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Ergonomic Assessment of Excavator Seat

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Abstract: This study investigated the factors that affect sitting discomfort of excavator seat. There were 20 male professional excavator operators served as the subjects. Firstly, they were asked to assess the static features of the two seats. Secondly, there were two body part discomfort questionnaires to be filled out. One is at the beginning and the other is at the end of an operation period of 3 hours. During the 3 hours operation period, subjects were asked to dig a gutter on ground and then to fill in the gutter repeatedly. The results showed that seat type did significantly affect mean body part discomfort and mean subjective preference score. Seat C resulted in lower body part discomfort and better subjective preference score than that of seat K. In summary, greater adjustment range of seat features and better adjustment mechanism of seat can meet operators' more requirements and then decrease body part discomfort and increase subjective preference.

Keywords: excavator seat; subjective preference; body part discomfort.

1. Introduction

Since William Otis proposed the first steam shovel of rail-mounted model of the early precursor of today's excavator in 1835, its diversity and convenient operating nature have made it popular [1]. Today, excavator is used all over the world and is the most important construction machine. Many researches have been devoted to improve excavator operation performance, but most of them focus on the engineering feature of hardware, such as control system [2] and operational safety [3]. However, ergonomic assessment about human-seat interaction is lacking.

Excavator operators often spend long hours in the cabin- sometimes even more than 8 hours a day and their main problems are physical pains and fatigue in the neck/shoulder and low back region after a long period of operation [4]. Moreover, operating fatigue also resulted in the stress for the operator [5]. The seat is one of the most important components in the cabin that may affect the operator's body postures. Zhao and Tang [6] have indicated that the sitting posture was significantly related to the Electromyography (EMG) of back muscles that may affect operator's discomfort. Lusted et al. [7] have pointed out that the seat design should be encouraged for the occupants to adopt a good posture instead of poor postural habits. Kuijt-Evers et al. [8] investigated the cabin comfort according to operators' opinion. They concluded that cab comfort of excavators could be increased by improving seat comfort. However, in order to design comfortable seats in excavators, the opinion (subjective assessment) of the operators is important as they are the end-users of the excavators. Their user experience may be of great help in designing more comfortable seats in excavators. Further,

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cabin vibration was concomitant with frequent of lower back pain, and other muscular-skeletal injuries like leg pain [9].
Several subjective approaches have been used to achieve an overall assessment of a seat. Björkstén et al. [10] have pointed out that the questionnaire ably reveals subjects' conditions of work related musculoskeletal disorders. Helander and Mukund [11] confirmed that the subjective assessment technique is the only way to explore user preferences and detect changes in discomfort. Sitting discomfort is the most frequent subjective measurement for assessment of seat features in previous studies [12]. Fenety et al. [13] indicated that sitting discomfort was traditionally evaluated with subjective rating scales. Zhang et al. [14] defined discomfort as independent entities associated with different factors. Mehta and Tewari [15] concluded that discomfort is the subjective experience, which can result from a combination of physiological and psychological processes, total time spent on task, and body posture assessment for task related muscle fatigue. Discomfort in seats is a complex phenomenon based on subjective feeling and physical properties of the interface to the human body [16]. Helander and Zhang [17] indicated that discomfort is related to fatigue accumulated during the workday. Fortunately, there are many well-established scales to assess sitting discomfort. Shackel et al. [18] developed a general comfort rating scale for assessment of sitting discomfort. Corlett and Bishop [19] have published a body part discomfort scale, which has general applicability to measure discomfort to all types of work. Lusted et al. [7] have developed a discomfort checklist for body area chart to assess subjects' discomfort.

There were also many items proposed to assess seat features. Ng et al. [20] investigated the important features of a car seat. They indicated that the lumbar support, seat pan tilt and the height of the seat pan are the important features for a seat. Zhang et al. [14] constructed a chair evaluation checklist which consist 16 questions and uses a 9-point Likert scale to assess the intensity of each descriptor. Park et al. [21] pointed out that the fitness cushion, back and head rest were the important factors for the overall sitting comfort.
In summary, excavator is one of the most important construction machines in industry, but its ergonomic assessment is lacking. Studies are needed to empirically evaluate the excavator seat according to operators' opinion in a prolonged operation. Because the overall seat discomfort is influenced by both static and dynamic situation [22-23]. The present study assessed both of the static (subjective preference) and dynamic (body part discomfort) features of excavator seats.

