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Original research papers

ASSESSMENT OF HEALTHY STUDENTS' LOCOMOTION IN A WHEELCHAIR

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Abstract
Introduction. Efficient locomotion in a wheelchair is of great importance for the life quality of people with diseases that make them unable to walk, and also in many sport disciplines for the handicapped. The aim of this study was to compare the grip strength with the force of propulsion of a constrained wheelchair for different positioning of the hand on the wheel, and to observe the influence of grip strength and static propulsion force of the wheelchair on the results of a test ride on a given box-shaped path. ***Materials and methods.*** 84 healthy subjects took part in the test (52 female and 32 male), each being a Physiotherapy student of the Joseph Rusiecki Academy in Olsztyn. The grip strength measurement was conducted using a tensometric dynamometer in a sitting position. The propelling force was measured in static conditions with a dynamometer in three different hand positions on the push rim. The ability to move efficiently on a wheelchair was assessed on a "box" shaped track with measured completion times. ***Results.*** It was observed that women have lower grip strength of both hands than men and that their middle phalanx is shorter. In both groups a significant correlation was observed between grip strength and anthropometric parameters: body height, body weight, length of middle phalanx and between grip strength of the left and right hands. It has been found that grip strength is significantly correlated with the propulsion force of the wheelchair in almost all positions of the hand on the wheel. There was no significant correlation between the force generated with the left hand on the middle of the rim and the grip strength measured with a dynamometer. Men also achieved better results during the "box" test. A significant positive correlation was observed between body mass of both male and female subjects and the time of completing the "box" test. No correlation was found between the time of completing the "box" test and the propulsion force measured in constrains. Conclusions. Men achieve higher values of propulsion force than women in all cases of hand positioning on the wheel. Both men and women achieve highest values of propulsion force when positioning the hands in front of the rim. In all measured positions the average propulsion force was higher for men. In the case of healthy people who are not accustomed to using a wheelchair, the time of completing the "box" test depended mostly on their technical abilities and not their physical strength.

Key words: sports wheelchair, hand grip, propulsion force

Introduction

Gait and running are a basic form of human locomotion ensuring the movement of the whole body [1, 2]. The lack of locomotive functions can lead to physical, mental and social degradation of the patient. Modern diseases, trauma caused by accidents and sports, ubiquitous strokes have increased the number of people with locomotive function impairments [3].

Most people on wheelchairs have suffered a motion apparatus defect. Some are caused by illnesses, others by accidents, unfortunate jumps into water, falling from heights [4, 5]. A wheelchair ensures a stable position of the body and enables locomotion. There are many types of wheelchairs. Comfort, functionality, durability, proper matching to the type and degree of disability, even aesthetics, are important factors influencing efficient movement. Wheelchairs can be divided into indoor and outdoor categories. Indoor wheelchairs are further divided into deckchair-type chairs that can be set to a vertical position and armchair-type chairs that can be propelled with one or both arms, intended for patients with paralysis, paresis, hemiplegia and amputees. The outdoor wheelchairs are designed to be used on longer distances. These are either hand-propelled wheelchairs that require high levels of agility from the patient or electric wheelchairs for patients with total arm disability. Wheelchairs can be further divided into wheelchairs intended for spastic children (cerebral palsy and other diseases of the nervous system) and ACTIV type wheelchairs, intended for patients with permanent motion apparatus dysfunctions, paralysis, paresis and amputees. The first type of wheelchairs can be used both indoors and outdoors, are lead by a guardian and can stabilize the torso, limbs and head. The ACTIV type wheelchairs ensure a high level of independence, as they are adjusted to the needs and abilities of the user. They are matched individually to the existing dysfunctions [6, 7]. Wheelchairs are divided into hand-propelled (active) and passive ones, usually driven by electric motors. Wheelchairs that allow locomotion both with the use of the hands and also have mechanical propulsion are called active-passive or hybrid wheelchairs. Each wheelchair is chosen individually for its user with parameters suited to the dysfunction [7]. These actions increase functional independence, life quality and reduce medical complications [6, 8].

