Wrist Deviation influence on Initial Hand Force before Wheelchair propulsion Using Digital Human Modeling

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Abstract

Manual wheelchair users face many difficulties during their daily activities. These users demand a high amount of force from their upper extremities to move or turn. Due to exerting these forces over time, more pressure on the wrist's median nerve is applied, and the users suffer from severe pain in their arm muscles. In general, manual wheelchair users provide repetitive motion for an extended time leading to CTS. This study uses digital human modeling to investigate wrist deviation in radial and extension positions, body dimension, and gender on the maximum hand force. Three wrist radial deviation (i.e., 10°, 15°, and 20°), three extension wrist degrees (i.e., 25°, 35°, and 50°), both genders (i.e., male and female), and three percentiles (i.e., 5th, 50th, 95th) are involved. Jack digital human modeling software was used to simulate the wrist's deviation and test different body sizes. Force solver in Jack software calculates the amount of maximum hand force for 54 combination runs. Analysis of variance was used to determine the significant factors. The results show that radial deviation has no significant impact on the maximum hand force, while other factors have a considerable impact. The male, in general, provides more strength than the female. A person with the 95th percentile has less force than 50th, and both are less than 5th (62, 68, and 74, respectively). Wrist extension on 25° provides 95 Neuton force which is the maximum between another extension angel.

Keywords
Digital Human Modelling, Wrist Deviation, Manual Wheelchair, Wrist Pain

1. Introduction
People with disabilities are the essential group in our community; their needs and requirements are specific to their capabilities and limitations. Around 15% of the world population is suffering from a disability, and 2.2% are living with limited function (World Report on Disability, 2011). In the USA 6.9% of the population reported movement disability (Erickson, 2019), and In Jordan, 651,396 people if age 5 years and old are suffering from disability (movement and other disability), around 4.8% of the total population suffer from movement disability (Disability Facts and Number in Jordan, 2017), most of them are using manual wheelchair to do their daily activities, usually, they stay at home and need aids.

The manual wheelchair users have so many difficulties moving around due to muscle effort requirement and exertion (Collins et al., 2010). Manual wheelchair users may have Musculoskeletal disorders more than ordinary people, due to many constraints in their travel (Yoon, Yoo, Ha, Ji, & Kim, 1997). These disorders are mostly associated with upper extremity pain and injury (Boninger et al., 2000), many studies reach to number of factors affecting the upper extremity pain such as contact angle, rate of rise, and magnitude of peak forces and moments (Boninger et al., 2000; Boninger et al., 2005; Collinger et al., 2008), in addition to demographic information about the manual wheelchair users (Boninger et al., 2003; Dyson-Hudson & Kirshblum, 2004; Sinnott, Milburn, & McNaughton, 2000).

This project's primary purpose is to ergonomically assess using the manual wheelchair on people with different demographics such as BMI and the type of movement required to operate the manual wheelchair like moving forward

and backwards. This should be done using digital human modelling software called Jack. The ergonomic intervention which this project focuses on is the wrist deviation on the maximum hand force.

1.1 Objectives

This primary purpose of this study is to evaluate the use of manual wheelchair with different wrist deviation. Digital human modelling software called Jack will be used to simulate different wrist angle and by using force solver tool the maximum force will be recorded. The ergonomic intervention which this project focuses on is the wrist deviation on the maximum hand force.

2. Literature Review

The manual wheelchair is associated with the repetitive movement of the hand forward and backwards on the wheels to move the person; this repetitive motion may cause a cumulative trauma disorder (CTD) for the wheelchair (da Costa & Vieira, 2010). Around 68% of the manual wheelchair users suffer from the pain their upper extremities (Gellman et al., 1988); this percentage will increase if no attention is payed to the design of the wheelchair.

One of the majors complain in the manual wheelchair users is the carpel tunnel syndrome (CTS) which is (Dalyan, Cardenas, & Gerard, 1999); which cause intense pain in the hand of the manual wheelchair users. Boninger et. al., found that body weight may influence that risk of increasing the pain the hand due to pressure in the median nerve, which usually called CTS (Boninger et al., 1999). Another study showed that person who exercise regularly may has less chance of have CTS in the future (Boninger, Robertson, Wolff, Cooper, & rehabilitation, 1996).

