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EFFECTS OF KNOB SELECTIONS ON WORK POSTURE SELECTIONS IN MANUFACTURING COMPANIES

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ABSTRACT

Hand tools that fail to accommodate various hand and body postures can lead to serious injuries and potential development of hand-related musculoskeletal disorders. While some studies have shown that there are theoretical relations between different work postures and object shapes, it appears that there are no statistical analyses that investigate how the different selections of knobs affect the selections of different work postures. This paper aims to determine the effects of knob selections on the work posture selections of manual workers from several manufacturing firms. The analysis used for this study is regression analysis. The survey responses are entered into Minitab 16 for the analysis. The findings confirmed that majority of the workers normally and preferably use the knurled spherical knob for their manual work. The selection of this knob also significantly affects the selection of the work postures that they assume. The findings are useful preliminary guidelines for the development of ergonomic knob prototypes that accommodate different work postures to potentially reduce hand-related injuries at the workplace.

Keywords: work posture, knob selections, ergonomics, hand-related injuries, musculoskeletal disorders.

INTRODUCTION

Studies show that using pinch grips with inappropriate body and hand postures is one of the main factors that cause hand-related cumulative trauma disorders (CTDs) [1]. The problems that result from CTDs can include work time loss, production quality reduction, rise of medical costs and low job satisfaction [1-3]. However, researchers do believe that with proper ergonomic design considerations of work-task and control interface, the risk of hand-related injuries can be minimised [1]. Shivers, Mirka [4] suggested that designers and engineers need to collect basic information about the biomechanical behaviours and different postural characteristics before designing equipments so that the fatigue and discomfort of the user can be reduced. Peebles and Norris [5] stated that design characteristics such as the size, shape and tactile sensation of control devices can vary depending on the postures assumed when using them at work. In this case perhaps more ergonomics-related data are needed to not only improve the design of different shapes and sizes of knobs, but also accommodate various work postures [5-7]. While the abovementioned studies have shown that there are some theoretical relations between different work postures and object shapes, it appears that there are no statistical analyses that investigate how the different selections of knobs affect the selections of different work postures. This paper aims to determine the effects of knob selections on the work posture selections of manual workers from several manufacturing firms.

WORK POSTURES

Body Postures

Hyatt, Whitelaw [8] posited that human grip strength is greatly affected by upper extremity postures. A number of researchers have also studied how different body postures can affect grip strength [9]. Teraoka [10] substantiated that the grip strength exerted by experimental subjects while standing is greater than those who were sitting or in a supine posture. The findings of Balogun, Akomolafe [11] also supported that grip strength is greater when generated in a standing posture than in a seated posture, on the condition that both postures are assumed with an extended elbow. On the other hand, the grip strength is stronger when generated in a seated posture than in a supine posture [10]. This study chooses to involve common body postures that have been used and identified from previous studies. The body postures involved in this analysis include the standing, seated, supine, squatting and kneeling postures [10-13].

Arm Postures

Richards, Olson [9] mentioned that the length of the extrinsic muscles of the hand can be potentially affected by forearm posture, causing a change in the generated grip strength. According to researchers, the extrinsic muscles limit most of the hand grip strength [14, 15]. Researchers also found that grip strength is significantly affected by different shoulder, elbow and wrist angles [12, 16-17]. Maximum grip strength can be achieved with the elbow flexed at 135 degrees and with the shoulder and wrist in a natural posture [16]. The arm postures considered in this study are the extended, bent upward, straight, above shoulder and below shoulder postures. Kee [18] mentioned that large forearm motions can be involved in knob operations. It is hence suggested that researchers should take arm postures into account when studying the design of knobs.

Finger Postures

When applying a certain grip on a tool, the grip strength can be affected by the shape, size and surface condition of the gripped tool through the change in the muscle-tension relationship and moment arm of the hand muscles [19-23]. Since all muscles have an optimal length to produce the maximum contraction force, any degree of muscle fibre length variation in the fingers and thumb could affect the ability to maximally contract force [24-25]. In studies by Dempsey and Ayoub [26] as well as Swanson, Matev [27], it was found that different finger postures yielded different maximum pinch forces. Based on previous studies, this study chooses to use common finger postures such as the three-jaw chuck pinch, pulp-2 pinch and lateral pinch [13, 26, 28].