Handicapped people who are engaged in physical activity are more often becoming members of sport clubs and taking active part in tournaments on amateur and also professional levels. Sport and other types of activity, as with able-bodied people, have a positive influence on the bodies of handicapped people [9]. Choosing a sports wheelchair for the competitor and its configuration are done individually. Some handicapped sportsmen require a special wheelchair, one that fulfills the requirements of the given discipline and also is safe for other participants. The coach, besides improving the tactical and technical aspects, also has to improve the physical conditioning of the competitor. The level of sport abilities always depends on the functional abilities of the sportsman [9, 10]. Each of the disciplines has qualifying systems that allow choosing teams with similar levels of disabilities so that they have equal chances of winning. The International Wheelchair Basketball Federation (IWBF) uses the most developed functional classification [11].

The proper choice and adjustment of the wheelchair is very important due to its influence on the adaptation abilities of the handicapped person to living with a disability [4, 7]. The increasing knowledge and its use in designing wheelchairs allows us to match a person with the "perfect wheelchair". However there still remains the common lack of knowledge and skill of proper locomotion on the wheelchair. Bad technique and most of all excessive loading of the lower limbs due to riding in difficult terrain for long periods of time can lead to musculoskeletal injuries [11, 12]. It seems significant to seek the most ergonomic way of locomotion on the wheelchair, especially for people not involved in sports. Due to the necessity of adapting the construction of the wheelchair to the functional state of its user, attempts have been made to establish the possibility of propelling the wheelchair by healthy people in adjacent conditions.

The main aim of this study was to compare grip strength with the propelling force generated statically on a wheelchair and to compare these forces generated in different hand positions on the rim with the results of a test ride on a box shaped path.

Material and methods

A group of 52 female and 32 male Physiotherapy students of the Joseph Rusiecki Academy in Olsztyn were tested. Table 1 shows the characteristics of the group.

Table 1. Characteristic of the investigated group

Women n=52			
	x±sd	min	max
Age [years]	29.27 ± 8.44	24	55
Body height BH [cm]	167.02 ± 5.47	156	180
Body mass BM [kg]	64.13 ± 12.45	44	117
Length of the phalanx LPI [mm]	60.2 ± 3.4	51	72
Men n=32			
Age [years]	26.84 ± 3.18	24	36
Body height BH [cm]	182.88 ± 6.80	170	200
Body mass BM [kg]	87.45 ± 16.96	61	143
Length of the phalanx LPI [mm]	67.2 ± 3.9	60	83

The grip strength measurement was conducted using a tensometric dynamometer with automatic recording of maximal force values. The width of the dynamometer grip was chosen according to the size of the hand. The width of the grip matched the proximal phalange of the middle finger. Phalange length and grip width were measured with a caliper. Grip strength was measured in a sitting position. Each of the subjects sat in the wheelchair with one upper limb hanging loose, holding the dynamometer in the hand, the other arm holding the rim (Fig. 1). Given a signal, the subject generated maximal force by compressing the dynamometer. Both left and right hand were measured twice. The best results of the grip force FG [N] were recorded along with the length of the middle phalanx LPI [mm].

Figure 1. Grip strength measurement using a tensometric dynamometer

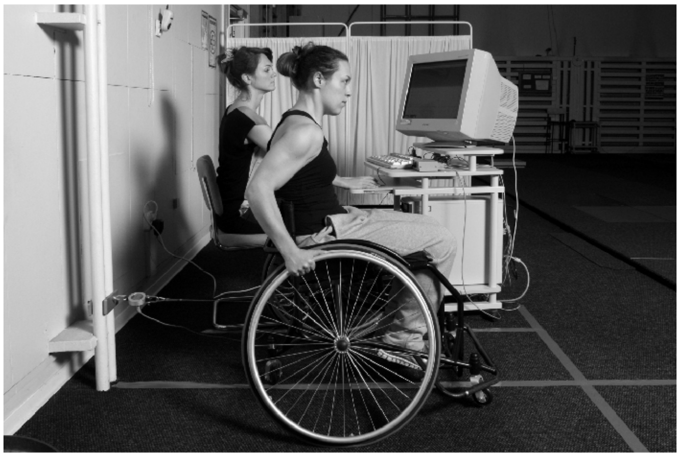

Figure 2. Propelling force measurement with hands placed on the back of the pushrim (FP1)