One of the suitable measures of the fitting the person with job force requirement is the job strength rating, which is defined as a ration between maximum job force demand to the person maximum voluntary force (Chaffin, DB, GD, & WM, 1978). So, it is important to study the maximum hand force and measure the manual wheelchair force requirement to be able to avoid any unnecessary pain may developed when moving the wheelchair for long period of time.

A study showed that the wrist deviation may vary in the amount of moment, wrist at extension posture is weakest than flexors, radial, and ulnar deviation by 50% (Sabick, Kotajarvi, An, & rehabilitation, 2004). A study investigates the range of motion of manual wheelchair users concluded that personal with high range of motion with arm may have less chance of getting CTS, that mean less flexion and extension of wrist (Boninger, Impink, Cooper, Koontz, & rehabilitation, 2004).
Digital human modeling software's were developed for long time now, they have been used in many studies. These software's provide fast and safe experiment for the researchers. Jack is one of these digital human modeling owned by Siemens company. Wolkiewicz et. al., used this software the investigate the lower back injuries for people who used snow shovel more often, they tested different type of design and conclude with which one has less risk (Wolkiewicz, Collins, Aqlan, & Al Meanazel, 2018).

Another study conducted on static box lifting in different position (Standing and Sitting) with different box sizes in virtual manufacturing environment, they studied the amount of back muscle tension (Al Meanazel, Al-Shudiefat, Al-Momani, & Aqlan).

3. Methods

The project will focus on assessing the wrist deviation during operating manual wheelchair, the person using manual wheelchair expose to dynamic kind of movement while moving the wheelchair forward. These deviations can create stress on the wrist and may cause wrist disorders. In this study three wrist extension and three wrist radial degree will be examined to find the maximum acceptable fore for each combination of these deviations. Afterward the results are recorded, and Statistical analysis of variance (ANOVA) is used to test the influence of different combination on the user maximum force. All these will be conducted using JACK digital human modeling software. Figure 1 shows the methodology followed by this project.

To simulate the activities the team work on two different software: Google SketchUp and JACK. The chair was designed using Google Sketchup software, then it's imported to JACK digital human modeling software, then the

wheelchair was adjusted to meet human characteristics. Figure 2 shows the simulation design. Minitab is used to analyze the results; the data is tested using one-way ANOVA.

