한국전문물리치료학회지 제11권 제4호
KAUTPT Vol. 11 No. 4 2004.

The Effect of Wheelchair Propulsion on Carpal Tunnel Syndrome of Wrist Joint

Kong Jin-yong, Ph.D., P.T.
Dept. of Rehabilitation Technology, Daegu University
Kwon Hyuk-cheol, Ph.D., P.T.
Dept. of Rehabilitation Technology, Daegu University
Chang Ki-yeon, Ph.D., O.T.
School of Health and Social Welfare, Woosong University
Jeong Dong-hoon, Ph.D., P.T.
Dept. of Rehabilitation Science and Technology, Nazarene University

Abstract

Individuals who propel wheelchairs have a high prevalence of upper extremity injuries (i.e., carpal tunnel syndrome, elbow/shoulder tendonitis, impingement syndrome). Musculoskeletal injuries can result from overuse or incorrect use of manual wheelchairs, and can hinder rehabilitation efforts. To better understand the mechanisms of upper extremity injuries, this study investigates the motion of the wrist during wheelchair propulsion. This study also examines changes in the variables that occur with fatiguing wheelchair propulsion to determine how the time parameters of wheelchair propulsion and the state of fatigue influence the risk of injury. A two dimensional (2-D) analysis of wrist movement during the wheelchair stroke was performed. Twenty subjects propelled a wheelchair handrim on a motor-driven treadmill at two different velocities (50, 70 m/min). The results of this study were as follows; The difference in time parameters of wheelchair propulsion (cadence, cycle time, push time, recovery time, and PSP ratio) at two different velocities was statistically significant. The wrist kinematic characteristics had statistically significant differences at two different velocities, but wrist radial deviation and elbow flexion/extension had no statistically significant differences. There were statistically significant differences in relation to fatigue in the time parameter of wheelchair propulsion (70 m/min) between initial 1 minute and final 1 minute. The wrist kinematic characteristics between the initial 1 minute and final 1 minute in relation to fatigue had statistically significant differences but the wrist flexion-extension (50 m/min) had no statistically significant differences. According to the results, the risk of musculoskeletal injuries is increased by fatigue from wheelchair propulsion. To prevent musculoskeletal injuries, wheelchair users should train in a muscle endurance program and consider wearing a splinting/grove. Moreover, wheelchair users need education on propulsion posture, suitable joint position, and proper recovery patterns of propulsion.

Key Words: Carpal tunnel syndrome; Musculoskeletal injury; Wheelchair propulsion.

Corresponding author: Kong Jin-yong *rehabtech@hanmail.net*

Introduction

Increase of injuries by traffic accident, industrial disaster and medical development has consequently increased the number of persons with disabilities who demand rehabilitation services. As of the end of December, 2000, the number of the persons with disabilities was 102 million, and then it rose to 145 million by the end of December 2003. This rise is considerable, compared to the population increase of .7%, and the number of disabled people continues to rise.

The cultural focus in the 21st century is transitioning from the basic necessity of food, clothing and shelter to quality of life and overall well-being. To ensure quality of life becomes an important objective in life not only for normal people, but also for the people with disabilities. For disabled persons to enjoy a life of quality and cultural experiences such as leisure and recreational activities, various components of society should be made accessible to the disabled. The most important aspect of improving such accessibility is securing mobility. Therefore, one of the most crucial devices for their mobility is a manually propelled wheelchair (Pentland and Twomey, 1991; Rodgers et al, 2003; Shimada et al, 1998; Sie et al, 1992; Wei et al, 2003).

One's self propulsion with a manual wheelchair is achieved by the bilateral, simultaneous and repetitious movement of each joint of the upper extremity and such movement is a major factor in causing damage to each joint of the upper extremity. The disabled who use a wheelchair to do activities of daily living, transfer and weight loading as well as self-propulsion, heavily depend on the upper extremity (Veeger et al, 1998). Therefore, the upper extremity of manual wheelchair users, which inherently is not supposed to carry the weight of the body, suffer from various problems due to long periods of propulsion work on the wheelchair (Rodgers et al, 2003; Sabick et al, 2001; Wei et al, 2003).

