Evaluation of perceived discomfort in repetitive arm reaching and holding tasks

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ABSTRACT

This study investigates the effects of arm reaching and holding related factors on subjective discomfort rating. Fifteen males and fifteen females participated in the experiment. Independent variables include shoulder flexion (60°, 90° and 120°), reaching frequency (2 motions/min and 4 motions/min), holding weight (0.86 kg and 1.12 kg), and holding duration (5 s and 10 s). The response measures include subjective discomfort ratings of the whole body (WBD), shoulder (SD) and upper arm (UAD). The ANOVA results indicate that the effects of gender, shoulder flexion, reaching frequency, holding weight, and holding duration significantly influence all measures. Findings also show significant positive correlations among WBD, SD and UAD. Arm reaching over shoulder height is the main factor affecting WBD for both males and females. Further, the high frequency of arm reaching shows greater influence on female participant’s WBD than other factors. On the other hand, holding weight shows greater influence on male participant’s WBD than other factors. Moreover, this work constructs nine regression models to predict WBD, SD and UAD from arm reaching and holding related factors. The discomfort prediction models explain at least two-thirds of the variations.

Relevance to industry: This study evaluates the effects of shoulder flexion, reaching frequency, holding weight, and holding duration on whole body and body part discomfort. The findings of this study can be used for job and workplace design.

1. Introduction

Work-related neck and upper limb musculoskeletal disorder is a worldwide problem. In North America, 20 percent of newspaper employees in Canada (Polanyi et al., 1997) and 11.7 percent of US workers identify themselves with upper limb discomfort (Morse et al., 2003). Further, 30 percent of non-manual UK workers report discomfort at one or more sites in the neck or upper limbs (Palmer et al., 2001). In Taiwan, the prevalence of neck and shoulder discomfort is 14.8 percent and 16.6 percent in a survey of 17,669 workers, respectively (Lee et al., 2005). The effect of working posture, force exertion and task frequency reportedly has a positive influence on workers' musculoskeletal discomfort (NIOSH, 1997).

Discomfort assessment of physical effort is reported as a more economical, and efficient method than electromyography (EMG), motion analysis or biomechanical analysis. There is an association between the risk of musculoskeletal disorders and discomfort (Dul et al., 1994). Previous research used discomfort assessment to evaluate the stress of working posture (Corlett and Bishop, 1976), force exertion (Olendorf and Drury, 2001) and task frequency (Radwin et al., 1994) in a job task.

For the gender factor, subjective discomfort rating is reportedly different between males and females. Kee (2005) investigated the effect of maintaining one-minute posture at five motion levels (from neutral to maximum range of motion) for eight joints on whole body discomfort rating of males and females. Results show that on average, female’s discomfort rating is greater than male’s. In addition, Kumar et al. (1999) studied a dynamic lifting task and found that the tendency of discomfort for females and males is inconsistent and depended on task condition. The difference in discomfort ratings between males and females is due to the difference in muscle strength, body dimensions, and soft tissue properties.

Subjective discomfort rating for task-related factors tends to be affected by at least one of the following task factors including working posture, frequency and force exertion. Khan et al. (2009) examined the influence of wrist deviation and forearm rotation angle on subjective discomfort and found that the discomfort rating increases rapidly while both the wrist deviation and forearm rotation are greater than 30% joint range of motion. Radwin et al. (1994) investigated the effect of wrist flexion and task frequency on subjective discomfort rating, finding a high discomfort association...
with high frequency wrist flexion. Ulin et al. (1993) also studied the effect of three vertical and two horizontal work locations and task frequency on discomfort rating in screw-driving tasks. Findings show that both work location and frequency show significant influence on discomfort ratings. Olsendorf and Drury (2001) evaluated the effect of body posture and load on whole body and local discomfort for holding tasks of twenty durations using the Ovako Working posture Analyzing System (OWAS). The OWAS postures include four back postures, three arm postures and seven leg postures as well as three force categories. Results show that load factor has greater influence than postural factors. A greater discomfort difference exists among different postures at a high load level. Recently, O’Sullivan and Clancy (2007) simulated a manual assembly task to estimate the effect of force exertion and task frequency on subjective discomfort rating and found that discomfort increases with the increase of force and frequency.

