Ergonomic Assessment of Snow Shovels Using Digital Human Modeling

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Abstract

Snow shoveling can cause ergonomic risks to the back and shoulders and result in musculoskeletal disorders (MSDs). The design of snow shovels should make snow removal easier and less strenuous. This study utilizes Digital Human Modeling (DHM) to assess the ergonomic risks associated with the snow shoveling process. Several designs for the shovels were created using Computer Aided Design (CAD) software. Statistical analysis was used to study the different factors associated with the shoveling process such as shovel design, gender, and body mass index (BMI). The results provide recommendations for avoiding ergonomic risks and selecting the proper snow shovels.

Keywords
Ergonomics, snow shovels, digital human modeling, lower back pain

1. Background

Snow shoveling can be a good exercise. In the United States, snow shovels are used seasonally to remove snow. A common use of the snow shovels occurs in and around the home by individuals who represent a cross-section of the American workforce (Watson et al., 2011). Ergonomic risks associated with snow shoveling include injuries to the shoulder and low back (McGorry et al., 2013) and cardiovascular incidents such as myocardial infarction (Heppel et al., 1991). The design of the snow shovel is an important factor to reduce the ergonomic risks associated with the shoveling process. There are several designs of snow shovels that differ in shape, size, and capacity (see Figure 1). A snow shovel consists of a handle, a scoop, and a shaft that connects the handle with the scoop. Most of the snow shovels are designed for either pushing snow or lifting snow. Both operations require applying forces by the shovelers. An illustration of the snow shoveling process is shown in Figure 2.

Snow shoveling is a hard work and can cause Musculoskeletal Disorders (MSDs) if it not performed properly of if wrong shovels are used. Snow shoveling can also cause heart attack, slips and falls, back injuries, hypothermia, and frostbite. The National Safety Council (www.nsc.org) provides a set of recommendations for safe shoveling such as using a small shovel, pushing the snow as you shovel, shoveling only fresh snow, etc. However, the Council does not provide any recommendations about the proper shoveling postures and the ergonomic designs of the shovels. In this study, we provide an ergonomic assessment of snow shoveling using Digital Human Modeling (DHM). Digital Human models are developed for individuals performing snow shoveling using different designs of the shovels. The study considers the effect of different factors such as shovel design, gender, and percentile on ergonomic risks during snow shoveling. Studying these factors can help identify and avoid the ergonomic risk factors associated with snow shoveling process. However, it is not an easy task to perform such a study in a physical environment and digital human modeling can be effectively used in this case.

Design 1 Design 2 Design 4 Design 5

Figure 1. Different designs of snow shovels

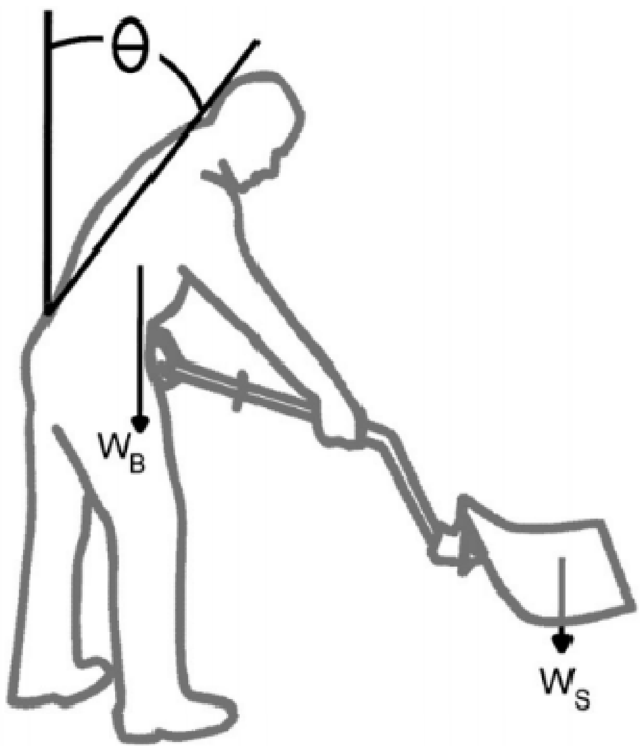

Figure 2. An illustration of snow shoveling (McGorry et al., 2003)

2. Research Methodology

In this study, four common designs for snow shovels are evaluated using DHM. First, we created CAD models for the four designs as indicated in Figure 3. We used Autodesk Inventor® software. Then, we imported the four designs into a DHM software and perform the analysis. Digital Human Modeling (DHM) is a computer-generated representation of human beings and work environments (Woldstad, 2006). In this study, we used Siemens Tecnomatix Jack software to evaluate the designs. The software provides many options for ergonomic assessment and analysis. The software also includes different anthropometric databases that can be used to study the ergonomics of different populations. Moreover, different human percentiles (1^{st}, 5^{th}, 50^{th}, 95^{th}, 99^{th}) are provided. Figure 4 shows different human percentiles for both males and females obtained from Siemens Jack® software. The DHM environment for the snow shoveling process is shown in Figure 5.