The propelling force FP [N] was measured in static conditions on a sport wheelchair produced by Spin-off in China for the American MOTIVATION foundation. The wheelchair was tied to the wall using a cable with a dynamometer that registered the maximal force values (Fig. 2, Fig. 3, Fig. 4). The wheelchair was positioned adequately to the direction of the movement. The subject was sitting in the wheelchair with hands placed on the back of the rim. Given a signal the subject exerted maximal force PBH1 with both hands, propelling the wheelchair forward (Fig. 2). The same measurement was repeated with hands placed on the upper part of the rim (Fig. 3), registering propelling force PBH2. Propelling force PBH3 was measured with hands placed in front of the rim (Fig. 4). Also the propelling force was measured for only the right hand placed on the back of the rim PRH1, on the top PRH2 and in front PRH3. Similarly the forces were measured for the left hand – PLH1, PLH2, PLH3. During the test for the right hand, the left hand was stopping the left wheel, so that the wheelchair remained straight. Each subject had two attempts at measuring the propelling force for each position, the better result was recorded.

Figure 3. Propelling force measurement with hands placed on the middle of the pushrim (FP2)

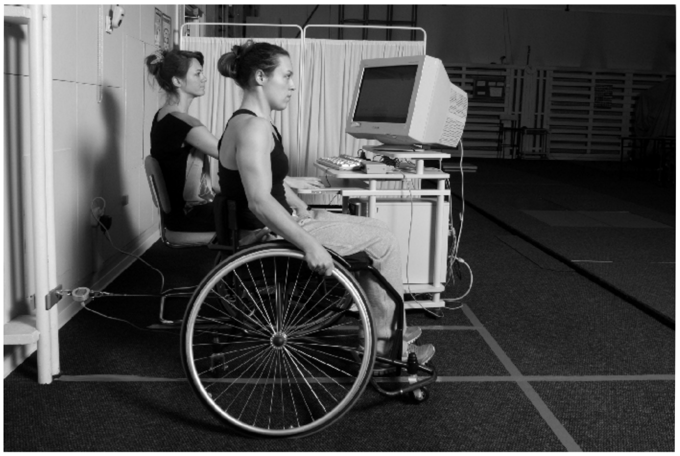

Figure 4. Propelling force measurement with hands placed on the front of the pushrim (FP3)

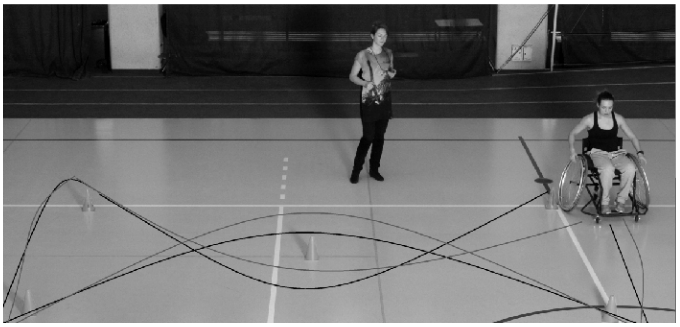

Figure 5. Track of the "box" test

The aim of the "box" test was to complete a given path in the shortest possible time without touching any cones. The test began on the sound of a whistle, the timer was started, then it was stopped as the subjects crossed the finish line. The subjects performed this test twice, and the shortest time was recorded. The subject was allowed to use the help of an assistant, who, standing outside the box, would guide him suggesting the proper path (Fig. 5).

Results

The normality of the distributions was checked using the Shapiro-Wilk test. All measured variables had normal distributions ($p>0.05$).

The average values of body height HG and body mass BM, the length of the proximal phalanx of the middle finger LPI and the age of the subjects (Tab. 1) were compared using t-Student test in male and female groups. There was no major age difference between the groups. The average body height, body mass and phalanx length were significantly higher ($p<0.001$) for men.

Table 2. Mean values ±sd, minimum and, maximum of the hand grip force: right hand HGR, left hand HGL, [N]

Women n=52			
FG	x±sd	min	max
HGR	293±59	163	441
HGL	277±51	182	415
Men n=32			
HGR	533±98	362	875
HGL	518±96	314	748

Table 3. Mean values ±sd minimal, maximal propulsion force [N] of the wheelchair depending of hand position on the wheel

Women n=52				
	position	x±sd	min	max
PBH	I	322±81	164	587
	II	301±64	164	428
	III	322±81	167	520
PRH	I	263±60	133	410
	II	254±72	115	468
	III	275±66	152	441
PLH	I	228±50	84	312
	II	231±70	111	411
	III	240±63	108	384
Men n=32				
PBH	I	515±92	346	697
	II	519±80	349	665
	III	562±139	281	791
PRH	I	437±72	279	616
	II	463±87	260	633
	III	462±106	220	659
PLH	I	420±90	233	587
	II	434±104	274	681
	III	427±100	257	668

I position – hands in the back of the wheel; II position – hands on the top of the wheel; III position – hands in front of the wheel; PRH – propulsion force right hand; PLH – propulsion force left hand; PBH – propulsion force booth hands.

