JESK J Ergon Soc Korea 2014; 33(6): 553-563
http://dx.doi.org/10.5143/JESK.2014.33.6.553
http://jesk.or.kr eISSN:2093-8462

Evaluation of Gender Effect in Various Pliers' Grip Spans for Maximum Isometric Grasping Tasks

Yong-Ku Kong[1], Dae-Min Kim[1], Ji-Soo Park[1], Sung-Yong Lee[1], Kyeong-Hee Choi[1], Kyung Ran Kim[2]

[1]Department of Industrial Engineering, Sungkyunkwan University, Suwon, 440-746
[2]National Academy of Agricultural Science, Rural Development Administration, JeonJu, 560-500

Corresponding Author
Yong-Ku Kong
Department of Industrial Engineering,
Sungkyunkwan University, Suwon,
440-746
Mobile : +82-10-2417-0779
Email : ykong@skku.edu

Received : November 10, 2014
Accepted : November 17, 2014

Objective: The purpose of this study was to evaluate the effect of gender (male, female) and grip spans (45, 50, 60, 70, 80mm) on total grip strength, resultant force, finger force and subjective discomfort ratingl.

Background: In order to prevent musculoskeletal disorders, studies of hand tools need to be preceded based on grip strength, finger force, and subjective discomfort rating. However, experimental apparatus using tools such as pliers that reflect the actual work place was almost non-existent.

Method: Fifty-Two (26 males and 26 females) participants were recruited from the student population. In this study, a pair of revised pliers, which can change grip span from 45 to 80mm was applied to estimate total grip strength, resultant force and individual finger forces. All participants were asked to exert a maximum grip force with three repetitions, and to report the subjective discomfort rating for five grip spans of pliers (45, 50, 60, 70, 80mm).

Results: There were significant differences of total grip strength, resultant force, individual finger forces and subjective discomfort rating according to grip span. The lowest total grip strength was obtained from the grip span of 80mm for both genders. For resultant force, the highest resultant force was exerted at grip spans of 50, 60 and 70mm for females and 50 and 60mm for males. The lowest subjective discomfort rating was observed in the 50mm for both genders.

Conclusion: Based on the result, 50mm and 60mm grip spans which provide the highest force and lowest discomfort rating might be recommendable for the male and female pliers users.

Application: The findings of this study can provide guidelines on designing a hand tool to help to reduce hand-related musculoskeletal disorders and obtain better performance.

Keywords: Grip span, Grip strength, Maximum gripping task, Gender effect, Subjective discomfort rating

1. Introduction

Recently, occupational musculoskeletal disease patients are rapidly increasing each year, due to simple work repetitions and improper working postures, and over-exertions in workplace. Especially, many carpal tunnel syndrome (CTS) patients increased to the extent that CTS was classified into a separated code and managed

since 2008, and therefore, a countermeasure is urgently needed. In the U.S., the lacking working days (28 days) due to the CTS were the second largest, following the lacking working days (30 days) due to fracture (US Bureau of Labor Statistics, 2007), which implies that difficulties of workers due to CTS are huge worldwide. CTS occurs, when one exerts excessive force, or when work by hand repeats in the improper posture of wrist.

CTS, especially is known to frequently occur to women. Women's prevalence of CTS showed more than three times higher than that of men, and high prevalence was observed from middle-aged women (Phalen, 1972; Frederick et al., 1992). Hales and Bernard (1996) and Lassen et al. (2005) revealed women's high CTS prevalence was based on the differences of the strength of muscle, body dimensions and hormones between men and women. In addition, there are some research results that several characteristics of taking an oral conceptive, ovary removing operation and pregnancy that are peculiar to women have correlations with CTS (Sabour and Fadel, 1970; Vessey et al., 1990; Bjorkqvist et al., 1977; Pascual et al., 1991; Wand, 1990).