Figure 3. CAD models for the four types of snow shovels

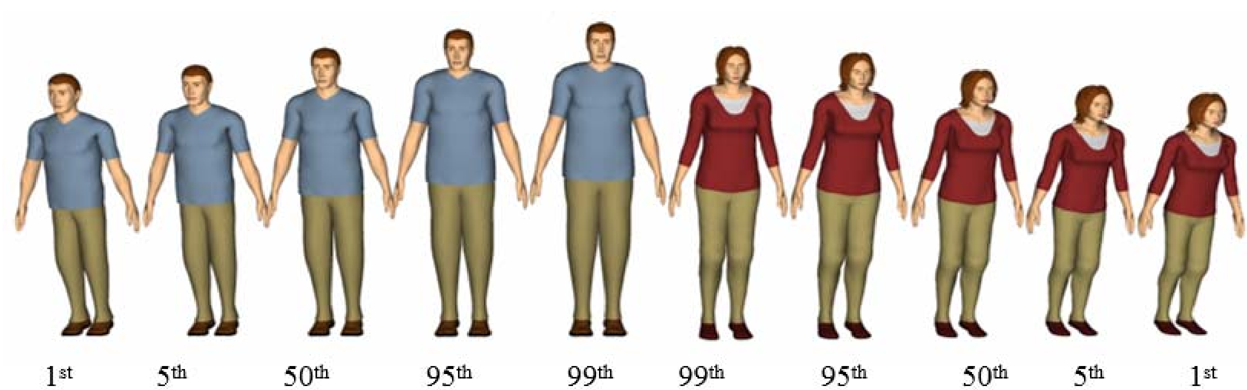

Figure 4. Different human percentiles in Jack® software

Several simulation experiments and statistical analysis were performed. The following factors were considered: a) human physical characteristics which includes the weights and heights of students (percentiles), b) design concept, and c) gender. A general factorial design experiment was developed. The number of observations needed for this factorial design was 2×3×5 = 30. The response variables are compression force on the lower back and percent capable. Table 1 shows the factors, factor levels, response variables, and description of the response variables.

Figure 5. Snow shoveling model in Jack® software

Table 1. Factors and factor levels for the ergonomic risk analysis

Factors	Levels	Response Variables	
		L4/L5 Force	% Capable
Gender	Male (M)	Evaluates spinal forces acting on a virtual human's lower back, under any postures and loading conditions. Calculates compression & shear forces at L4/L5 vertebral joint & compares compressive forces to NIOSH recommended threshold limit values.	Evaluates the percentage of a working population that has the strength to perform a task based on posture, exertion requirements, and anthropometry.
	Female (F)		
Percentile	5th Percentile		
	50th Percentile		
	95th Percentile		
Shovel Design	Basic		
	Handle-in-Shaft		
	Two Handles		
	Bent Shaft		

3. Results and Analysis

The simulation results are shown in Table 2. The lower back compression force, L4/L5, is measured in Newton and the % capable is measured in percentage.

Table 2. Simulation runs for the factorial analysis of ergonomic risk

Gender	Percentile	Design	L4/L5 Force	% Capable
Male	5th	Basic	1556	97
Male	5th	Handle-in-Shaft	1501	96
Male	5th	Two Handles	1352	98
Male	5th	Bent Shaft	1298	97
Male	50th	Basic	1940	94
Male	50th	Handle-in-Shaft	1573	96
Male	50th	Two Handles	1693	97
Male	50th	Bent Shaft	1672	97
Male	95th	Basic	2572	90
Male	95th	Handle-in-Shaft	2094	94
Male	95th	Two Handles	2251	92
Male	95th	Bent Shaft	2169	96
Female	5th	Basic	1125	97
Female	5th	Handle-in-Shaft	1143	98
Female	5th	Two Handles	1004	98
Female	5th	Bent Shaft	976	98
Female	50th	Basic	1407	93
Female	50th	Handle-in-Shaft	1167	98
Female	50th	Two Handles	1247	96
Female	50th	Bent Shaft	1216	97
Female	95th	Basic	1822	90
Female	95th	Handle-in-Shaft	1514	92
Female	95th	Two Handles	1610	93
Female	95th	Bent Shaft	1557	92