For the combination of three task factors, Wiker et al. (1989) studied the effect of shoulder posture, load, and work-to-rest ratio on the whole body, neck and upper arm fatigue for a repeated Fitts’ tapping task. Results show that hands above shoulder level increase discomfort even in light weight conditions. Carey and Gallwey (2002) investigated the effect of force exertion, frequency, and the level of wrist flexion/extension and radial/ulnar deviation on discomfort rating. They found that extreme wrist flexion causes higher discomfort than other deviations, and the combination of wrist flexion and ulnar deviation causes higher discomfort than the other posture combinations. Force is the dominant factor, followed by level of deviation (i.e. posture) and frequency. More recently, Mukhopadhyay et al. (2007) investigated the effect of forearm rotation, elbow flexion, task frequency and forearm torque exertion. Discomfort is higher at 45° elbow flexion as compared to 90° and 135°, and discomfort is also higher in forearm pronation posture as compared to forearm supination or neutral posture.

Previous studies investigate the effect of posture, force, and frequency factors on subjective discomfort rating in short duration (a few seconds). In real world practice, using automobile assembly tasks as an example, operators hold a power screwdriver, position and fasten one screw, then pick up another screw and perform another screw fastening task. Discomfort assessment for the task involves holding a hand tool to perform assembly tasks in different working heights, and working frequency requires further investigation. This study tests whether contributions for each task related factor for both genders is equal or not.

Thus, this study evaluates the relative contributions of shoulder flexion, reaching frequency, holding weight, and holding duration to whole body and local discomfort ratings, and then establishes prediction models of whole body and local discomfort for both males and females. Results of this study provide some insights about job and workplace design for both genders.

2. Methods

2.1. Participants

Fifteen men and fifteen women participated in the experiment as paid volunteers. All participants were Taiwanese and free from any known musculoskeletal disorders. Table 1 summarizes anthropometric and demographic data. All participants were right-handed.

2.2. Experiment design

Arm reaching and holding tasks simulate automobile industry assembly tasks. Some automobile assembly line workers perform the screw-driving task with arm extended static posture in short cycle time with pneumatic screwdrivers. Thus, independent variables include shoulder flexion (60°, 90° and 120°) without elbow flexion, reaching frequency (2 motions/min and 4 motions/min), holding weight (0.86 kg and 1.12 kg), and holding duration (5 s and 10 s). This investigation also considers gender factor. Holding weight is based on the weight of two commercial available screwdrivers (NR-STL1811, Minfeng Co.) with the same length and diameter.

This work employs a nested factorial design and twenty-four experiment combinations are conducted by each participant. Response measures include discomfort ratings of whole body and local body parts, as shown in the following section.

2.3. Discomfort rating

Discomfort rating considers both whole body and local body parts. The whole body discomfort (WBD) is an overall evaluation of perception and experience of whole body discomfort after completing physical work. The local discomfort measures subjective discomfort in local body areas. Olsendorf and Drury (2001) applied two different subjective rating scales to measure whole body and local body discomforts and found both WBD and local discomfort are sensitive to different experimental conditions. This study used the Category Partitioning Scale (CP-50) to measure WBD and the Body Part Discomfort Scale (BPD) (Corlett and Bishop, 1976) to measure local discomfort.

The CP-50 scale starts from point 0 denoting “no discomfort” with five discomfort categories: very slight, slight, medium, severe, very severe. Each category further divides into ten scale points to rate points above fifty for any extreme intensity. Participants first select the category that fits their perception, and then refine their judgment by choosing a number from 1 to 10 within the selected category. Shen and Parsons (1997) tested the reliability and validity of CP-50. For the BPD scale in relevant body areas of shoulder and upper arm, this study used a 6-point scale, with 0 for “No discomfort perceived” and 5 for “Intolerable discomfort” (Corlett and Bishop, 1976). The BPD scale is easy to use and requires almost no training (Drury and Coury, 1982).

2.4. Experimental procedure

The experimental procedure involves two phases: preparation, and arm reaching and holding. The preparation phase measures the participant’s stature, body weight, shoulder height (SH) and upper arm maximum reach distance (from heel) (D) without torso participation. This procedure allows specific target position in shoulder flexion. The height of arm reaching in shoulder flexion 60° is calculated by: SH – D*sin30°. Similarly, the height of arm reaching in shoulder flexion 120° is calculated by: SH + D*sin30°. The height of arm reaching in shoulder flexion 90° is just SH. Fig. 1 illustrates the experimental arrangement.

