCU, and TB activities, ML sway, and Borg RPE scores. Based on these results, tire air pressure less than 25% of the maximum value could affect musculoskeletal load and energy expenditure during wheelchair driving. The clinical literature suggests the importance of appropriate tire air pressure during wheelchair use, but there is a lack of research related to the specific tire air pressure conditions. The safety level of accessories such as the tire air pressure condition should be considered for wheelchair users.

This study had several limitations. The first was a lack of EMG information for the other upper extremity muscles, such as the latissimus dorsi and deltoids, which may have been affected by the tire air pressure conditions. Second, our results cannot be generalized because of the small number of subjects included in the study.

V. CONCLUSION

A tire air pressure condition less than 25% of the recommended maximum resulted in significantly elevated ECR, FCU, and TB activities, ML sway, and Borg RPE scores. In addition, tire air pressure less than 25% of the maximum value could affect musculoskeletal load and energy expenditure during wheelchair driving.

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Conflict of interest

The authors have no conflict of interest to report.

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