Most wheelchair users appear to suffer musculoskeletal injury such as carpal tunnel syndrome due to incorrect use, prolonged repetitive activity and weight loading of the manual wheelchair (Gellman et al, 1988b; Madorsky and Curtis, 1984; Monahan, 1986). Many of the disabled who manually propel their wheelchair complain of pain in their wrists and arms. Worse, many of them suffer from secondary damage, such as damage to soft tissue. According to an existing previous study, more than 50% of those with spinal cord injury who use manual wheelchair suffer from pain in the wrists and arms, which limits activities of daily living (Wei et al, 2003), and according to Sie et al (1992) about 16% of them who use a manually propelled wheelchair suffer from elbow joint pain.

The part of the upper extremities most vulnerable to musculoskeletal injury is the wrists, and a typical symptom is carpal tunnel syndrome, which occurs by the compression on the median nerve (Burnham and Steadward, 1994; Jessurun, 1983). It is a fact the current revalence rate of the disabled with spinal cord injury exceeds 50~60% (Aljure et al, 1985; Gellman et al, 1988a; Rodgers et al, 1994).

Excessive flexion and extension of the wrist joints increases the pressure within the carpal tunnel by more than 30 ㎜Hg, and presses on the nerve in the carpal tunnel, thus causing carpal tunnel syndrome (Goodman et al, 2001; Wei et al, 2003). Radial deviation and ulnar deviation of the wrists are major causes of carpal tunnel syndrome, which damage soft tissue (Rodger et al, 1994; Veeger et al, 1998).

As for major factors that increase the risk of carpal tunnel syndrome, there are trunk elevation, transfer, and the propulsion of manual under wrist joints and elbow joints fixed. Of these movements, One's self-propulsion with a manual wheelchair further increases the risk of carpal tunnel syndrome because the motion consists of repetitive flexion, extension, radial deviation and ulnar deviation of the wrists (Veeger et al, 1998). The propulsion of a wheelchair with the flexed fingers on the handrim increases the risk more than other general motions do, by increasing the pressure within the carpal tunnel with flexor activity (Armstrong et al, 1987; Cooper, 1998; Dozono et al, 1995; Masse et al, 1992). The accumulation of muscle fatigue and incorrect use of a wheelchair cause abnormal alignment of the upper extremity (Glaser et al, 1997), which then causes secondary problems. musculoskeletal problems. The secondary disability eventually results in a decrease in rehabilitation effectiveness. To prevent this problem, the kinematic and kinetic analysis of the joints which are used for wheelchair propulsion should be carried out first. The Kinematic analysis of the upper extremities and the study on wheelchair propulsion characteristics can give a clue for the explanation of interaction between wheelchair users and their wheelchairs according to Bednarczyk and Sanderson (1994).

Despite all the existing kinematic and kinetic analysis of wheelchairs (Boninger et al, 2002; Cooper et al, 1998; DiGiovine et al, 2001; Shimada et al, 1998; Veeger et al, 1998), the studies done on the risk of carpal tunnel syndrome under various wheelchair speeds is insufficient. Wrist kinematic analysis and a study of the change in ROM under various wheelchair speeds are necessary.

The purpose of this study was to diagnose any risk factor that can cause secondary disability, and thereby to provide guidelines for correct wheelchair propulsion patterns and adaptive wheelchair selection. This can be accomplished by examining both the impact of fatigue accumulated under various wheelchair speeds and the risk factor of upper extremity musculoskeletal disease.

Methods

Subjects

For the study, 20 healthy subjects of Daegu University, Daegu City were selected. None of them had any abnormality in the musculoskeletal system and nervous system of their upper extremities.