In the arm reaching and holding experiment phase, an auditory tone from the PC signals the start of the experiment trial. The task

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Anthropometric data of the participants.</th>
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<tbody>
<tr>
<td></td>
<td>Men (N = 15)</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>25.53 ± 2.47</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>175.41 ± 6.28</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>67.81 ± 5.19</td>
</tr>
<tr>
<td>Shoulder height (cm)</td>
<td>146.78 ± 6.45</td>
</tr>
<tr>
<td>Reach distance (cm)</td>
<td>68.36 ± 4.86</td>
</tr>
</tbody>
</table>

* Upper arm maxima reach distance (from heel) without torso participation.
requires the participant to grasp a 26 cm long and 3 cm diameter in-line pneumatic screwdriver (0.86 kg or 1.12 kg), and transfer it from home position in front of the participant at hip height, to a target position marked on the target shelf. After hearing a second auditory tone, 5 s or 10 s later, the participant returns the hand tool back to home position. This experiment regards each cycle as one repetition. The transferring frequency of 2 or 4 motions/min represents two or four repetitions per minute for each arm reaching and holding task. Each experiment trial involves a one-minute reaching and holding task and then rests one minute (measures WBD, shoulder discomfort (SD) and upper arm discomfort (UAD)).

A total of 24 experimental combinations (3 shoulder flexion*2 reaching frequency*2 holding weight*2 holding duration) were involved in the study. They were randomized, and performed once for each condition. After completing twelve experiment trials, a five-minute rest is scheduled before the second twelve experi-

2.5. Statistical analysis

Analysis of variance (ANOVA) was preformed to analyze the gender and task factors effect on subjective discomfort rating. Post-hoc testing with Duncan’s multiple range test was then performed to identify which level differed significantly from each other. Further, Pearson correlations were performed to determine the inter-variable relationships. Moreover, regression analysis with a forward stepwise procedure was conducted to construct discomfort prediction models for WBD, SD and UAD with independent factors including: gender, shoulder flexion, holding weight, reaching frequency and holding duration. The significance level was set \( \alpha = 0.05 \).

3. Results

3.1. Subjective discomfort rating

Table 2 shows ANOVA results of significant main effects and interactions on WBD, SD and UAD. The main effects significantly influence all measures. Interactions of gender*reaching frequency and gender*shoulder flexion*reaching frequency also significantly influence the WBD, SD and UAD ratings.

Table 3 shows the means and Duncan groupings of the shoulder flexion effect. Increasing shoulder flexion, holding weight, reaching frequency and holding duration correspondingly increase the WBD, SD and UAD ratings. The average WBD rating for females is greater than that of males for about 8%. Arm reaching in shoulder flexion 120° produces the greatest WBD rating and arm reaching in shoulder flexion 60° produces the least WBD rating, only 56% of the discomfort rating for shoulder flexion 120°. The WBD rating at a lower level of load, frequency and duration is almost 90% of the discomfort rating for a higher level of load, frequency and duration.

![Fig. 1. The illustration of the experimental arrangement.](image-url)
The discomfort rating of females is greater than that of males for about 20% in SD and 80% in UAD. The Duncan groupings show that the SD and UAD for the shoulder flexion factor can be classified into three levels. The highest discomfort rating occurs at shoulder flexion 120°, followed by shoulder flexion 90° and 60°. The order of increase in local discomfort rating for holding weight, reaching frequency and holding duration factor is somewhat different from the shoulder flexion factor. UAD has greater increase from a low level of weight (0.86 kg) to a high level of weight (1.12 kg), followed by SD. Results of reaching frequency and holding duration factors are similar to load. In short, the change from low to high level in shoulder flexion, holding weight, reaching frequency and holding duration causes substantial increase in UAD and a slight increase in SD.

Fig. 2 shows two-way interactions of the four experiment factors in WBD rating. For females, the WBD rating has the greatest increase with shoulder flexion from 90° to 120°, followed by shoulder flexion from 60° to 90°. Reaching frequency level changes from 2 to 4 motions/min, holding weight level changes from 0.86 to 1.12 kg and holding duration level changes from 5 to 10 s. For male participants, increase in shoulder flexion causes greatest increase in WBD rating, followed by increase in holding weight, holding duration and reaching frequency level. Therefore, the reaching height above shoulder is the main factor affecting WBD rating for males and females. Except for this postural effect, reaching frequency is the dominant factor affecting female participant’s WBD rating. On the other hand, holding weight is the dominant factor affecting male participant’s WBD rating.