2. Method

2.1. Subjects

There were 20 male professional excavator operators served as the subjects. All subjects have held Taiwan excavator operating license for at least two years. The characteristics of the responding subjects are shown in Table 1.

2.2. Experimental procedure and task

Figure 1 shows the procedures of the experiment. Subjects were random assigned to the excavator seats.

Firstly, they were asked to assess the static features of the two seats. Before the assessment, subjects were able to adjust the seats to fit their most comfort posture. A seat features assessment (subjective preference) checklist adapted from Zhang et al. [14] and Kolich [24] was used. The subjects were asked to rate the seat features on a 5-point Likert scale with '1 = too high, too low, too narrow, too hard, etc…' and '5 = adequate' for item 1 to 5; and to rate it on a 5 points scale with '1 = poor' and '5 = good' for item 6 to 9 (see Table 2).
Secondly, there were two body part discomfort questionnaires to be filled out. One is at

the beginning and the other is at the end of an operation period of 3 hours. The body part discomfort questionnaire (Figure 2) adapted from Corlett and Bishop [19], Corlett et al. [25] and Lusted et al. [7] were used to obtain subjects' opinions [26, 28]. The subjects were asked to identify body areas experiencing discomfort and to rate this discomfort on a 100-point scale from 'no discomfort' to 'agony'

Table 1. Characteristics of the operators

Characteristics	Min	Max	Mean	S.D.
Height (cm)	160	182	170.5	7.06
Weight (kg)	68	95	76.0	11.02
Popliteal height (cm)	43	47	45.1	2.03
Buttock-popliteal length (cm)	45	63	53.2	5.64
Years of operating	2.5	7.5	4.9	1.54