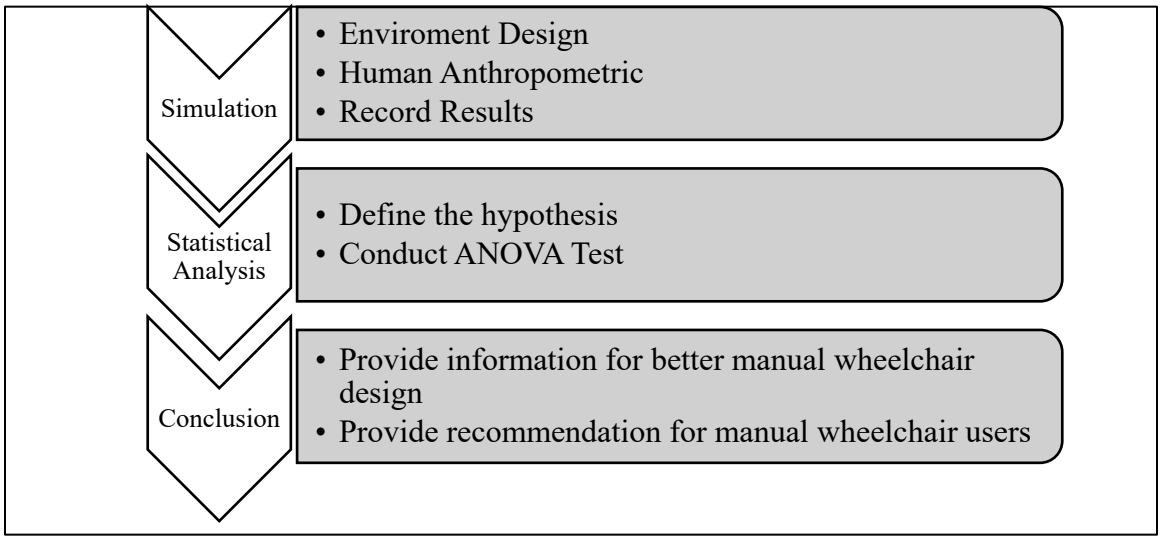

Figure 1. Methodology Flow

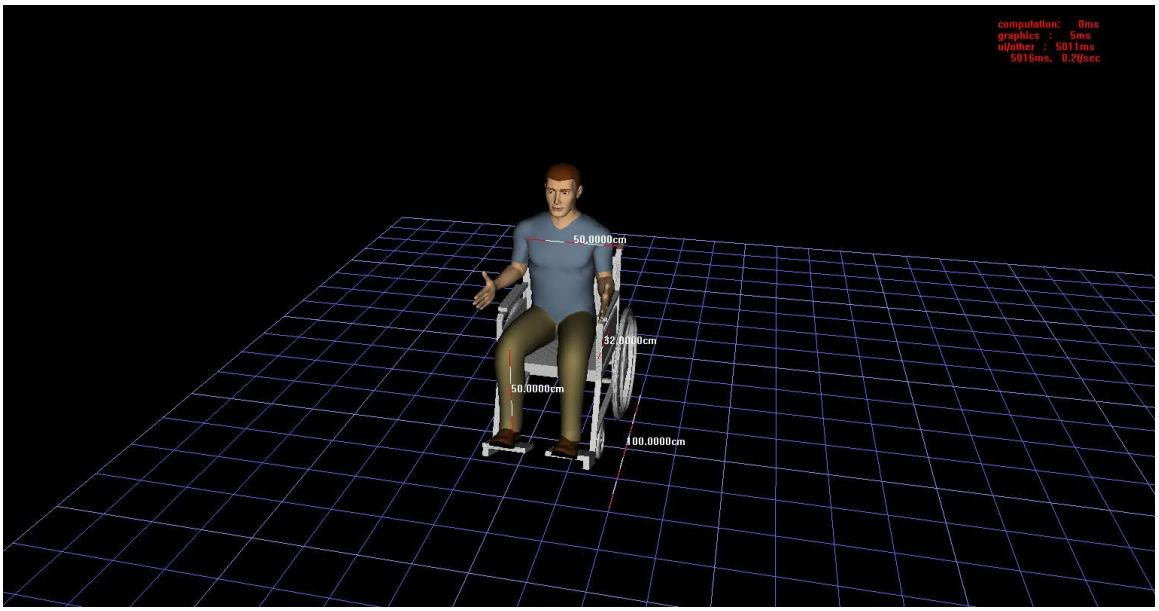

Figure 2. Model Design

4. Data Collection

To design the experiment four factors were selected to test their influence on the maximum hand force, this force is important to operate the manual wheelchair. The factors are gender, percentile, wrist extension, and wrist radial; The wrist usually has five different postures; (1) normal, (2) extension, (3) flexion, (4) radial, and (5) ulnar, Figure 3. Two postures will be studied in this project extension and radial with different angles along with gender and percentile.