Fig. 3 shows two-way interactions of the four experiment factors in the WBD rating. Fig. 3A shows the WBD rating increase for arm reaching in shoulder flexion from 60° to 120° is about 90% at a lower holding weight level and about 70% at a higher holding weight level. For shoulder flexion and reaching frequency (Fig. 3B), the WBD rating increase caused by increased frequency from 2 to 4 motions/min is less than the increase caused by change in shoulder flexion from 90° to 60° or 120°. Further, Fig. 3C shows that the WBD rating caused by increase in shoulder flexion from 60° to 120° is about 80% at both holding duration levels. The WBD rating increase caused by weight increase from 0.86 Kg to 1.12 Kg is about 8% for both duration levels (Fig. 3D). Also, increased frequency from 2 to 4 motions/min results in increased WBD rating for about 13% at both holding duration levels (Fig. 3E).

3.2. Correlation analysis and regression analysis

Correlations between WBD, SD and UAD are all significant at p < 0.001, and the correlation coefficient between WBD and SD, WBD and UAD, as well as SD and UAD is 0.87, 0.88 and 0.76, respectively.

For multiple regression analysis, the WBD, SD and UAD are used as dependent variables, and the four task factors (shoulder flexion, holding weight, reaching frequency and holding duration) are used as independent variables. This study obtains three regression models for males, females and all participants respectively, using a forward stepwise searching procedure (Table 4). The coefficients of determination ($R^2$) are greater than 0.60. Moreover, this investigation adopts an indicator variable to represent the gender factor with: “0” for female, and “1” for male. Results show these models to be statistically significant (p < 0.001) with $R^2$ greater than 0.80 for predicting WBD and greater than 0.85 for predicting UAD and SD. The coefficient of determination 0.80 from regression analysis results is high enough to support the model, indicating the relationship between WBD and task factors. Shoulder flexion, holding weight, holding duration and reaching frequency factors are all significant in the regression models. Moreover, the
standardized partial regression coefficient of the shoulder flexion factor is 0.84, greater than that of reaching frequency (0.23), holding weight (0.15), and holding duration (0.09) factors for all participants. Shoulder flexion influence seems greater than other factors regardless of the gender factor.

3.3. Biomechanical analysis

Extreme joint angle with greater exertion (holding weight) can cause higher biomechanical loads on shoulder joint. To further analyze biomechanical stresses, this study applies the three-dimensional static strength prediction program (3D SSPP™, version 5.05) to calculate shoulder joint moment. The results of shoulder moment and shoulder discomfort rating among different shoulder flexion and load are presented in Table 5. The joint moment for shoulder flexion 60° and 120° is equal to or smaller than the joint moment for shoulder flexion 90°. But the shoulder discomfort rating for shoulder flexion 120° is greater than that of the others. Moreover, male subjects tend to generate a higher shoulder moment than females.

4. Discussion

4.1. Effect of gender

According to regression analysis results, the order of importance among the four task factors for females is different from that of males. For male participants, the order of dominance is shoulder flexion, holding weight, holding duration and reaching frequency; for female participants, reaching frequency is the dominant factor after shoulder flexion. It seems that the shoulder flexion is the main factor affecting whole body discomfort for all participants. The reaching frequency factor is second for females, and the holding weight factor is second for males. Increase arm reaching frequency means that subjects need to exert force with high repetition in short duration. The significantly smaller fast-twitch fiber areas and less fast-twitch fibers in females (Sale et al., 1987) put them at a disadvantage condition in generating short burst strength as compared to males. In addition, the glycolytic enzyme activity of females is also lower than that of males (Jaworowski et al., 2002), thus resulting in higher perceived discomfort with increased arm reaching frequency. These factors perhaps explain the phenomenon of a higher prevalence of upper extremity disorders for females while performing high repetition tasks (Silverstein et al., 1986).

On the other hand, holding weight factor is the dominant factor for males, similar to the finding of Carey and Galloway (2002). Moreover, Table 5 indicates that male subjects tend to generate a higher shoulder moment than females due to longer segment length, larger moment arm, and greater segment mass. Males are more sensitive to hand load change than females. Thus, considering gender differences in anatomical structure and physiological responses when designing workplace and job tasks is important.

Table 4

<table>
<thead>
<tr>
<th>Participant</th>
<th>Equation</th>
<th>R²</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>WBD = -8.81 + 0.84SF + 0.23F + 0.15L</td>
<td>0.80</td>
<td>***</td>
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<tr>
<td></td>
<td>- 0.14 G + 0.09D</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>SD = -3.73 + 0.76SF + 0.20F + 0.15L</td>
<td>0.67</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>- 0.13 G + 0.09D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UAD = -3.86 + 0.65SF</td>
<td>0.68</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>- 0.39 G + 0.27F + 0.15L + 0.11D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>WBD = -9.88 + 0.88SF + 0.18L</td>
<td>0.83</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.12D + 0.09F</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD = -3.34 + 0.78SF + 0.16L</td>
<td>0.66</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.12F + 0.12D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UAD = -3.59 + 0.79SF + 0.23L</td>
<td>0.72</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.14F + 0.14D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>WBD = -10.39 + 0.82SF + 0.36F</td>
<td>0.83</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.12L + 0.06D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD = -4.28 + 0.76SF + 0.28F</td>
<td>0.69</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.15L + 0.06D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UAD = -5.16 + 0.69SF + 0.40F</td>
<td>0.66</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>+ 0.13L + 0.11D</td>
<td></td>
<td></td>
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</table>