CTS is also closely related with the use of hand tools. A study of Myers and Trent (1989) revealed that the use of hand tools has huge potential risk causing muscle injuries. Although, many researchers have studied major hand tool design factors including optimum grip span to prevent musculoskeletal diseases, due to the use of hand tools (Pheasant and Scriven, 1983; Fransson and Winkel, 1991; Blackwell et al., 1999), the study on grip span of A-type hand tools (two-handle tools) including pliers, wrench and scissors has been conducted by only some researchers. Fransson and Winkle (1991) proposed men's optimum grip span as 55~65mm, and women's as 50~60mm. However, they have some problem to be applied to the hand tool design for Koreans, since their study was for only western people. Another study by Kong et al. (2014) presents Korean men's optimum grip span is 50mm. However, it does not address women's grip span. As mentioned above, studies on grip span of hand tools and other relevant studies are insufficient in reality, although, women have a higher possibility to have hand-related diseases than men.

In this context, the purpose of this study is to measure finger force, total grip strength and resultant force, and suggest optimum grip span, according to gender by using the measurement equipment that can freely adjust grip spans and effectively measure finger force, total grip strength and resultant force, which was developed by researchers in this study.

2. Method

2.1 Participants

For this study, 52 students without musculoskeletal diseases on upper arms (26 males and 26 females) were recruited. The anthropometric dimensions including height, weight and arm length were measured before the experiment, and the basic information of the participants were recorded. Additional anthropometric dimensions information is shown in Table 1.

Table 1. Characteristics of participants

Characteristics	Male		Female	
	Mean	SD	Mean	SD
Age [yr.]	25.8	1.5	22.9	2.4
Weigh [kg]	74.0	12.9	52.5	7.4
Height [cm]	173.8	5.4	161.7	5.1
Arm length [cm]	54.1	4.5	51.8	2.3
Upper arm length [cm]	34.8	5.3	31.8	1.4

Table 1. Characteristics of participants (Continued)

Characteristics	Male		Female	
	Mean	SD	Mean	SD
Lower arm length [cm]	26.4	1.6	24.8	1.4
Upper arm circum [cm]	31.2	3.4	22.8	2.0
Elbow circum [cm]	28.0	3.0	23.0	2.1
Wrist circum [cm]	16.0	0.7	13.9	1.2
Hand length [cm]	18.5	0.7	16.6	0.9
Hand width [cm]	8.1	0.3	7.0	0.1
Hand depth [cm]	2.9	0.2	2.6	0.2

2.2 Measurement system

This study made grip span be freely changed by renovating the A-type pliers used in the actual industrial sites. The pliers were manufactured by inserting gears at the top part of the handles to enable grip span to be adjusted freely [Figure 1].

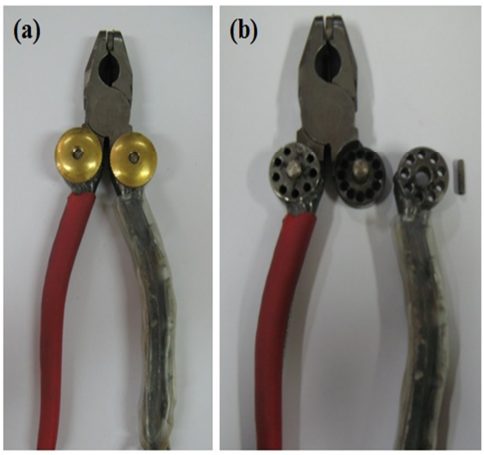
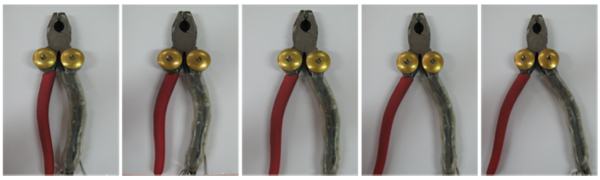


Figure 1. Renovated A-type pliers (a), principle of changeable grip span (b)

Five grip spans (45, 50, 60, 70, 80mm) were selected on the basis of the middle finger and Table 2 demonstrates the specifications of the pliers.