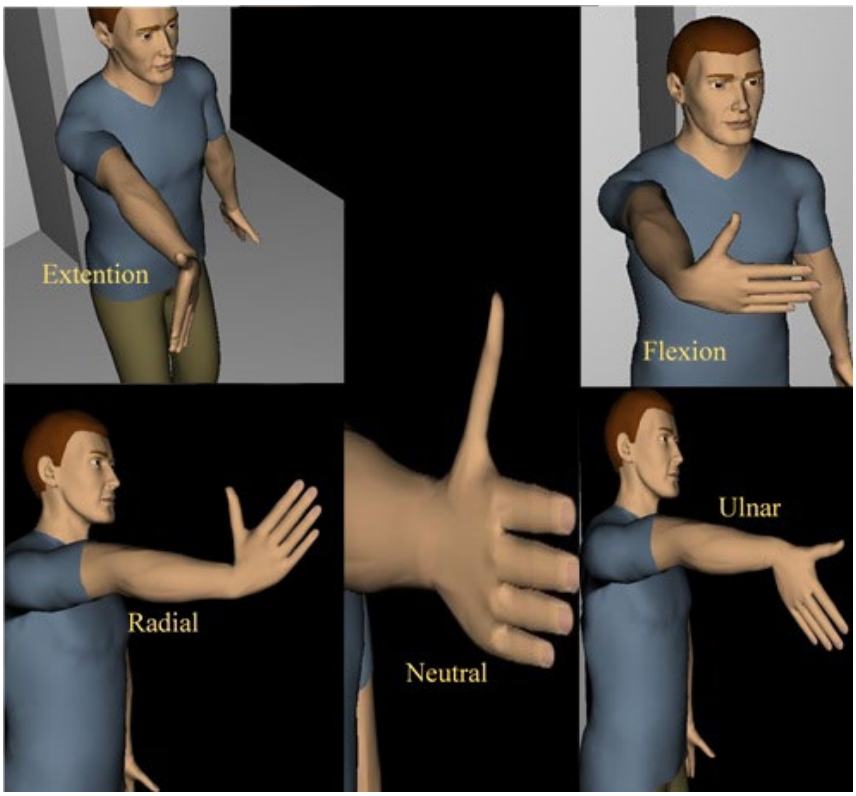

Figure 3. Wrist Posture

To setup the experiment the factors were designed three level of wrist radial deviation, three level of extension, two level for gender, and three level of percentile, full combination of these factors is shown in Table 1, total number of combinations is 54 run.

Table 1. Factors Information

Factor	Levels	Values
Gender	2	Male, Female
Wrist Extension (degree)	3	25°, 35°, 50°
Wrist Radial (degree)	3	10°, 15°, 20°
Percentile	3	5^{th}, 50^{th}, 95^{th}

The simulation in Jack world is the second task in this project, to simulate a manual wheelchair work, a wheelchair is imported from google SketchUp and it is adjusted to regular wheelchair size, the chair dimensions are length = 100 cm, width = 50 cm, overall height = 90 cm, and seat height = 50 cm, those dimensions are like dimensions in www.dimensions.com website (Dimensions), Figure 4 shows the dimensions on the wheelchair from Jack Software. The percentiles for the body are also changed in the Jack environment, Figure 4-6 shows different body shape for male and female with different percentile, this figure is extracted from research conducted by Wolkiewicz et. al., (Wolkiewicz et al., 2018). These percentiles adapted from the Anthropometric Survey of US Army Personnel (ANSUR).