Table 2 shows the mean values of grip strength HGR of the right hand and HGL for the left hand, as well as their maximal and minimal values for both men and women. The mean values were compared using t-Student test. Women had lower grip strength of both left and right hands than men (p<0.001). No asymmetry was found between right and left hand grip strength in women. Men had significantly higher right hand grip strength (p<0.05).

Table 3 shows the mean values of propelling force measured with the wheelchair in constraints. While propelling with both hands, female subjects achieved the lowest grip strength results with hands placed on the uppermost spot on the rim (p<0.05). The propelling forces did not differ much in the cases of hand placement in front and in the back of the rim. The propelling force was significantly lower for the upper position (position 2) than for the back (position 1) and front (position 3), (p<0.05). Men achieved the highest force values with position 3 (in front, p<0.05). Men generated similar propelling forces for the front and back positions, both of them significantly lower than the upper position (p<0.05).

The average values of propelling force in female subjects were significantly different for each side of the body as well as for the grip positioning. While in the back grip (position 1) women achieved significantly higher values for the right hand (p<0.001).

Table 4 shows the mean values, the maximal and minimal results for the "box" test.

Table 4. Mean ±sd, minimal and maximal values of the "box" test

	x±sd	min	max
Women n=52			
T	33.17±2.35	28.5	38.9
Men n=32			
T	30.08±2.69	24.7	37.6

T – run time [s]

Table 5. Correlation coefficients between body height – BH, body mass – BM, length of the proximal phalanx of the third hand finger – LPH, hand grip force of the right hand – HGR, hand grip force of the left hand – HGL and mean hand grip force of the hands – HGM in men and women

	BH	BM	LPH	HGR	HGL	HGM
Women n=52						
HGR	0.436**	0.358**	0.434**	1.000***	0.758***	0.947***
HGL	0.487***	0.385**	0.317*	0.758***	1.000***	0.927***
HGM	0.490***	0.395**	0.405**	0.947***	0.927***	1.000***
Men n=32						
	BH	BM	LPH	HGR	HGL	HGM
HGR	0.514**	0.458**	0.676***	1.000***	0.831***	0.958***
HGL	0.401*	0.468**	0.643***	0.831***	1.000***	0.955***
HGM	0.479**	0.484**	0.689***	0.958***	0.955***	1.000***

* p<0.05; ** <0.01; *** <0.001

Table 5 shows the correlation indexes of the measured anthropometric parameters and the grip strength. Significant correlation between right hand grip HGR and left hand grip HGL (r=0.758, p<0.001) was observed for both the female and male groups (r=0.831, p<0.001). Correlation was also observed between grip strength of each hand and the average grip strength of both hands HGM on significance level p<0.001. All anthropometric parameters – body height BH, body mass BM, middle phalanx length LPI – were compared to the grip strength of both hands compared to each other (for the right hand HGR, left hand HGL and mean sum for left and right hand HGM). A significant correlation exists in women between body height BH and the average sum of grip strength HGM (r=0.490, p<0.001) and between right and left hand grip strength (r=0.758, p<0.001). In men the strongest correlation exists between right hand HGR, left hand HGL grip strength (r=0.831, p<0.001), the length of the middle phalanx LPI and the average sum of both hands grip strength HGM (r=0.689, p<0.01).

Men achieve higher propulsion forces of the wheelchair for each hand position on the rim (Tab. 6). The highest correlation index in men was recorded between propelling force of left hand PLH2 placed in position 2 and the average grip strength HGM (r=0.665, p<0.001). In the female group a strong correlation was recorded between body mass BM and the propelling force of the right hand PRH (r=0.520, p<0.01). The same parameters in the male group correlate on a level of r=0.587 (p<0.001). A strong correlation was also observed between grip strength and propelling force in almost all positions. The strongest correlations in the female group existed between average grip strength HGM and propelling force in the middle position PBH2 (r=0.574, p<0.001), for the male group between the pro-pelling force of the left hand in the middle position PLH2 and the average grip strength HGM (r=0.665, p<0.001). No correlation exists between propelling force of the left hand in the middle position in women and their grip strength.