To measure finger force, total grip strength and resultant force upon using the pliers, this study used load cell (Subminiature Load cell, Model 13, Honeywell). For the measurement of individual finger forces, load cell was inserted to the parts of the handles of the pliers, where index, middle, ring and little fingers touched. The sum of each finger force measured by load cell was defined as total grip strength, and the pliers were designed to measure the resultant force by inserting the load cell at the part, where pliers' jaws interlinked [Figure 2].

Table 2. Specifications of pliers



	45mm	50mm	60mm	70mm	80mm
Index	43.8	47.2	55.4	60.8	67.9
Middle	**45.0**	**50.0**	**60.0**	**70.0**	**80.0**
Ring	39.2	48.2	63.4	76.0	91.4
Little	32.1	42.3	60.0	75.4	95.3

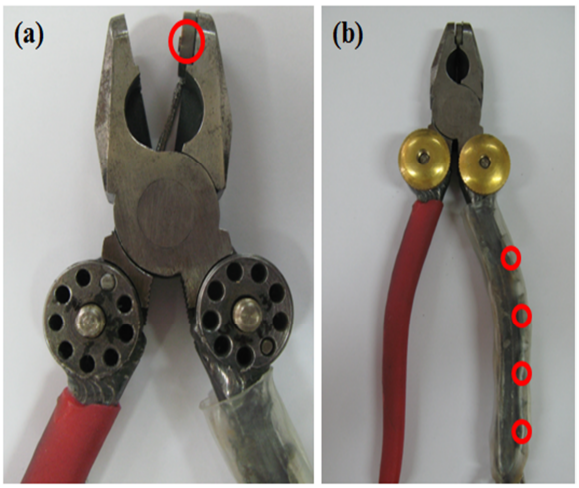


Figure 2. Locations of inserted load cells for resultant force (a), individual finger forces (b)

The data coming from the load cells was transmitted to the computer by converting the data into digital values through National Instrument USB-6008 DAQ board. The transmitted values were monitored in real time, and programmed using LabView (National Instrument, Austin, TX, USA) for the storage and analysis of the data [Figure 3].

2.3 Posture

Concerning the posture for the experiment, the participants were instructed to naturally take down shoulders, bend elbow 90° and maintain neutral posture of forearms and wrists in a sitting position, according to the suggestion of the American Society of Hand Therapists (ASHT) (Fess and Moran, 1981). The participants gazed the front at the position of straight back and minimized the use of strength generated by arm movement and pliers' load.

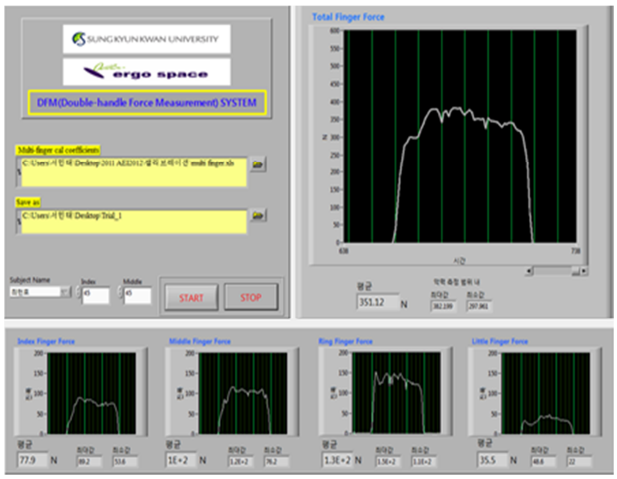


Figure 3. Force measurement program (LabView)

2.4 Experimental design

This study selected five grip spans (45, 50, 60, 70, 80mm) as independent variables and also selected total grip strength, individual finger forces, resultant force and subjective discomfort rating with a 10-point scale as dependent variables. Total grip strength was defined as the sum of individual finger forces. For statistical analysis, ANOVA was carried out using SPSS (ver. 18.0). For multiple comparisons, this study selected Tukey HSD and analyzed at the significance level of 0.05.