First, 3 subjects were selected for the primary experiment from January 15 through January 20, 2004, and the problems and errors that occurred while propelling wheelchair and collecting data were corrected and complemented before expanding the experiment to the whole sample group for the period of February 9 through

Table 1. General characteristics of subjects (N=20)

	Mean±SD	Range
Age (yrs)	23.2±2.5	20~27
Weight (㎏)	71.8±6.3	62~78
Height (㎝)	172.7±4.1	165~178

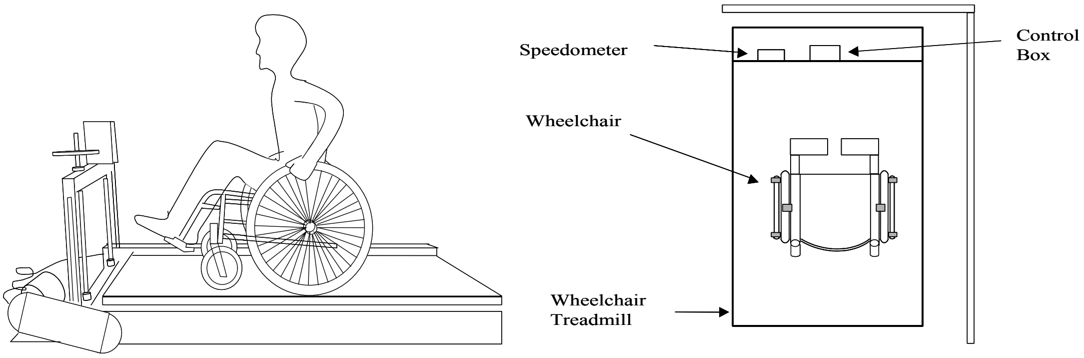

Figure 1. The wheelchair propulsion situation and the wheelchair treadmill

February 27, 2004.

General characteristics of the subject group

The average age of the 20 participants in the experiment is 23.2 years with an average height of 172.2 ㎝, and a mean weight of 71.8 ㎏ (Table 1).

Experiment

1) Propulsion of wheelchair

For the experiment a standard wheelchair (Daese, Korea, P7000A) with a handrim diameter of 60 ㎝ and a seat width/depth of 39.9 ㎝ was used. The armrest was removed to limit the scope of the upper extremity motion (Newsam et al, 1999). In the experiment, the same condition as in normal use of daily living was applied, and wheelchair treadmill was used for free-wheeling (Figure 1).

According to Gayle (1990), the average propulsion speed of wheelchairs in daily living was 60 m/min. In the experiment, the two speeds 50 m/min and 70 m/min were applied. The angle between the hip joint and knee joint was 90 degrees while the subjects were seated, and the seat height was adjustable.

2) Dynamic range of motion measurement

The range of motion measurement of wrist flexion-extension and ulnar deviation-radial deviation was measured with an electrogoniometer Data Logger1) which works by the principle of strain gauges.

(1) Placement of electrogoniometer

To measure wrist flexion-extension and ulnar deviation-radial deviation, the arms were placed on the each side of the trunk, with the forearms pronated, the elbow at 90 degrees flexion, and the wrists in neutral position for the SG65 twin-axis goniometer, before positioning the electrogoniometer as shown in the study of Serina et al (1999) and Wei et al (2003).

The distal endblock of the goniometer was placed at the ulnar side of the 3rd metacarpal bone, the proximal endblock at the midline of the dorsal side of the pronated forearms, and the axis of the electrogoniometer at the mid-carpal joint (Figure 2).

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1) Biometrics Limited, Gwent, UK.

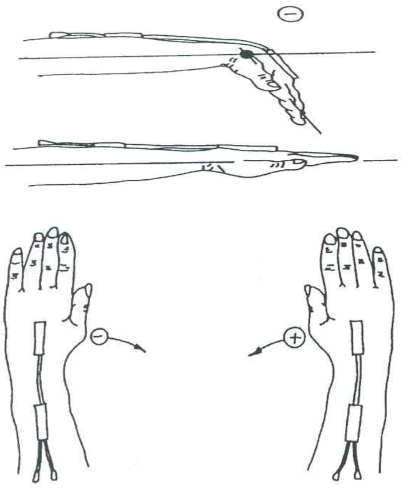

Figure 2. Goniometer placement
: wrist joint

(2) Joint angle measurement and procedure

The anatomical position of the electrogoniometer was calibrated at 0 degrees in the beginning. The signal of the electrogoniometer was sent to the Data Logger through the cable (J500), changed into a digital signal, and analyzed with Data Log software (Version 3.0). The sampling rate of the signal was set at 20 ㎐.