Table 6. Correlation coefficients between body height – BH, body mass – BM, hand grip force of the right hand – HGR, hand grip force of the left hand – HGL, mean hand grip force of the hands – HGM, mean propulsion force of the both hands in back hand position – PB I, mean propulsion force of the both hands in top hand position – PB II, mean propulsion force of the both hands in front hand position – PB III, propulsion force of the right hand in back hand position – PR I, propulsion force of the right hand in top hand position – PR II, propulsion force of the right hand in front hand position – PR III, propulsion force of the left hand in back hand position – PL I, propulsion force of the left hand in top hand position – PL II, propulsion force of the left hand in front hand position – PL III in men and women

No.	Force	BH	BM	HGR	HGL	HGM
Women n=52						
1	PB I	0.118	0.232	0.400**	0.300*	0.377**
2	PB II	0.314*	0.400**	0.487***	0.544***	0.547***
3	PB III	0.193	0.332*	0.279*	0.296*	0.306*
4	PR I	0.418**	0.466***	0.480***	0.492***	0.518***
5	PR II	0.192	0.438**	0.500***	0.428**	0.498***
6	PR III	0.148	0.520***	0.434***	0.399**	0.445***
7	PL I	0.181	0.440**	0.396**	0.348*	0.399**
8	PL II	0.063	0.245	0.223	0.241	0.246
9	PL III	0.140	0.441**	0.274*	0.294*	0.302*
Men n=32						
1	PB I	0.385	0.361*	0.275*	0.148*	0.222*
2	PB II	0.361	0.387*	0.498**	0.516**	0.530**
3	PB III	0.363	0.525**	0.586***	0.555***	0.596***
4	PR I	0.025	0.251*	0.420*	0.357*	0.406*
5	PR II	0.029	0.362*	0.189*	0.218*	0.212*
6	PR III	0.187	0.459**	0.387*	0.319*	0.370*
7	PL I	0.207	0.439*	0.422*	0.432*	0.446**
8	PL II	0.273	0.454**	0.621***	0.653***	0.665***
9	PL III	0.200	0.587***	0.437*	0.552**	0.516**

* p<0.05; ** <0.01; *** <0.001

The analysis of the "box" test (Tab. 7) shows a significant correlation between body mass BM and the time T of completing the test both in female (r=0.502, p<0.001) and male subjects (r=0.579, p<0.001). Additionally, the propelling force of the left hand in the front position PLH3 correlates with the time of the "box" test T – r=0.278 for women (p<0.05) and r=0.353 for men (p<0.05). No correlation was found between static propelling force and the time of completing the "box" test.

Table 7. Coefficients of correlation between the values of body height – BH, body mass – BM, HGR, HGL, mean propulsion force of the both hands in back hand position – PB I, mean propulsion force of the both hands in top hand position – PB II, mean propulsion force of the both hands in front hand position – PB III, propulsion force of the right hand in back hand position – PR I, propulsion force of the right hand in top hand position – PR II, propulsion force of the right hand in front hand position – PR III, propulsion force of the left hand in back hand position – PL I, propulsion force of the left hand in top hand position – PL II, propulsion force of the left hand in front hand position – PL III, and ride time of "box" test

	relationship	"box" test; Women n=52	"box" test; Men n=32
1	BH	-0.026	0.206
2	BM	0.502***	0.579***
3	HGR	-0.077	0.082
4	HGL	-0.070	0.168
5	LPI	0.159	0.174
6	PB I	-0.032	-0.035
7	PB II	-0.069	0.063
8	PB III	0.078	0.256
9	PR I	0.081	0.043
10	PR II	0.096	0.272
11	PR III	0.223	0.243
12	PL I	0.133	0.236
13	PL II	0.044	0.246
14	PL III	0.278*	0.353*

* p<0.05; ** <0.01; *** <0.001

Discussion

The aim of this study was to investigate the influence of grip strength on the propelling force of the constrained wheelchair in different hand positions on the rim. An attempt was also made to establish the influence of grip strength and propelling force on the results of a test, which required tackling a box shaped course measuring 36 meters in the shortest possible time.