2.5 Experimental procedures

After completing the questionnaire asking the status of upper arm musculoskeletal diseases and other diseases that may affect the experiment before the experiment, the experiment participants' information was obtained and anthropometric dimensions were measured. For grip strength measurement, a mainly-used hand was used and pre-exercise on the experimental posture and grip span method was conducted prior to the experiment. Each participant exerted the maximum grip strength for about six seconds and was provided about 3-min break time between measurements to minimize participant's muscle fatigue. 15 times of grip strength in total were measured for five grip spans with three repetitions per each grip span.

3. Results

3.1 Total grip strength

The effects of grip span on total grip strength in maximum grip force measurement was statistically significant for both males and females (p-value < 0.001). Regarding males as shown in Table 3, significantly largest grip forces of 310.12N and 311.79N at 50mm and 60mm grip spans, respectively, were demonstrated, and the smallest grip force of 210.15N was shown at 80mm grip span. In the case of females, similar grip forces were shown in all grip spans except 80mm grip span. Actually, significantly small grip force was revealed at 80mm grip span. The grip force between males and females showed a statistically significant difference: the grip force of females (146.1N) was just about 52.8% of males' (276.5N).

Table 3. Total grip strength (N) over gender

	Total grip strength (N)	
	Male	Female
45mm	273.08^{C}	152.59^{A}
50mm	310.12^{AB}	159.77^{A}
60mm	311.79^{A}	158.52^{A}
70mm	277.19^{BC}	148.92^{A}
80mm	210.15^{D}	110.69^{B}
Mean	276.46	146.10

(Note: alphabetic letters represent groupings for total grip strength by statistical significance)

3.2 Individual finger forces and contribution

According to the analyses for individual finger forces and contributions in Table 4, the finger that showed the biggest force and contribution was the middle finger, followed by ring, index and little fingers in the order. Interaction effects of gender and finger for the individual finger contribution (Figure 4) were also statistically significant (p-value < 0.001). The difference in contribution of females' middle finger (36.71%) and ring finger (32.59%) was only 4.1%, but males' was 10.6% between the middle finger (37.40%) and ring finger (26.81%), showing a big difference, compared to the females. Females' little finger contribution (7.98%) was significantly smaller than males' (15.10%). And, females' ring finger contribution (32.59%) was relatively higher than males' (26.81%).

Table 4. Individual finger forces and contributions

	Grip span (mm)	Individual finger forces and contributions			
		Index	Middle	Ring	Little
Male	45	74.64N	112.05N	62.52N	23.86N
		27.27%	*41.02%*	*22.91%*	*8.80%*
	50	69.37N	115.24N	79.35N	46.17N
		22.35%	*36.97%*	*25.64%*	*15.04%*
	60	60.52N	112.73N	83.54N	55.01N
		19.53%	*36.12%*	*26.90%*	*17.47%*
	70	50.99N	100.39N	75.31N	50.45N
		18.43%	*36.18%*	*27.45%*	*17.95%*
	80	*34.57N*	*75.83N*	*64.75N*	*35.00N*
		15.91%	*36.71%*	*31.14%*	*16.24%*
	Mean	***58.02N***	***103.25N***	***73.09N***	***42.10N***
		20.70%	***37.40%***	***26.81%***	***15.10%***

Table 4. Individual finger forces and contributions (Continued)