To compare angle changes by the speed, the angle changes were collected for 1 minute after the propulsion of the wheelchair. To compare the angle changes by fatigue accumulation, the angle changes were collected for the initial 1 minute (before fatigue accumulation) and for the last 1 minute (after fatigue accumulation) after 10 minutes of propulsion of the wheelchair.

(3) Temporal parameter measurement for wheelchair propulsion

To measure temporal parameter of wheelchair propulsion, the propulsion cycle was divided into push phase and recovery phase, and Data Log software was used for the analysis. The push phase is the period when the elbow flexion angle of the main joints decreases, and recovery phase is the period when the elbow flexion angle increases. Measurement was carried out for cycle time, push time, recovery time, cadence, PSP ratio, etc. The cadence is the number of the propulsions of the handrim for 1 minute, and the PSP ratio is calculated by propulsion time and recovery time.

Statistical Analysis

The changes of temporal parameters and joint angles under the propulsion speeds of 50 m/min and 70 m/min were included in the calculation of changes. The Wilcoxon Signed Rank Test was used to compare the joint angle changes by fatigue accumulation and propulsion speed, and to compare the temporal parameter of the propulsion cycle. For the statistics for data processing and analysis, the ordinary statistic program SPSS 11.0 for Windows was used and the significance level was set at $p<.05$.

Results

1. Qualitative analysis of muscle fatigue by propulsion of wheelchair

Table 2. Qualitative analysis of fatigue

	m/min	Before propulsion	After propulsion	p
VAS[a]	50	2.38±2.15[b]	7.24±1.37	.00
	70	2.85±1.95	8.47±2.01	.00

aVAS: Visual Analog Scale
bMean±SD

The comparison of subjective evaluation of the degrees of fatigue accumulation which the participants had after the start of propulsion produced by the VAS was 2.38 before the start of 50 m/min propulsion and 7.24 after the start of 50 m/min propulsion. For the 70 m/min propulsion, the scores were 2.85 before the propulsion and 8.47 after the propulsion (Table 2).

2. Wrist kinematic variable analysis by wheelchair propulsion speed

According to the findings, there were statistically significant differences between the wrist flexion and ulnar deviation angle of propulsion speed, but for the extension and radial deviation angle, there were no statistically significant differences of the propulsion speed (Table 3).

3. Temporal parameter variable analysis by muscle fatigue accumulation from wheelchair propulsion

For the cadence at the speed of 50 m/min, there were no statistically significant differences with the recovery time. However, for the cycle time and push time, there were statistically significant differences in the PSP ratio.

For the speed of 70 m/min, there were

Table 3. Wilcoxon signed rank test of wrist joint angle

	m/min	Mean±SD	p
Flexion (degree)	50	31.72±6.58	.00
	70	33.80±6.34	
Extension (degree)	50	20.94±6.21	.24
	70	20.33±6.40	
Radial deviation (degree)	50	11.81±3.27	.06
	70	10.75±3.08	
Ulnar deviation (degree)	50	21.02±3.47	.00
	70	18.84±3.43	

Table 4. Wilcoxon signed rank test of temporal parameter in cycle time

	m/min	Non-fatigue	Fatigue	p
Cadence	50	74.78±17.73[a]	74.33±19.89	.67
	70	85.00±16.28	90.67±20.31	.03
Cycle time	50	.88±.29	.92±.30	.02
	70	.75±.21	.86±.24	.01
Push time	50	.54±.19	.57±.19	.03
	70	.48±.14	.54±.16	.01
Recovery time	50	.35±.11	.34±.11	.36
	70	.28±.19	.32±.14	.01
PSP ratio	50	1.60±.12	1.58±.37	.22
	70	1.50±.13	1.33±.25	.01

[a] Mean±SD

statistically significant differences with cadence, cycle time, push time, recovery time, and PSP ratio (Table 4).

4. Wrist kinematic variable analysis by fatigue from wheelchair propulsion

The finding for 50 m/min is that there were no statistically significant differences in wrist flexion and extension between before and after propulsion fatigue accumulation. With wrist ulnar deviation and radial deviation, however, there were statistically significant differences. For the 70 m/min, there were statistically significant differences between before and after propulsion fatigue accumulation, with wrist flexion, extension, radial deviation and wrist ulnar deviation (Table 5).