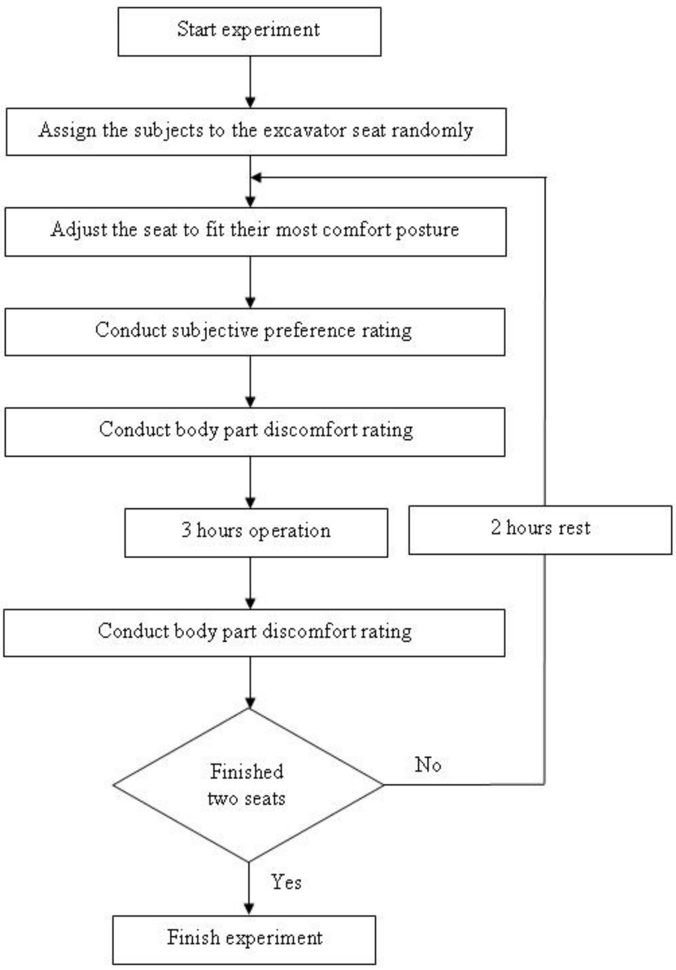

Figure 1. The procedures of the experiment

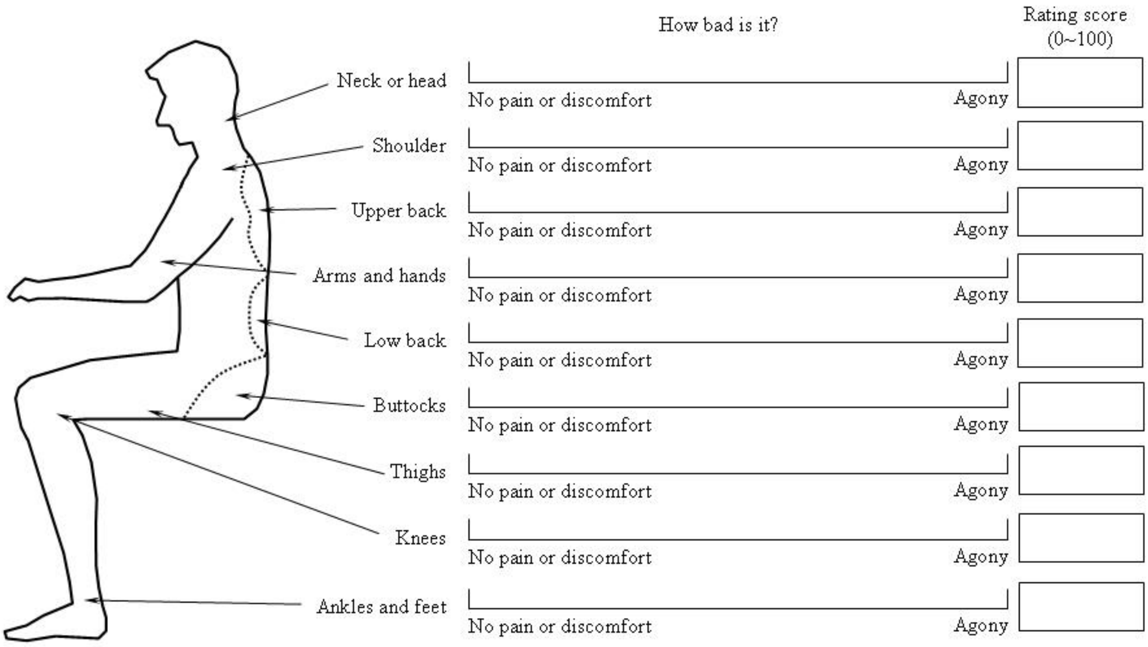

Figure 2. Body part discomfort assessment checklist

During the 3 hours operation period, subjects were asked to dig a gutter (5 meters length × 1 meter width × 1 meter depth) on ground and then to fill in the gutter repeatedly. They were asked to perform the task as quick and best as possible. To maintain work motivation, subjects were paid US$ 10.0 per hour, plus an extra US$ 1.5 for each operation (digging a gutter and fill in the gutter). To prevent body fatigue, subjects were required to avoid any kinds of physical task for at least one hour prior to the experiment. Between the two seats assessment, there was also a 2-hours break was given to prevent subjects' body fatigue.

2.3. Apparatus

The present study investigated seat features on subjective assessment of excavator seat. Two levels of excavator seat types were employed: seat K in excavator K and seat C in excavator C (Fig.3). The excavator K and excavator C are the most popular two brands in Taiwan. Seat K is the seat which generally used in excavators. Seat C is the seat which has greater adjustment range of seat pan height, backrest angle and has large seat back and forth adjustment range. Further, the seat C has hydraulic suspension system and easy to adjust the seat height automatically according to operator's weight during sitting. Hypothetically, seat C might result better subjective preference score than that of seat K and reduce body part discomfort score. Table 2 shows the features of the two seats.

2.4. Dependent measure and data analysis

Subjective preference (short-term assessment) and body part discomfort (long-term assessment) score were collected and analyzed. Higher subjective preference rating score indicated that subjects regarded the seat with better seat features. Body part discomfort score was defined as the end rating score minus the beginning rating score. Higher body part discomfort score indicated that the subject felt more discomfort increasing of the body part during the 3 hours operation period. Analysis of variance (ANOVA) was conducted on the dependent measurements. All calculations were made with the Statistical Analysis System (SAS).