	Grip span (mm)	Individual finger forces and contributions			
		Index	Middle	Ring	Little
Female	45	*35.19N*	*63.66N*	*51.82N*	*3.57N*
		22.48%	*40.92%*	*34.18%*	*2.43%*
	50	*34.68N*	*60.99N*	*56.93N*	*10.03N*
		21.37%	*37.41%*	*34.89%*	*6.33%*
	60	*34.56N*	*55.99N*	*51.64N*	*17.86N*
		21.74%	*34.34%*	*32.57%*	*11.35%*
	70	*34.47N*	*52.91N*	*47.85N*	*14.85N*
		23.45%	*34.88%*	*32.08%*	*9.58%*
	80	*28.24N*	*40.68N*	*32.52N*	*11.25N*
		24.82%	*36.02%*	*29.21%*	*9.95%*
	Mean	***33.48N***	***54.85N***	***47.95N***	***11.51N***
		22.74%	***36.71%***	***32.59%***	***7.93%***

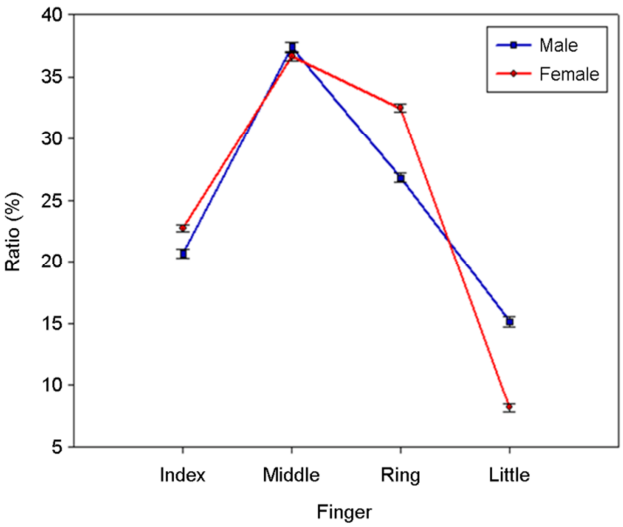


Figure 4. Interaction effect on finger and gender

3.3 Subjective discomfort rating

Subjective discomfort rating showed statistically significant differences, according to grip span ($p < 0.001$). Both males and females showed the lowest discomfort rating at 50mm grip span and the highest discomfort rating was demonstrated at 80mm grip span [Figure 5].

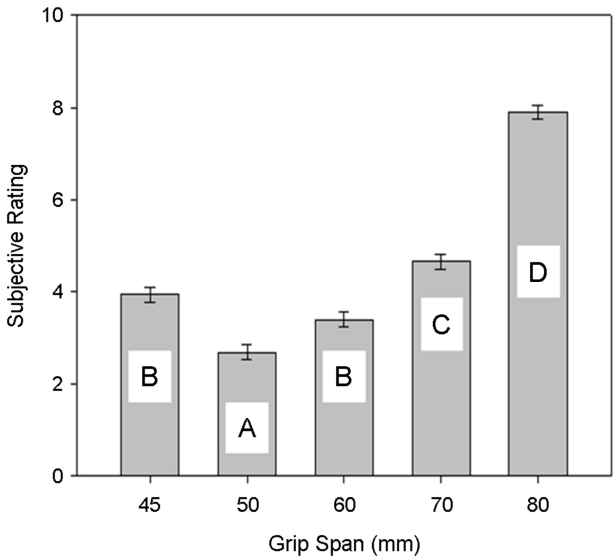


Figure 5. Subjective discomfort rating over grip span (Note: Alphabetic letters represent groupings for total grip strength by statistical significance)

3.4 Resultant force

The effect of grip spans on resultant force was statistically significant to both males and females (p-value < 0.001). As shown in Table 5, males demonstrated the largest resultant force with 706.70N and 737.85N at 50mm and 60mm grip spans, respectively, and significantly small resultant force of 501.74N was obtained at 80mm grip span. Females showed the smallest resultant force of 257.02N at 80mm grip span and significantly large resultant forces of 367.14N, 376.68N and 343.71N at 50mm, 60mm and 70mm grip spans, respectively. The resultant force between males and females revealed a statistically significant difference: females' resultant force (334.39N) was only 53.5% of males' (625.26N).