Discussion

This is to investigate the effect of fatigue accumulation on the wrist angle under various wheelchair propulsion speeds, and then to provide a correct approach for propulsion patterns and their application to wheelchairs. This may be accomplished by looking into the effects of wrist angle changes on the risk factor of upper extremity musculoskeletal injury for early diagnoses of secondary disability factors.

The effect on wheelchair propulsion parameters varies, depending on seating posture (Wei et al, 2003). Existing investigations were carried out without such normalization of wheelchair seating. These investigations offer comparative study suitable to individual personal differences. It is thought that an unusual seating position may have had influence on propulsion cycle, temporal parameter and arms angles. Therefore, uniform seating position was maintained throughout the experiment, by adjusting the seat height for comparative analysis among individual participants.

For wrist kinematic analysis, Penny & Giles electrogoniometer, which is used for 2-dimensional analysis, was used to measure the joint angles. According to the verification result on the accuracy and reproducibility of electrogoniometer, the confidence level of accuracy was as high as 1.0±1.2 degrees (range: 0~3 degrees), and the reproducibility was as confident as 1.3±1.5 degrees (range: 0~5.2 degrees), similar to that of the study done by Maupas et al (2002).

According to the analysis of the kinematic

Table 5. The Wilcoxon signed rank test of the wrist joint angle

	m/min	Non-fatigue	Fatigue	p
Flexion(degree)	50	31.72±6.58[a]	31.59±6.85	.72
	70	33.80±6.34	35.97±6.87	.01
Extension(degree)	50	20.94±6.21	21.37±6.36	.33
	70	20.33±6.40	22.74±5.83	.00
Radial deviation(degree)	50	11.81±3.27	10.61±2.47	.00
	70	10.75±3.08	8.62±2.77	.00
Ulnar deviation(degree)	50	21.02±3.47	19.80±3.67	.01
	70	18.84±3.43	16.04±3.57	.00

[a] Mean±SD

parameter by propulsion speed of a wheelchair, the wrist flexion angle increased from 31.72 degrees to 33.80 degrees as the speed increased from 50 m/min to 70 m/min. There was, however, no significant difference in the extension angle. Neither was there any no significant difference in the wrist radial deviation angle, but the ulnar deviation angle decreased from 21.02 degrees to 18.84 degrees as the speed increased from 50 m/min to 70 m/min. Veeger et al (1998) reported that as the speed increases wrist extension angle decreases while the flexion angle increases.

For determination of the time in which the fatigue occurs and qualitative analysis of the fatigue, VAS was used to score the degree of fatigue into numerical value (Mori et al, 2004). VAS is widely used in fatigue accumulation, dyspnea and quality test of living (Miller and Ferris, 1993), with the advantage that it can be easily applied in various circumstances (Philip, 1990). In the experiment, the VAS for 50 m/min was 2.38 before propulsion and 7.24 after the propulsion. For 70 m/min, the score was 2.85 before the propulsion and 8.47 after the propulsion, showing that the level of fatigue of the subjects significantly increased as the speed increased, especially after the propulsion at the speed of 70 m/min.

The investigation into the effects of fatigue accumulation on wrist kinematic variables showed that there was no significant difference in wrist flexion and extension between before and after the propulsion at the speed of 50 m/min. For 70 m/min, however, there was significant increase in the level of fatigue between the various stages. Even though Rodgers et al (1994) said there was no significant difference in flexion and extension between before and after the propulsion effort, this experiment showed that the joint angle increased for the speed of 70 m/min. Such difference was considered to have been attributed to different seat height, propulsion speed, resistance, and handrim diameter at propulsion. The increase of flexion angle indicates the increase in muscle activity of flexor, which is used for the flexion of the wrist joint and MP joint. Such increase of muscle activity is said to be one of the carpal tunnel syndrome risk factors, according to Veeger et al (1998). The experiment was able to identify that fatigue of wheelchair propulsion increases the risk of carpal tunnel syndrome.