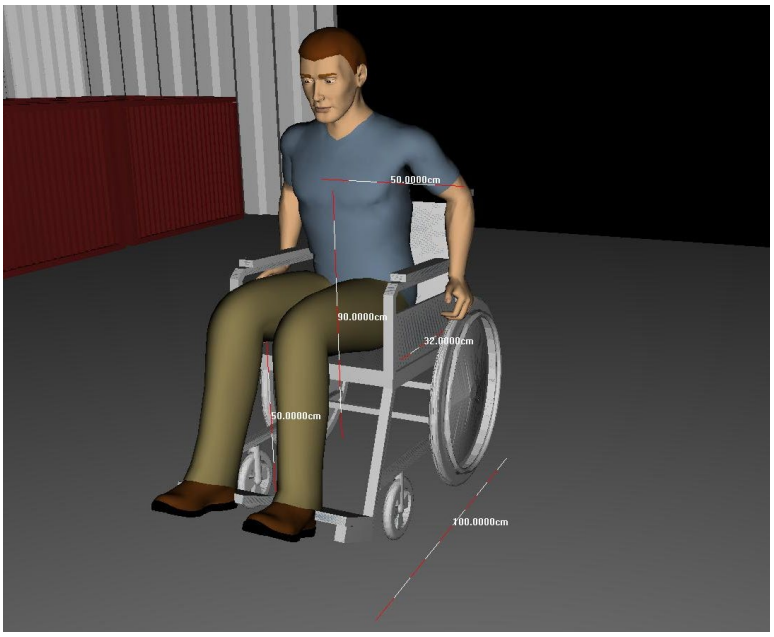

Figure 4. Wheelchair Dimensions

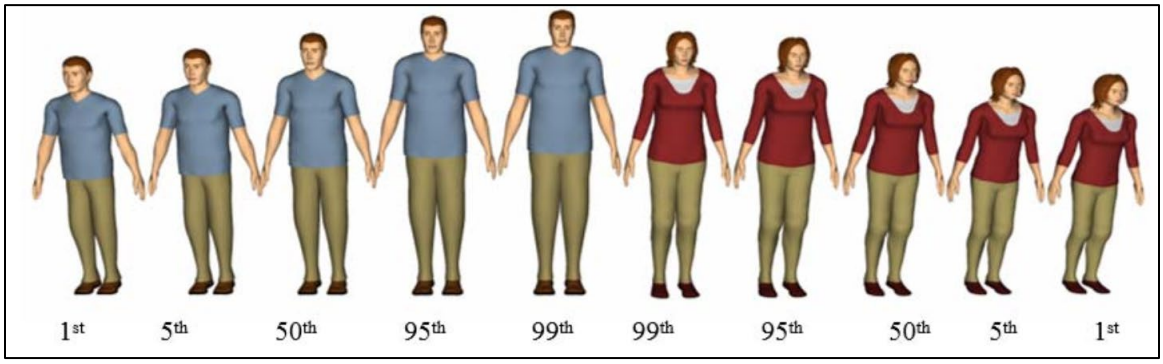

Figure 5. Different human percentile in Jack software (Wolkiewicz et al., 2018)

The posture is simulated like a normal person is trying to push the wheels forward, the wrist joint angle is adjusted after open control window, Figure 5. To simulate the actual practice of person the frequency of this posture is edited to be 30 per minutes, this number is estimated based on the experience knowledge.

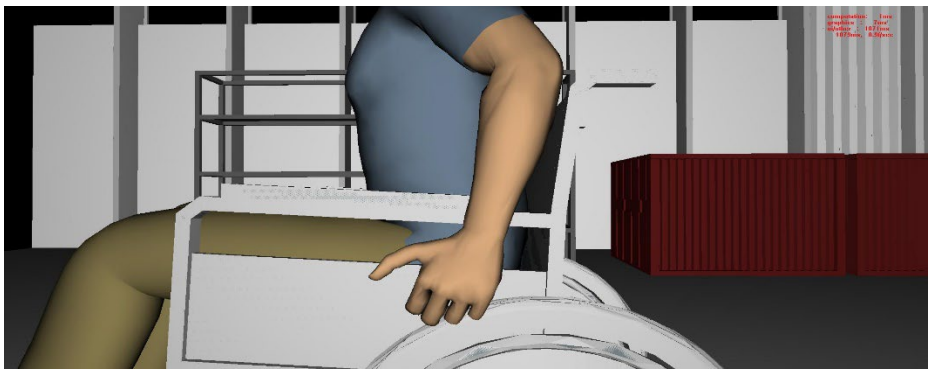

Figure 6. Wrist joint of person using manual wheelchair

The independent variable is the maximum hand force based on different characteristics; this force is calculated in Neuton (N). Table 2 shows sample of the results extracted from Jack software; all the data is shown in Appendix 1.

Table 2. Sample of data

Gender	Wrist Extension Degree	Wrist Radial Degree	Percentile %	Max. Hand Force N
Male	25	10	5	127
Male	25	10	50	116
Male	25	10	95	104
Male	25	15	5	125
Male	25	15	50	114
Male	25	15	95	103
Male	25	20	5	123
Male	25	20	50	113
Male	25	20	95	101
Male	35	10	5	85
Male	35	10	50	78
Male	35	10	95	71
Male	35	15	5	84
Male	35	15	50	78
Male	35	15	95	70
Male	35	20	5	83
Male	35	20	50	77
Male	35	20	95	70
Male	50	10	5	56
Female	35	10	50	54
Female	35	10	95	49
Female	35	15	5	58
Female	50	10	5	40
Female	50	10	50	37
Female	50	10	95	34
Female	50	15	5	40
Female	50	15	50	37
Female	50	15	95	34
Female	50	20	5	40
Female	50	20	50	37

5. Results and Discussion

Using Minitab 19, the data was tested for goodness-of-fit in regression and ANOVA, as shown in Figure 7, shows that the data is fit to conduct ANOVA test. The ANOVA results show that wrist radial deviation has no influence on the maximum hand force (P-Value = 0.835); However, all other factors have significant impact (P-Value <0.05), that mean if a female with wrist extension will have less, or high force and it will vary significantly.