Table 5. Resultant force over gender

	Resultant force (N)	
	Male	Female
45mm	520.61^{C}	327.41^{C}
50mm	706.70^{AB}	367.14^{AB}
60mm	737.85^{A}	376.68^{A}
70mm	659.38^{BC}	343.71^{AB}
80mm	501.74^{D}	257.02^{D}
Mean	625.26	334.39

(Note: alphabetic letters represent groupings for total grip strength by statistical significance)

4. Conclusions

This study carried out a maximum gripping task to evaluate A-type pliers' optimum grip span. Both males and females showed significant differences in individual finger forces, total grip strength, resultant force and subjective discomfort rating according to grip span. In the case of total grip strength, females did not show statistically significant differences at all the grip spans, except 80mm grip span. However, males revealed the largest grip force at 50mm and 60mm grip spans, respectively, and the smallest grip force at 80mm grip span. When it comes to resultant force, the females showed the highest resultant force at 50mm, 60mm and 70mm grip spans, respectively, and the males showed the highest resultant force at 50mm and 60mm grip spans, respectively. Concerning subjective discomfort rating, both the males and females revealed significantly the least subjective discomfort rating at 50mm grip span. In consideration of grip force, resultant force and subjective discomfort rating in using pliers, this study may propose 50~60mm of the optimum grip spans for both males and females.

The limitation of this study is that only maximum grip force experiment was performed without consideration of the tasks carried out in actual industrial sites. The suggestion of guidelines for all age brackets is insufficient, because this study targeted only the males and females in their 20s. In the further study, an experiment on the task frequently performed in actual industrial sites should be undertaken for more diverse age brackets, centered on 40~50s with the high ratio of people engaged in industrial sites. The findings in this study are expected to be reflected in ergonomic hand tool design and to help the prevention of occupational musculoskeletal diseases mainly caused by hand tools and worksite's efficiency enhancement.

Acknowledgements

This work was carried out with the support of "Cooperative Research Program for Agricultural Science & Technology Development (Project No. PJ01007906)" Rural Development Administration, Republic of Korea.

References

Bjorkqvist, S.E., Lang, A.H., Punnonen, R. and Rauramo, L., Carpal tunnel syndrome in ovariectomized women, *Acta Obstetrica et Gynecologica Scandinavica,* 56(2), 127-130, 1977.

Blackwell, J.R., Kornatz, K.W. and Heath, E.M., Effect of grip span on maximal grip force and fatigue of flexor digitorum superficialis. *Applied Ergonomics*, 30(5), 401-405, 1999.

Fransson, C. and Winkel, J., Hand strength: the influence of grip span and grip type, *Ergonomics*, 34(7), 881-892, 1991.

Fess, E.E. and Moran, C.A., Clinical assessment recommendation. *American Society of Hand Therapists,* 1981.

Frederick, H.A., Carter, P.R. and William Litter, J., Injection injuries to the median and ulnar nerves at the wrist. *The Journal of Hand Surgery,* 17(4), 645-647, 1992.

Lassen, C.F., Mikkelsen, S., Kryger, A.I. and Andersen, J.H., Risk factors for persistent elbow, forearm and hand pain among computer workers. *Scandinavian journal of work, Environment & Hearth*, 122-131, 2005.

Myers, J.R. and Trent, R.B., Hand tool injuries at work: A surveillance perspective. *Journal of safety research*, 19(4), 165-176, 1989.

Hales, T.R. and Bernard, B.P., Epidemiology of work-related musculoskeletal disorders. *The Orthopedic Clinics of North America*

27(4), 679-709, 1996.

Hunter, J.M., Schneider, L.H., Mackin, E.J. and Bell, J.A. (Eds.), *Rehabilitation of the Hand*. C.V. Mosby Company, St. Louis, MO, 1978.