Figure 6 shows the analysis of the simulation data to validate the assumptions for the statistical analysis. The figure shows that the assumption (normality, constant variance, and independence) are valid. The analysis results for the factorial design are shown in Figures 7-10. Figure 7 shows the main factor plots for the first response variable, L4/L5 compression force, Figure 8 shows the interaction plot for the same response variable. Both figures as well as the ANOVA table shown in Figure 9 indicate that all the factors and factor interactions are significant. In Figure 7, it can be seen that the bent-shaft shovel design is the best because it produces the lower compression force on the lower back. Results for the response variable "% capable" are shown in Figure 10. The ANOVA table indicates that only "percentile" and "design" factors are significant.

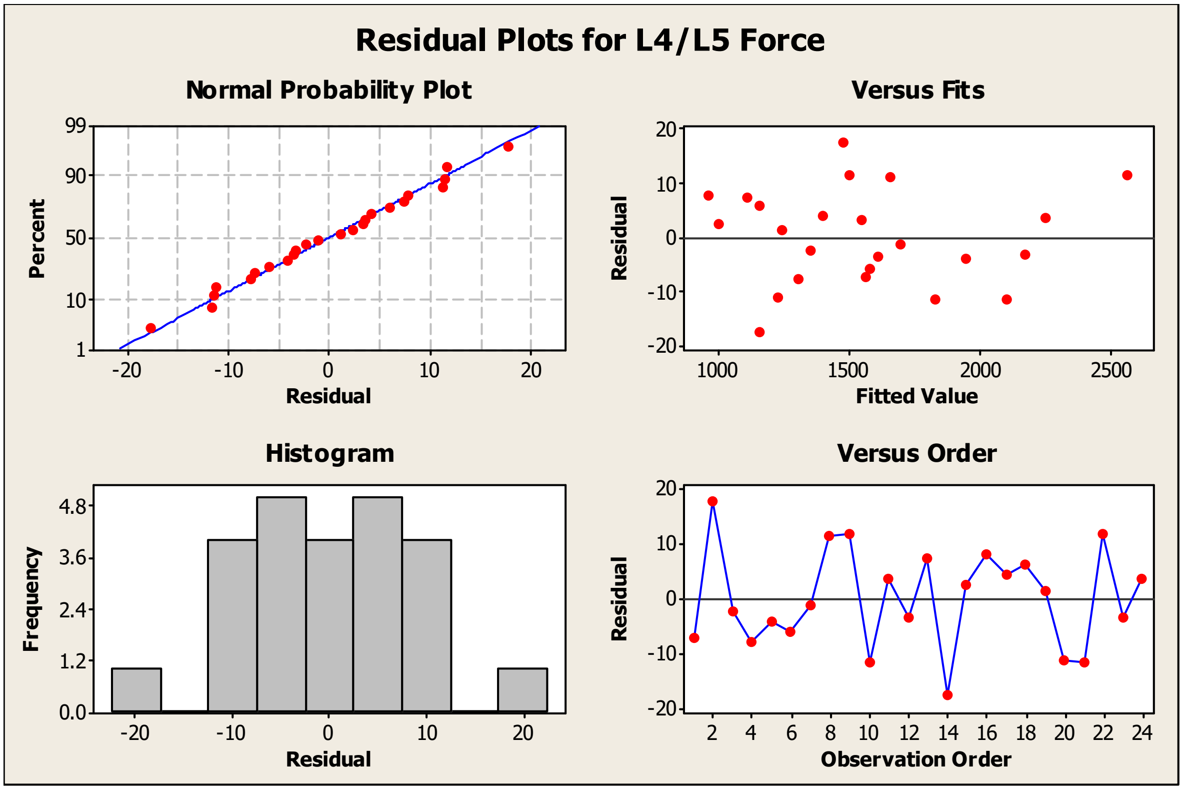

Figure 6. Checking the assumptions for the experimental design

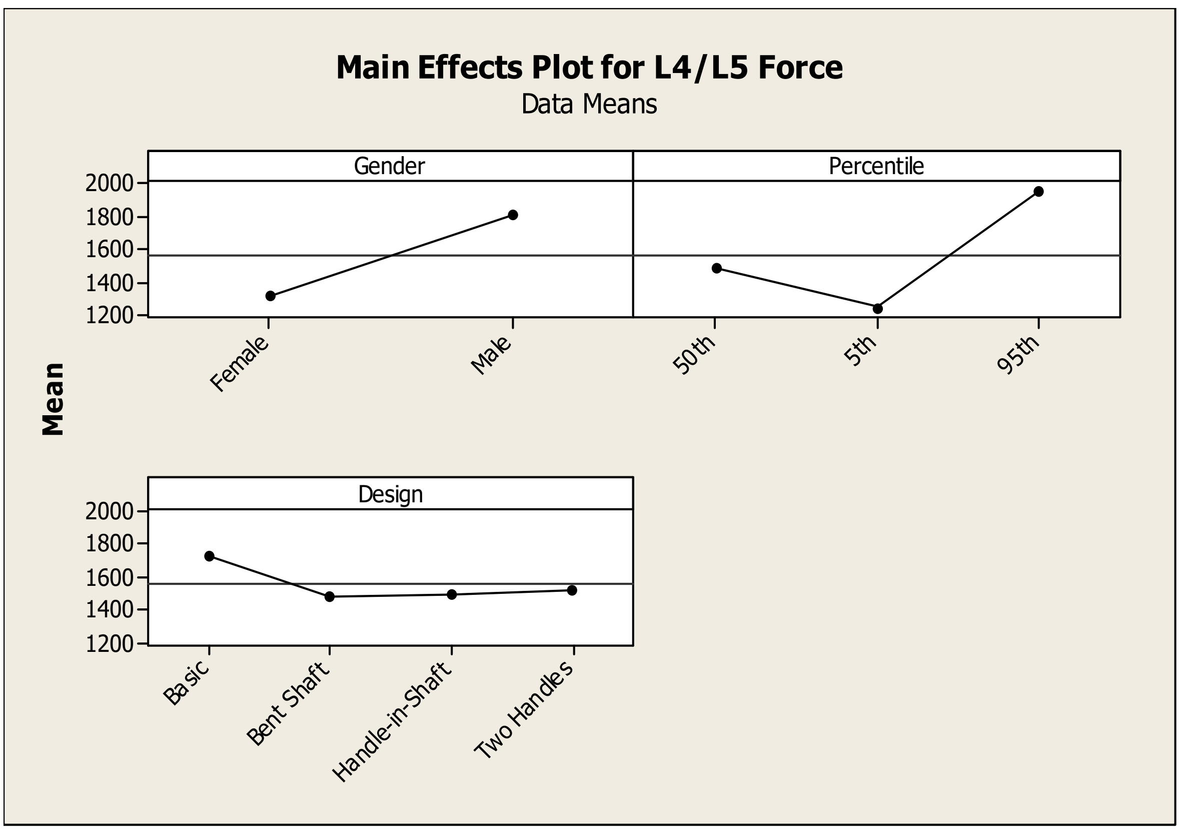

Figure 7. Main factor plot for the “compression force” variable

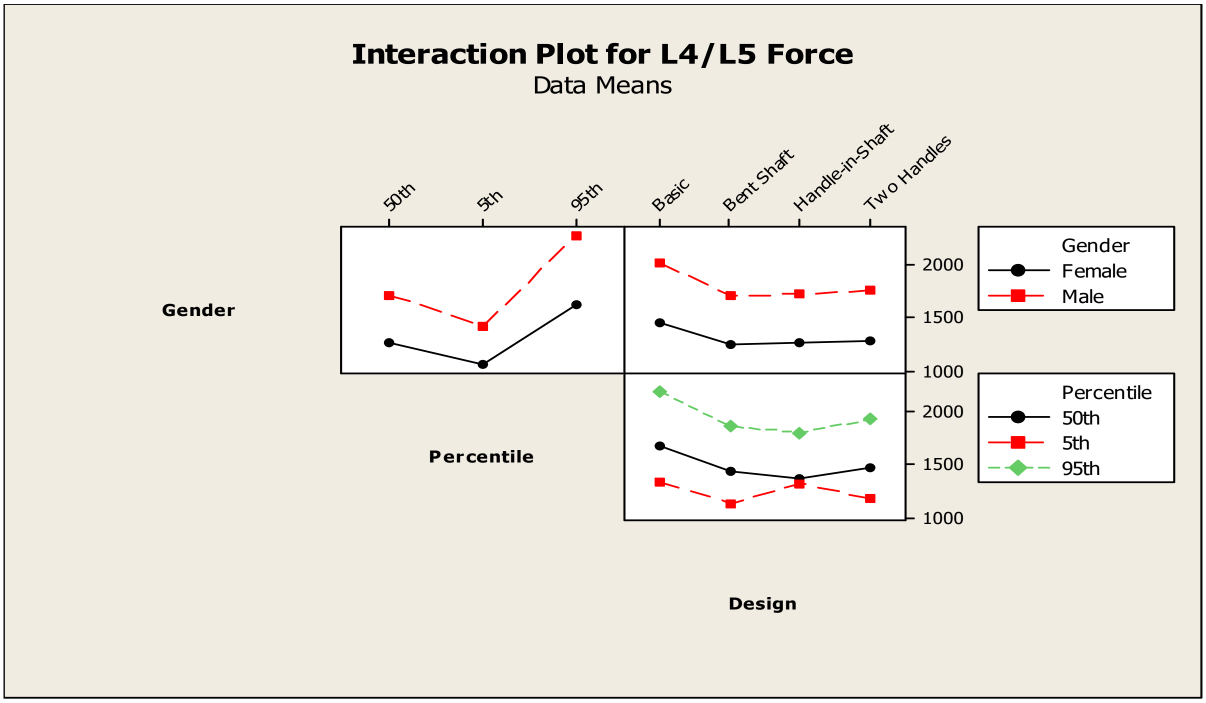

Figure 8. Interaction factor plot for the "compression force" variable

General Linear Model: L4/L5 Force versus Gender, Percentile, Design

Factor	Type	Levels	Values
Gender	fixed	2	Male, Female
Percentile	fixed	3	5th, 50th, 95th
Design	fixed	4	Basic, Handle-in-Shaft, Two Handles, Bent Shaft

Analysis of Variance for L4/L5 Force, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	1442070	1442070	1442070	4710.08	0.000