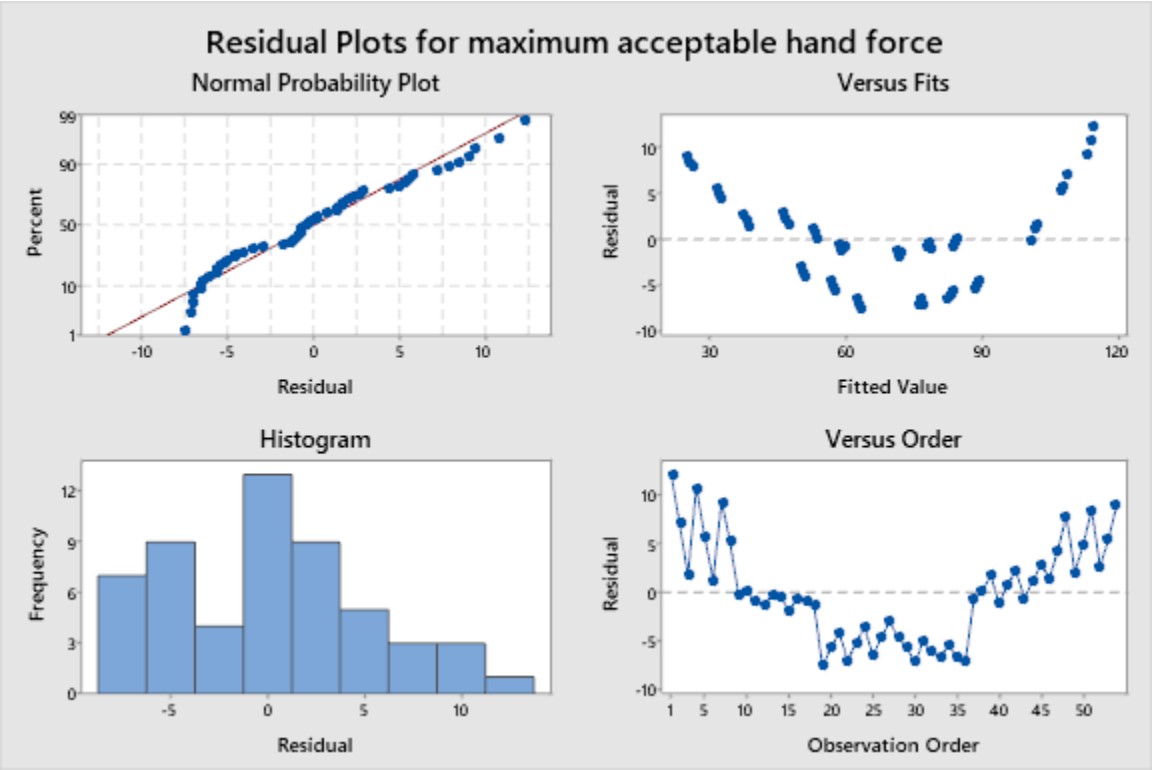

Figure 7. Test for goodness-of-fit in regression and ANOVA

As shown in Figure 8 male in general has higher maximum force that female; Moreover, as wrist is extended more the force decrease. The person with less height and weight (5th percentile) will have higher force than overweight person (Table 3 and figure 8).