Kattel, B.P., Fredericks, T.K., Fernandez, J.E. and Lee, D.C., The effect of upper-extremity posture on maximum grip strength. *International Journal of Industrial Ergonomics*, 18(5), 423-429, 1996.

Kong, Y.K., Freivalds, A. and Kim, S. E., Evaluation of handles in a maximum gripping task. *Ergonomics*, 47(12), 1350-1364, 2004.

Kong, Y.K. and Lowe, B.D., Optimal cylindrical handle diameter for grip force tasks. *International Journal of Industrial Ergonomics*, 35(6), 495-507, 2005.

Kong, Y.K., Seo, M.T. and Kang, H.S., Evaluation of total grip strength and individual finger forces on opposing (A-type) handles among Koreans, *Ergonomics*, 57(1), 108-115, 2014.

Pascual, E., Giner, V., Arostegui A., Conill, J., RUIZ, M.T. and Pico, A., Higher incidence or carpal tunnel syndrome in oophorectomized women, *Rheumatology*, 30(1), 60-62, 1991.

Phalen, G.S., The carpal-tunnel syndrome: clinical evaluation of 598 hands, *Clinical orthopaedics and related research*, 83, 29-40, 1972.

Pheasant, S.T. and Scriven, J.G., Sex differences in strength: Some implications for the design of handtools. *In Proceedings of the Ergonomics Society's Annual Conference*, 9-13, 1983.

Radwin, R.G., Oh, S., Jensen, T.R. and Webster, J.G., External finger forces in submaximal five-finger static pinch prehension. *Ergonomics*, 35(3), 275-288, 1992.

Sabour, M.S. and Fadel, H.E., The carpal tunnel syndrome - a new complication ascribed to the 'pill', *American Journal of obstetrics and gynecology*, 107(8), 1265-1277, 1970.

US Bureau of Labor Statistics. *Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work* 2007.

Vessey, M.P., Villard-Mackintosh, L. and Yeates, D., Epidemiology of carpal tunnel syndrome in women of childbearing age. Findings in a large cohort study, *International Journal of Epidemiology*, 19(3), 655-659, 1990.

Wand, J.S., Carpal tunnel syndrome in pregnancy and lactation. *The Journal of Hand Surgery: British & European Volume*, 15(1): 93-95, 1990.

Author listings

Yong-Ku Kong: ykong@skku.edu
Highest degree: PhD, Department of Industrial Engineering, The Pennsylvania State University

Position title: Associate Professor, Department of Industrial Engineering, Sungkyunkwan University
Areas of interest: Musculoskeletal Disorders, Hand tools, Ergonomic Product Design

Dae-Min Kim: kimdaemin@skku.edu
Highest degree: MS, Department of Industrial Engineering, Sungkyunkwan University
Position title: PhD Candidate, Department of Industrial Engineering, Sungkyunkwan University
Areas of interest: Musculoskeletal Disorders, Hand tools

Ji-Soo Park: plusememery@naver.com
Position title: BS Candidate, Department of Industrial Engineering, Sungkyunkwan University
Areas of interest: Ergonomic Product Design

Sung-Yong Lee: syong1625@naver.com
Highest degree: BS, Department of Industrial Engineering, Hannam University
Position title: MS Candidate, Department of Industrial Engineering, Sungkyunkwan University
Areas of interest: Musculoskeletal Disorders

Kyeong-Hee Choi: ckhee@skku.edu
Highest degree: BS, Department of Industrial Engineering, Kyunghee University
Position title: MS Candidate, Department of Industrial Engineering, Sungkyunkwan University
Areas of interest: Ergonomic Product Design, Musculoskeletal Disorders

Kyung Ran Kim: Kimgr@korea.kr
Highest degree: PhD, Department of Clothing and textiles, Seoul National University
Position title: Senior Researcher, Department of Agricultural Engineering, Academy of Agricultural Science, Rural Development Administration
Areas of interest: Farmer's occupational safety and health