Figure 3. The configuration of seat K (left) and seat C (right)

Table 2. Characteristics of the two excavator seats

Item number	Seat features	Seat C	Seat K
1	Seat pan width	51 cm	51 cm
2	Seat pan depth	51 cm	48 cm
3	Seat pan height	42~50 cm	44 cm
4	Backrest width	53 cm	47 cm
5	Backrest height	50 cm	50 cm
6	Headrest height	20 cm	20 cm
7	Headrest width	32 cm	30 cm
8	Seat back and forth adjustment range	35 cm	22 cm
9	Backrest adjustment angle	-70º~+50º	-35º~+45º

3. Results

The results of ANOVA (Table 3) indicated that seat pan height (F(1, 19)=28.50, p<.001), seat pan depth (F(1, 19)= 4.75, p<.05), seat pan cushion (F(1, 19)=15.26, p<.001), seat stability (F(1, 19)=15.55, p<.001) and seat adjustment (F(1, 19)=31.41, p<.0001) had significant effects on subjective preference score. Subjective preference scores under each level for the significant factors were shown in Table 4. In general, seat C resulted in better subjective preference score than that of seat K in all seat features.

The results of ANOVA (Table 5) indicated that only thighs ($F(1, 19)=4.811$, $p<.05$) was significantly affected by the seat type. Seat C (mean: 21.9) had lower thighs rating score than that of seat K (29.2). Body part discomfort score under each level for the independent factors were shown in Table 6. Although seat C resulted in lower body part discomfort score than that of seat K in other items, the difference was not statistically significant.

4. Discussion

Seat features with regard to seat pan (height, depth and cushion), seat stability and seat adjustment had the significant effects on subjective preference score. The results were similar with previous findings [8, 20-21] that seat features might affect subjective comfort.

Four reasons may be offered to explain the effect of seat features. First, seat C had better subjective preference scores with regard to seat pan than that of seat K. Due to human metabolism, heat and moisture are generated continuously during sitting. Therefore the feeling of discomfort is related to the parameters such as seat pan height and depth at the human body and support interface [16]. Hänel et al. [16] concluded that the hardness (seat pan cushion) of a seat is an important factor in reducing or preventing the discomfort. Ebe and Griffin [26] also indicated that static seat pan cushion discomfort seemed to be affected by two factors, a 'bottoming feeling' and a 'foam hardness feeling'. In addition, the seat C has hydraulic suspension system that easy to adjust the seat height automatically according to operator’s weight during sitting. Automatic adjustment of seat pan height can increase the adaptability of seat to fit individual different of subjects. Second, adjustment range of seat pan height, range in back and forth adjustment and backrest adjustment angle of seat pan were better for the seat C than that for the seat K. The seat pan height adjustment range of seat C was 42~50 cm, contrarily, the seat pan height of seat K was fixed (44 cm); the range in back and forth adjustment of seat pan of seat C (35 cm) was greater than seat K (22 cm); the range in backrest adjustment angle of seat C (-70º~+50º) was also greater than seat K (-35º~+45º). Adjustment flexibility can increase the adaptability of seat to fit individual needs of subjects. Better adaptation of seat may decrease subjects’ sitting discomfort and increase preference rating. Result shows that the seat C had better subjective preference score for seat adjustment than that of seat K. Third, lumbar support is an important feature for a seat [20] and contributes to a reduction in low back pain [27]. The subjective preference score for backrest cushion of seat C was higher than that for seat K. In addition, the seat C had greater adjustment range than that of the seat K in backrest angle. Andreoni et al. [28] pointed out that the lumbar flexion angle (range in backrest adjustment angle) could be an indicator of the postural comfort. Greater adjustment range of backrest angle can satisfy more adjust need for operators’ and then decreased sitting discomfort and increased seat preference rating. Fourth, hydraulic suspension system also could efficiently reduce vibration and increase stability of seat that to decrease operator’s discomfort feeling [9, 29-31]. Bovenzi and Betta [30] indicated that low-back disorders were found to be significantly associated with vibration. Fairley [31] also indicated that vibration is one of the important factors that may affect sitting discomfort.