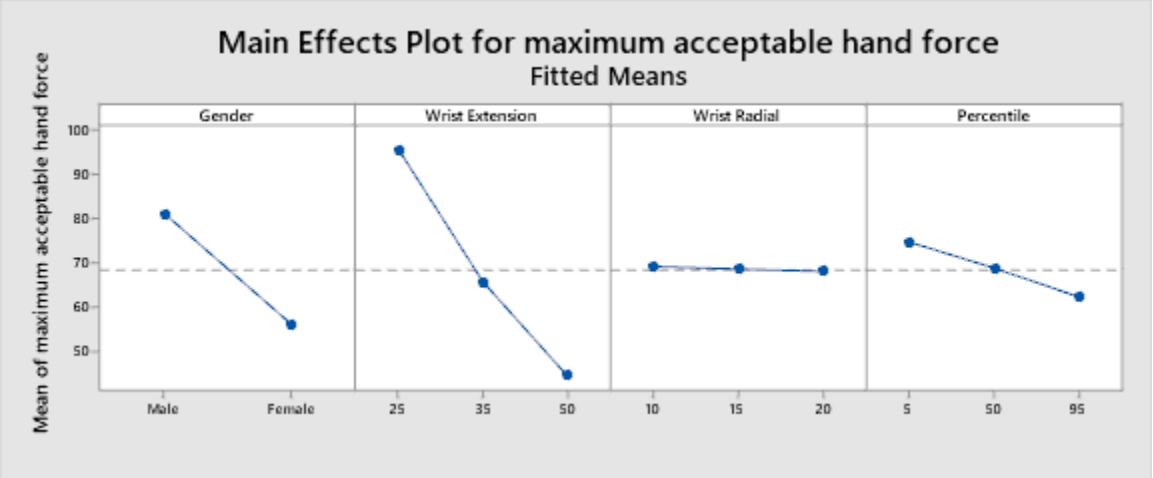

Figure 8. Main effect Plot

Table 3. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	33655.3	4807.9	156.41	0.000
Linear	7	33655.3	4807.9	156.41	0.000
Gender	1	8512.7	8512.7	276.93	0.000
Wrist Extension	2	23736.4	11868.2	386.09	0.000
Wrist Radial	2	11.1	5.6	0.18	0.835
Percentile	2	1395.1	697.6	22.69	0.000
Error	46	1414.0	30.7		
Total	53	35069.3			

6. Conclusion

As conclusion, female who use manual wheelchair can provide less force than male, that is important factor when designing wheelchair for female, if there is an incline in the road, they move in then they need support if the wheelchair has no extra support system. Usually, the person who use manual wheelchair and not exercising regularly will be overweighed soon, they should be informed that when they reach high body mass index, they will be able to provide enough force to the wheel to move the chair as they want.

Another important fact concluded from this project is the wrist deviation, most of the users will not notice the changes in their wrist extension, which may lead to less force and may cause pain in the hand due that awkward posture of wrist, when they trained to use the manual wheelchair, they should inform about the best posture to use. Small deviation in the wrist degree will significantly influence the amount of force they can provide to the wheels.

In future, more wrist posture should be tested with should elevation angle as some studies indicates that deviation should also influence the force exerted to move the wheelchair. In addition, the result in this study is based on simulation run should be verified with real experiment after getting IRB acceptance.

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References

Al Meanazel, O. T., Al-Shudiefat, A. A.-R. S., Al-Momani, H. A., & Aqlan, F. Factors affecting spine loading in a box lifting task: a digital human modelling study, *International Journal of Industrial and Systems Engineering,* vol 37, no 2, pp. 168-178, 2021.

Boninger, M. L., Baldwin, M., Cooper, R. A., Koontz, A., & Chan, L. Manual wheelchair pushrim biomechanics and axle position. *Archives of physical medicine and rehabilitation*, *81*(5), pp. 608-613, 2000.

Boninger, Michael L., Rory A. Cooper, Mark A. Baldwin, Sean D. Shimada, and Alicia Koontz. "Wheelchair pushrim kinetics: body weight and median nerve function." *Archives of physical medicine and rehabilitation* 80, no. 8, pp. 910-915, 1999.

Boninger, Michael L., Brad E. Dicianno, Rory A. Cooper, Jeffrey D. Towers, Alicia M. Koontz, and Aaron L. Souza. "Shoulder magnetic resonance imaging abnormalities, wheelchair propulsion, and gender." *Archives of physical medicine and rehabilitation* 84, no. 11, pp. 1615-1620, 2003.

Boninger, Michael L., Bradley G. Impink, Rory A. Cooper, and Alicia M. Koontz. "Relation between median and ulnar nerve function and wrist kinematics during wheelchair propulsion." *Archives of physical medicine and rehabilitation* 85, no. 7, pp.1141-1145, 2004.