Types of Knobs

Knobs have been widely used in adjustment applications for many years. Their user interface designs have now significantly improved, enabling knobs to be used in both simple and complicated tasks [29, 30]. A knob can be a subclass of rotary controls which include continuous control knobs, selector knobs, ganged knobs and jog shuttles [31]. Knobs can come in various shapes and designs depending on the applications [32-33]. For example, there are cylindrical-, ridged-, convex- and cone-shaped knobs as suggested by Peebles and Norris [5]. According to researchers, the knurls on the grasped surface of a knob can help increase the gripping torque as long as the object's diameter is larger than 86mm [5, 34-35]. The types of knobs chosen to be investigated in this study include the butterfly nut, tap knob, knurled cylindrical knob, convex knob, knurled spherical knob, spherical knob, cone shape knob, cylindrical knob and ridged knob.

METHODOLOGY

The independent variables of the study include the different types of knobs, whereas the dependent variable includes the different postures assumed. Survey and observational studies are carried out in order to gather the information of the commonly and preferably used knob selections and work postures. The observational study is done with a checklist, where the collected data are expressed in the form of frequency.

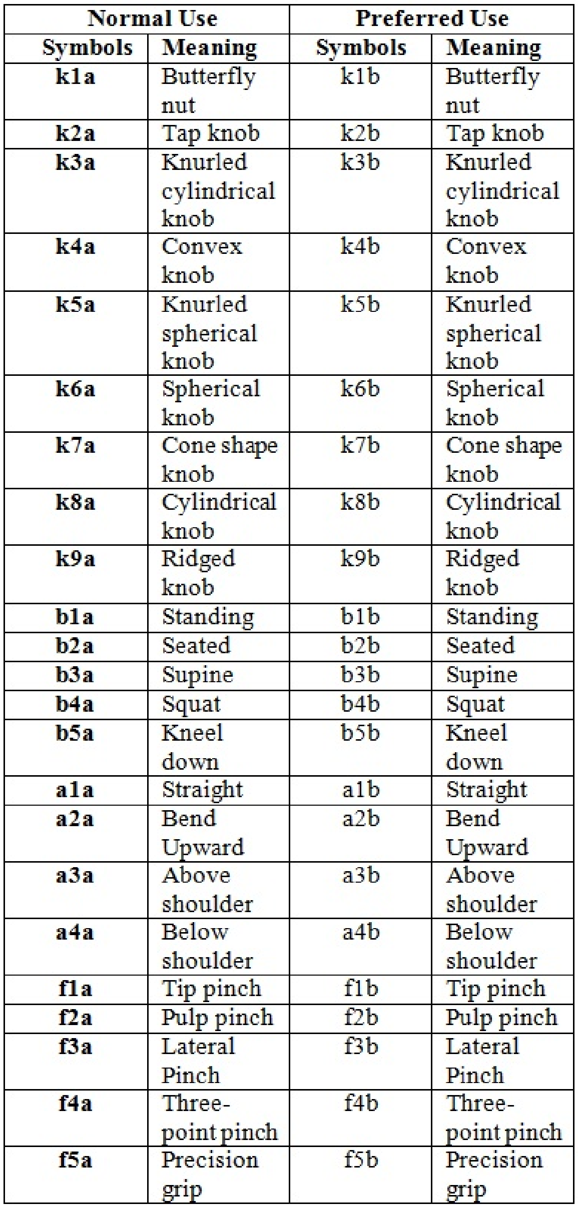
The survey is designed with a rating system that allows respondents to provide their feedback according to their preference or commonness of use. The rating scale used was modified from the Borg CR10 scale [36], with the ratings ranging from 1 to 5 as shown in Table-1. A smaller rating would imply that the use is more common or more preferable, whereas a larger rating would imply that the use is less common or less preferable. The corresponding score is ranging from 0 to 1 and in a reversed sequence with respect to the ratings with a score gap of 0.2. For example, the lesser normally or preferably used postures or knobs would be given a lower corresponding score and vice versa.

Table-1. Survey rating system (scale modified from Borg [36]).