For both 50 m/min and 70 m/min, the radial deviation and ulnar deviation significantly decreased after the propulsion. The decrease in the angle of radial deviation and ulnar deviation due to the fatigue is consistent with study by Rodgers et al (1994). Such decrease in wrist deviation angle is assumed to fix the wrist to minimize the wrist deviation angle while the propulsion from the arms is transfered onto the handrim.

The analysis of the effects of fatigue from wheelchair propulsion on the temporal parameters of propulsion cycle showed that there was no significant difference in the cadence between before and after the fatigue. However, cadence significantly increased after the occurrence of fatigue accumulation of 70 m/min.

According to Boninger et al (1999) who identified the correlation between the cadence and median nerve injury, the increase in cadence can do damage to the median nerve.

According to the experiment, the cadence appeared to increase significantly as the fatigue from propulsion work occured. The cycle time increased by .04 sec from .88 sec before the propulsion to .92 sec after the propulsion of 50 m/min. With a speed of 70 m/min, it increased by .11 sec from 0.75 sec to .86 sec after the propulsion. This is consistent with the study of Rodgers et al (1994) who said that the cycle time increases as the fatigue accumulates. Recovery time did not show significant differences for 50 m/min, but for 70 m/min, it increased as the fatigue accumulated.

The PSP ratio appeared to decrease after the fatigue accumulation for 70 m/min. Such decrease in PSP ratio means that the push time shortens while in cycle time, and gets longer for recovery time. Shimada et al (1998) said in their study that the longer the recovery time gets, the lower the mechanical efficiency of wheelchair propulsion becomes. That is, the accumulation of fatigue can have negative effect on the mechanical efficiency of wheelchair propulsion because increase in recovery time means a decrease in the PSP ratio.

The decrease of the PSP ratio was considered to have an impact on the mechanical efficiency of wheelchair propulsion by increasing the recovery time. The fatigue accumulation appeared to increase the wrist flexion and extension, and such increase can intensify pressure within the carpal tunnel. According to Kerwin et al (1996), normal pressure in the carpal tunnel is 30 ㎜Hg, but it rises to 94~110 ㎜Hg as the flexion increases. Such increase in the carpal tunnel can incur carpal tunnel syndrome by preventing blood circulation, thereby causing the tunnel to become ischemic.

These various factors can cause musculo-skeletal disease such as carpal tunnel syndrome. The factors that incur carpal tunnel syndrome can be summarized as first, excessive movement of the wrist joint, second, increase of the activity of the finger flexor at wrist extension, third, repulsive force applied on carpal tunnel, fourth, a rapid and repetitive pattern of wheelchair propulsion, fifth, an increase of cadence and a decrease of the PSP ratio, etc.

The complex interaction of such various factors can increase the risk of carpal tunnel syndrome. The best way to prevent carpal tunnel syndrome, therefore, can be the prevention of the generation of theses factors.

To prevent musculoskeletal disease, muscle strength and endurance training for shoulder extension are necessary. This training increases the PSP ratio and secures rapid back swing motion. To prevent carpal tunnel syndrome, it may be necessary to study ways to decrease excessive wrist angle change with an ergonomic approach.

According to the presentation of Faessen et al (1989), the optimum wrist range of motion for the prevention of carpal tunnel syndrome is a flexion within 15 degrees, an extension within 5 degrees and an ulnar deviation within 10 degrees. To help the propulsion take place within those ranges of motion, it is useful to provide wheelchair users with wrist protection splints and gloves. Theses tools can help reduce the risk of carpal tunnel syndrome considerably.

Conclusion

In this experiment, a group of 20 healthy adults in their twenties with no history of disease in their musculoskeletal system, nervous system, and cardiopulmonary system, were selected. They were then asked to use a wheelchair for 10 minutes at various speeds, to measure the temporal parameter of the propulsion cycle of the wheelchair and the changes in wrist angles due to fatigue accumulation. The accumulation of fatigue and the rapid propulsion of the wheelchair had an impact on wrist angle, which then increased the risk of musculoskeletal disease such as carpal tunnel syndrome. For prevention of carpal tunnel syndrome, various methods of wheelchair propulsion should be made available to enable wheelchair users to propel their wheelchair at wrist neutral position. Another alternative is the use of splints or gloves and a proper recovery pattern.

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