Although seat C resulted in lower body part discomfort score than that of seat K in many items, the difference was not statistically significant. The results indicated that subject (individual difference of operators) and only one item of body part discomfort (thighs) score were significantly affected by the seat type. The results were also similar with previous findings [8, 20-21] that seat features might affect subjective comfort. Ng et al. [20] indicated that seat pan height and cushion are very important features for a seat. They indicated that subjects' perception of seat discomfort was influenced most by thigh support (75 %), thoracic support (70 %), and lumbar support (65 %). Hydraulic suspension system of seat also could efficiently reduce vibration in the cabin and decreased operator's discomfort feeling.

Though the difference of body part discomfort score between seat C and seat K was not statistically significant, the Pearson product-moment correlation coefficient indicated that body part discomfort score was highly related to subjective preference score ($r=0.89$, $p<0.05$). This result indicated that the subjective preference score is suitable to evaluate the seat features.

5. Conclusion

Seat type did significantly affect on subjective preference score. Seat C resulted in better subjective preference and had the better subjective preference in seat pan height, seat pan depth, seat pan cushion, seat stability and seat adjustment. Seat C also resulted in slightly lower body part discomfort score for buttocks and thighs than that of seat K. Despite the findings in the present study, general ergonomic principles and recommendations for sitting conditions should be developed in the design of excavator seats further for obtaining the best sitting posture for the operator.

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Table 3. One-way ANOVA for subjective preference score of the seat features

Source	DF	SS	MS	F-value	p-value
Seat pan height (between seats)	1	3.60	3.60	28.50	0.0058**
Seat pan width (between seats)	1	0.30	0.30	3.33	0.0721
Seat pan depth (between seats)	1	0.40	0.40	4.75	0.0421*
Seat pan cushion (between seats)	1	4.90	4.90	15.26	0.0009***
Backrest cushion (between seats)	1	0.40	0.40	2.11	0.1625
Seat pan surface (between seats)	1	0.10	0.10	0.66	0.4283
Backrest surface (between seats)	1	0.40	0.40	1.36	0.2585
Seat stability (between seats)	1	3.60	3.60	15.55	0.0009***
Seat adjustment (between seats)	1	8.10	8.10	31.41	<0.0001***

*p<0.05 significant level; **p<0.01 significant level; ***p<0.001 significant level

Table 4. Subjective preference score for the significant factors

Seat features	Independent variables	Seat type	
		Seat C	Seat K
Seat pan height	Mean	3.4	2.8
	S.D	0.68	0.62
Seat pan depth	Mean	3.7	3.3
	S.D	0.51	0.47
Seat pan cushion	Mean	3.7	3.0
	S.D	0.80	0.46
Seat stability	Mean	3.8	3.2
	S.D	0.89	0.41
Seat adjustment	Mean	4.0	3.1
	S.D	0.65	0.31

Table 5. One-way ANOVA for body part discomfort score of the body part

Source	DF	SS	MS	F-value	*p*-value
Neck or head (between seats)	1	10.00	10.00	0.06	0.8149
Shoulder (between seats)	1	28.90	28.90	0.13	0.7272
Upper back (between seats)	1	136.90	136.90	0.76	0.3953
Arms and hands (between seats)	1	90.00	90.00	1.06	0.3157
Low back (between seats)	1	291.60	291.60	1.02	0.3264
Buttocks (between seats)	1	756.90	756.90	2.31	0.1452
Thighs (between seats)	1	532.90	532.90	4.81	0.0410*
Knees (between seats)	1	2.50	2.50	0.01	0.9216
Ankles and feet (between seats)	1	176.40	176.40	1.16	0.2940

*p<0.05 significant level; **p<0.01 significant level; ***p<0.001 significant level

Table 6. Body part discomfort score for the independent factors

Body part discomfort	Independent variables	Seat type	
		Seat C	Seat K
Neck or head	Mean	44.1	45.1
	S.D	21.13	26.52
Shoulder	Mean	33.2	31.5
	S.D	17.78	19.17
Upper back	Mean	32.7	29.0
	S.D	16.52	20.24
Arms and hands	Mean	24.6	27.6
	S.D	15.02	20.21
Low back	Mean	31.4	36.8
	S.D	16.40	22.01
Buttocks	Mean	18.0	26.7
	S.D	15.76	21.32
Thighs	Mean	21.9	29.2
	S.D	27.67	24.10
Knees	Mean	21.5	21.0
	S.D	21.46	30.07
Ankles and feet	Mean	14.5	18.7
	S.D	13.67	18.16

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