Ratings/ Score	More commonly/ preferably used			Less commonly/ preferably used		
						
Normal use	1	2	3	4	5	6
Preferred use	1	2	3	4	5	6
Correspond-ding score	1	0.8	0.6	0.4	0.2	0

The variables and corresponding symbols are shown in Table-2. These symbols are used in Minitab 16. There are 8 manufacturing companies in total involved in the survey and observational study. Out of the 8 companies, 5 of them produce machining and assembly-related equipment, while the other 3 produce plastic films and tissue papers. A total of 70 workers participated in the survey and a total of 79 workers participated in the observational study. Participants are first given a simple briefing of the study. They then filled up the questionnaires distributed to them. The observational study was done by the researcher of this study, who recorded the various postures and knobs that were used while the participants were at work. The data obtained are managed and tabulated in Minitab 16 and a general regression analyses is performed with the data. The results of the analyses determine the effects of the different knob selections on the work posture selections of the workers using the *p*-value (to signify the significance of the effects) and the R^2 value (to signify the percentage of variance in the response).

Table-2. Variables and corresponding symbols.



Normal Use		Preferred Use	
Symbols	**Meaning**	**Symbols**	**Meaning**
k1a	Butterfly nut	k1b	Butterfly nut
k2a	Tap knob	k2b	Tap knob
k3a	Knurled cylindrical knob	k3b	Knurled cylindrical knob
k4a	Convex knob	k4b	Convex knob
k5a	Knurled spherical knob	k5b	Knurled spherical knob
k6a	Spherical knob	k6b	Spherical knob
k7a	Cone shape knob	k7b	Cone shape knob
k8a	Cylindrical knob	k8b	Cylindrical knob
k9a	Ridged knob	k9b	Ridged knob
b1a	Standing	b1b	Standing
b2a	Seated	b2b	Seated
b3a	Supine	b3b	Supine
b4a	Squat	b4b	Squat
b5a	Kneel down	b5b	Kneel down
a1a	Straight	a1b	Straight
a2a	Bend Upward	a2b	Bend Upward
a3a	Above shoulder	a3b	Above shoulder
a4a	Below shoulder	a4b	Below shoulder
f1a	Tip pinch	f1b	Tip pinch
f2a	Pulp pinch	f2b	Pulp pinch
f3a	Lateral Pinch	f3b	Lateral Pinch
f4a	Three-point pinch	f4b	Three-point pinch
f5a	Precision grip	f5b	Precision grip

Mean Work Posture Selections

The work posture selections involved in this study are the normally and preferably used body, arm and finger postures. All of them are compositely set as one dependent variable or response. This response is termed as work posture selections. In order to group all of these work posture selections together, the means were computed with Minitab 16 and given the name Position A and Position B. Position A includes the mean of all the normally used work postures, whereas Position B includes the mean of all the preferably used work postures. These responses can be described with the below expression:

$$\text{Posture A}=\left.\begin{pmatrix} b1a+b2a+b3a+b4a \\ +b5a+a1a+a2a+a3a \\ +a4a+f1a+f2a+f3a \\ +f4a+f5a \end{pmatrix}\middle/ 14\right. \tag{1}$$

$$\text{Posture B}=\left.\begin{pmatrix} b1b+b2b+b3b+b4b \\ +b5b+a1b+a2b+a3b \\ +a4b+f1b+f2b+f3b \\ +f4b+f5b \end{pmatrix}\middle/ 14\right. \tag{2}$$

Frequency Analysis and Score Analysis

From the survey, the ratings are converted into scores using the survey rating system in Table-1. The score for each knob category is summed up. All the scores of the knob categories are then compared to determine the knob with the highest score, which would then imply that this knob is the most commonly or preferably used knob. The data from the observational study is in the form of frequency and is used as it is, with the highest frequency of observations implying that the knob is the most commonly or preferably used knob. The scores of the knob selections however are not in the same form. The two different forms of data collected cannot be compared with each other directly. Therefore, the knob selections data from the frequency analysis (observation) and score analysis (survey) are converted into percentages so that comparisons can be made between these two sets of data. The formula used to convert these data into percentages [37] is given as:

$$\text{Percentages} = [(\text{Value} - \text{Min}) / (\text{Max} - \text{Min})] \times 100\% \tag{3}$$

Regression Analysis

Regression analysis is used to determine the effects of the predictors (independent variables) on the response (dependent variable). The general regression equation is shown as:

$$Y_{\text{response}} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n \tag{4}$$

In the regression analysis, the *p*-value is used to determine whether the effects are significant or not. Any *p*-value which is lesser than 0.05 ($p < 0.05$) would indicate that the effect is significant.