Percentile	2	2045076	2045076	1022538	3339.81	0.000
Design	3	254528	254528	84843	277.11	0.000
Gender*Percentile	2	81661	81661	40830	133.36	0.000
Gender*Design	3	13839	13839	4613	15.07	0.003
Percentile*Design	6	89580	89580	14930	48.76	0.000
Error	6	1837	1837	306		
Total	23	3928592				

Figure 9. ANOVA analysis for the response variable "compression force"

Analysis of Variance for % Capable, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	0.167	0.167	0.167	0.10	0.758
Percentile	2	106.750	106.750	53.375	33.42	0.001
Design	3	25.500	25.500	8.500	5.32	0.040
Gender*Percentile	2	4.083	4.083	2.042	1.28	0.345
Gender*Design	3	2.167	2.167	0.722	0.45	0.725
Percentile*Design	6	10.250	10.250	1.708	1.07	0.469
Error	6	9.583	9.583	1.597		
Total	23	158.500				

Figure 10. ANOVA analysis for the response variable "% capable"

4. Conclusions

In this paper, we presented an ergonomic assessment of four different designs of snow shovels using DHM. Statistical analysis of the DHM results indicated that the type of shovel design along with human physical characteristics can affect the biomechanical force on human. The bent-shaft shovel showed the lowest compression force. It should be noted that this study did not take into consideration the amount of snow that can be removed using the shovel. For future work, we plan to incorporate the amount of snow to be removed as well as the lifting posture. Moreover, more designs of the snow shovel can be created and evaluated.

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Biographies

Carly Wolkiewicz and Katherine Collins are undergraduate students in the department of Industrial Engineering at Penn State Erie, The Behrend College.

Faisal Aqlan is currently an assistant professor of Industrial Engineering and Master of Manufacturing Management (MMM) at Penn State Behrend. He earned his Ph.D. in Industrial and Systems Engineering from the State University of New York at Binghamton in 2013. Aqlan has worked on industry projects with Innovation Associates Company and IBM Corporation. His work has resulted in both business value and intellectual property. He is a certified Lean Silver and Six Sigma Black Belt. He is a senior member of the Institute of Industrial and Systems Engineers (IISE) and currently serves as the president of IISE Logistics and Supply Chain Division, director of Young Professionals Group, and founding director of Modeling and Simulation Division. Aqlan is also a member of American Society for Quality (ASQ), Society of Manufacturing Engineers (SME), and Industrial Engineering and Operations Management (IEOM) Society. He has received numerous awards including the IBM Vice President award for innovation excellence, Penn State Behrend's School of Engineering Distinguished Award for Excellence in Research, and the Penn State Behrend's Council of Fellows Faculty Research Award. Aqlan is the Principal Investigator and Director of the NSF RET Site in Manufacturing Simulation and Automation at Penn State Behrend.

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