Boninger, Michael L., Alicia M. Koontz, Sue Ann Sisto, Trevor A. Dyson-Hudson, Michael Chang, Robert Price, and Rory A. Cooper. "Pushrim biomechanics and injury prevention in spinal cord injury: recommendations based on CULP-SCI investigations." *Journal of rehabilitation research and development* 42, no. 3, pp. 9, 2005.

Boninger, Michael L., Rick N. Robertson, Michael Wolff, and Rory A. Cooper. "Upper Limb Nerve Entrapments in Elite Wheelchair Racers1." *American journal of physical medicine & rehabilitation* 75, no. 3, 170-176, 1996.

Chaffin, Don B., Gary D. Herrin, and W. Monroe Keyserling. "Preemployment strength testing: an updated position." *Journal of occupational medicine,* pp. 403-408, (1978).

Collinger, Jennifer L., Michael L. Boninger, Alicia M. Koontz, Robert Price, Sue Ann Sisto, Michelle L. Tolerico, and Rory A. Cooper. "Shoulder biomechanics during the push phase of wheelchair propulsion: a multisite study of persons with paraplegia." *Archives of physical medicine and rehabilitation* 89, no. 4, pp. 667-676, (2008).

Collins, Eileen G., David Gater, Jenny Kiratli, Jolene Butler, Karla Hanson, and W. Edwin Langbein. "Energy cost of physical activities in persons with spinal cord injury." *Med Sci Sports Exerc* 42, no. 4, pp. 691-700, 2010.

Da Costa, Bruno R., and Edgar Ramos Vieira. "Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies." *American journal of industrial medicine* 53, no. 3, 285-323, 2010.

Dalyan, M., D. D. Cardenas, and B. Gerard. "Upper extremity pain after spinal cord injury." *Spinal cord* 37, no. 3, pp. 191-195, 1999.

Dimensions. Wheelchairs. Retrieved from https://www.dimensions.com/element/wheelchairs

Disability Facts and Number in Jordan. (2017). Retrieved from Department of Statistics in Amman: http://www.dos.gov.jo/dos_home_e/main/population/census2015/Disability%202021.pdf

Dyson-Hudson, Trevor A., and Steven C. Kirshblum. "Shoulder pain in chronic spinal cord injury, part 1: epidemiology, etiology, and pathomechanics." *The journal of spinal cord medicine* 27, no. 1, pp. 4-17, 2004.

W. Erickson, Lee, C., & von Schrader, S., "Disability Status Report: United States," Cornell University Yang-Tan Institute on Employment and Disability(YTI), Ithaca, NY2019.

Gellman, Harris, D. R. Chandler, Jacques Petrasek, I. Sie, R. Adkins, and R. L. Waters. "Carpal tunnel syndrome in paraplegic patients." *The Journal of bone and joint surgery. American volume* 70, no. 4, pp. 517-519, 1988.

Sabick, Michelle B., Brian R. Kotajarvi, and Kai-Nan An. "A new method to quantify demand on the upper extremity during manual wheelchair propulsion." *Archives of physical medicine and rehabilitation* 85, no. 7, 1151-1159, 2004.

Sinnott, K. A., Peter Milburn, and Harry McNaughton. "Factors associated with thoracic spinal cord injury, lesion level and rotator cuff disorders." *Spinal Cord* 38, no. 12, pp. 748-753, 2000.

Wolkiewicz, Carly, Katherine Collins, Faisal Aqlan, and Osama T. Al Meanazel. "Ergonomic assessment of snow shovels using digital human modeling." In *Proceedings of the international conference on industrial engineering and operations management*, vol. 2018, no. SEP, pp. 1146-1153. 2018.

"World Report on Disability," World Health Organization, World Health Organization 2011

Yoon, Seog Ju, Ji Yeon Yoo, Tae Hyun Ha, Tae Jeong Ji, and Sei Joo Kim. "Upper Extremity Peripheral Nerve Entrapments among Wheelchair Users." *Journal of the Korean Academy of Rehabilitation Medicine* 21, no. 5, pp. 888-895, 1997.

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