RESULTS AND DISCUSSIONS

Table-3 presents the overall results of the study. The results consist of the regression, score and frequency analysis. The regression analysis aims to determine the effects of knob selections on work posture selections, while the frequency and score analyses aim to determine the total number of normally and preferred knob selections based on the types of knobs investigated. Based on the results for the normal use, it appears that the effects of k1a, k2a, k3a, k4a, k5a, k7a, k8a and k9a on Position A are significant ($p < 0.05$). These results suggest that the selections of normally used work postures are significantly affected by normally used knobs such as butterfly nut, tap knob, knurled cylindrical knob, convex knob, knurled spherical knob, cone shape knob, cylindrical knob and ridged knob. As for the preferred use, it is found that the effects of k1b, k2b, k3b, k4b, k5b, k8b and k9b on Position B are also significant ($p < 0.05$). These results suggest that the selections of preferably used work postures are significantly affected by preferably used knobs such as butterfly nut, tap knob, knurled cylindrical knob, convex knob, knurled spherical knob, cylindrical knob and ridged knob. According to Stevenson, Coleman [38], the advantage of a spherical knob is that it allows a more natural wrist position regardless when the body and arm is in different positions. In the study of Peebles and Norris [5], it was discovered that the turning torque of a knob can be increased when knurls were added on the knobs. This is also supported by the findings of Imrhan and Jenkins [39] which suggested that the turning torque of a knurled knob is greater than the turning torque of a smooth surface knob by a margin of about 1.15 times. This means a higher breakaway strength (the amount of torque exerted on an object before it slips free) is required for a knurled knob [40]. This would also mean that only a minimum amount of pinch force would be required for this knob. A minimum amount of force requirement would potentially reduce fatigue and injury.

Based on the percentage Based on the percentage data in Table-3, it is clear that the respondents normally and preferably use the knurled spherical knob compared to all the other knobs, as the score and frequency for both k5a and k5b are the highest (k5a score = 31.4, k5a frequency = 46, k5b score = 30.8, k5b frequency = 46).

For normal use, the R2 is 73.63%, implying that 73.63% of the variance in normally used work postures can be explained by normally used knob selections. For preferred use, the R2 is 70.16%, implying that 70.16% of the variance in preferably used work postures can be explained by preferably used knob selections.

Table-3. Effects of normally/preferably used knob selections on normally/preferably used work posture selections.

Responses	Predictors	p	Knob selections affect work posture selections	Score for knob selections (Survey)	Frequency of knob selections (Observation)	Percentage of knob selections (%)	
						Survey	Observation
Position A (Normal) R^2 = 73.63%	k1a	0.000	Significant	17.6	3.0	48.5	0.0
	k2a	0.000	Significant	4.6	14.0	0.0	25.6
	k3a	0.000	Significant	13.8	13.0	34.3	23.3
	k4a	0.003	Significant	5.2	24.0	2.2	48.8
	k5a	**0.000**	**Significant**	**31.4**	**46.0**	**100.0**	**100.0**
	k6a	0.888	Not significant	5.4	28.0	3.0	58.1
	k7a	0.001	Significant	9.4	21.0	17.9	41.9
	k8a	0.000	Significant	9.8	13.0	19.4	23.3
	k9a	0.000	Significant	18.8	37.0	53.0	79.1
Position B (Preferred) R^2 = 70.16%	k1b	0.000	Significant	17.6	3.0	50.4	0.0
	k2b	0.001	Significant	4.6	14.0	1.5	25.6
	k3b	0.000	Significant	13.6	13.0	35.3	23.3
	k4b	0.007	Significant	4.2	24.0	0.0	48.8
	k5b	**0.000**	**Significant**	**30.8**	**46.0**	**100.0**	**100.0**
	k6b	0.969	Not significant	5.8	28.0	6.0	58.1
	k7b	0.281	Not significant	13.8	21.0	36.1	41.9
	k8b	0.001	Significant	11.8	13.0	28.6	23.3
	k9b	0.000	Significant	16.6	37.0	46.6	79.1

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