The results show that there is a correlation between grip strength and propelling force moments measured on a wheelchair in static conditions with different hand positions on the rim. No correlation was found only between the propelling force of left hand in the uppermost position on the rim in women and their grip strength of the left and right hand, as well as the average strength of both hands. The results achieved by healthy students are similar to those by Fidelus et al. [13] achieved by subjects with various diseases on wheelchairs. In this study the propelling force was measured in constraints, but Fidelus et al. [13] used a special stand for the wheelchair. The wheelchair was stabilized and it was not necessary to put additional effort into keeping it in a straight line.

The results of this study show significant correlation between body mass and the time of completing the "box" test. In addition, grip strength and static propelling moments have no influence over the time of completing the "box" test. These results point towards the fact that the ability to move efficiently in a wheelchair depends mainly on the technical skills of the user, not his/her strength potential. Thus, it is extremely important to master the proper technique of propelling the wheelchair and to adequately position the patient relative to the axis of the wheel.

The study showed that women achieve highest propelling forces when placing both hands in the front or in the back position on the rim. Men achieve best results placing their hands in the front position. The male group has better results in each test (grip strength, propelling force in static conditions, "box" test). Men and women have different levels of propelling strength measured in static conditions. The propelling force for different hand positions has significantly different mean values for groups of healthy men and women.

The proper matching of a hand-propelled wheelchair to its future user is divided into three stages and significantly affects the patient's ability to adapt to this type of life [7]. Each stage has its strict guidelines for the given user. Proper relations in the anthropotechnical system (user – wheelchair) have high influence on the social abilities of the handicapped person [7]. This study was conducted using a standard-dimension wheelchair designed for basketball. Individual fitting of the wheelchair to each subject could have resulted in higher propelling force values thus in consequence improving the locomotive abilities of wheelchair users.

Rodgers et al. [12] investigated the change of kinetic parameters during propelling of non-sport wheelchairs by paraplegic patients. The authors observed that with increased propelling force comes an increased angle in the shoulder and elbow joints, which leads to smaller range of motion and forward leaning of the torso. The given results suggest that overusing or misusing wheelchairs can lead to musculoskeletal dysfunctions and can impede rehabilitation [12].

During the last 65 years, the technological progress caused a substantial increase of wheelchair locomotive abilities, which in turn increased the popularity of such disciplines as basketball or wheelchair rugby [9]. The evolution of wheelchair construction was highly influenced by functional research of mobility with the use of biomechanical methodology. The cooperation of scientists, competitors and companies have lead to a significant decrease of wheelchair weight (the most advanced wheelchairs weigh up to 10 kg), allowing more maneuverability. The use of small wheels in the front and back of the chair increase safety and mobility [9]. Wheelchairs are being improved every day. According to Crespo-Ruiz et al. [11], the biomechanical analysis of wheelchair propulsion may become a way to objectively classify a competitor to a particular functional group. Mason [10] suggests, that the size and angle of wheels, method of sitting and the use of gloves while propelling the wheelchair have significant influence on the mobility and agility of the competitor on the field. In his study, the author tried to optimize the configuration of a sports wheelchair and gloves that would allow easier locomotion. He established the optimal wheel angle (18°) and the size of the wheels adjusted to moving in the field (25" and 26"). The results of kinetic parameters measurement while propelling the wheelchair can prove significant for manufacturers and can contribute to designing and constructing better wheelchairs dedicated to particular disciplines of sport and for the everyday activity of handicapped people.

In the future, it seems appealing to take up biomechanical research to identify the dynamic characteristics of the locomotive potential of handicapped people for the optimization of the construction and setup of wheelchairs used in sport and day-to-day life.

Conclusions

1. The average results of grip strength and propelling force in each position of the hand on the rim (back, middle, front) are significantly higher for men than for women.
2. Grip strength of right and left hand correlate with the body mass in both men and women.
3. Both men and women have significant differences between average values of propelling force for different positioning of the hands on the rim.
4. The highest propelling force was achieved for both men and women with hands placed in front of the rim.
5. A statistically significant correlation was found between the grip strength measured with a manual dynamometer and the propelling force of the constrained wheelchair with different positioning of the hand on the rim.
6. The male group achieved substantially better results in the "box" test than women.
7. In both men and women the grip strength and static force moments had no influence on the time of completing the "box" test.
8. In both groups a significant correlation was observed between body mass and the time of completing the "box" test.
9. It can be assumed, that the time of completing the "box" test is related to the technical skills of the subject, not the strength potential.

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