***Regression equation is significant at p < 0.001 and the p values for all independent variables in each regression equation were smaller than 0.05.
SF, shoulder flexion; F, reaching frequency; L, holding weight; D, holding duration; G, gender ("O" for females and "1" for males).

4.2. Gender differences

Women and men responded differently to the shoulder task. They probably have different muscle strength, fat distribution, flexibility, and the age that affects muscle strength. These factors will result in different discomfort level. The regression analysis results indicate that the shoulder flexion factor for males is greater than females, but the holding weight is smaller. In addition, female participants reported higher discomfort than male participants, which is consistent with the findings of Taylor and Hargreaves (2007). Therefore, age and sex can affect the discomfort level of shoulder joint.

4.3. Interaction analysis

The interaction analysis results indicated that the gender factor of the joint moment factor is greater for females than males. The holding duration factor is smaller for females than males. Moreover, the reaching frequency factor is different for males and females, with higher discomfort for females and lower discomfort for males. The shoulder discomfort rating of females is greater than that of males. The results of the regression analysis also indicate that the gender factor is significant for females, but it is not significant for males. Thus, the regression analysis results demonstrate that gender differences affect the discomfort level of the shoulder joint.
4.2. Effect of shoulder flexion

Several studies reported an increase in discomfort rating caused by increased upper arm elevation (Kee, 2005; Wiker et al., 1989). These results are due to the growth of intramuscular pressure and decreased blood flow in upper limb muscles with arm elevation. Restricted muscle blood flow impairs muscle metabolisms, with increased metabolite accumulation, hence causing local muscle fatigue. Moreover, a greater intramuscular pressure induces higher muscle discomfort (Jaervholm et al., 1991).

Extreme joint angle with greater exertion (holding weight) can cause higher biomechanical loads in shoulder joint. Table 5 shows that the joint moment in shoulder flexion 60° and 120° is equal to or smaller than the joint moment in shoulder flexion 90°, but shoulder discomfort rating in shoulder flexion 120° is greater than that of others. A simple biomechanical analysis may underestimate posture effect when shoulder flexion is greater than 90°. Thus, it would be better to use multiple ergonomics approaches including biomechanical analysis and other analyses such as EMG to evaluate posture effect on discomfort rating when shoulder flexion is greater than 90°.

### Table 5
Shoulder joint moment and shoulder discomfort rating between different flexion angle, holding weight and gender.

<table>
<thead>
<tr>
<th>Shoulder flexion</th>
<th>Holding weight (Kg)</th>
<th>JM</th>
<th>SD</th>
<th>JM</th>
<th>SD</th>
<th>JM</th>
<th>SD</th>
<th>JM</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°</td>
<td>0.86</td>
<td>11.00</td>
<td>0.23</td>
<td>11.40</td>
<td>0.55</td>
<td>11.59</td>
<td>0.85</td>
<td>13.17</td>
<td>1.17</td>
</tr>
<tr>
<td>90°</td>
<td>1.12</td>
<td>15.81</td>
<td>0.65</td>
<td>16.49</td>
<td>0.50</td>
<td>18.27</td>
<td>1.08</td>
<td>20.71</td>
<td>1.20</td>
</tr>
<tr>
<td>120°</td>
<td>0.86</td>
<td>14.28</td>
<td>0.08</td>
<td>15.81</td>
<td>0.50</td>
<td>16.49</td>
<td>0.50</td>
<td>18.27</td>
<td>1.08</td>
</tr>
</tbody>
</table>

JM, Shoulder joint moment (Nt-m); SD, Shoulder discomfort rating (BPD scale).

4.3. Effect of holding duration and reaching frequency

Results of this study find that not only shoulder flexion, holding weight, and reaching frequency factors show significant effect on discomfort ratings ($p < 0.001$), but also the holding duration factor. Increased holding duration causes increased sustained loading, resulting in disturbance of potassium homeostasis on upper limb muscles, leading to arm fatigue (Sjogaard et al., 1988). In the current experiment, shown in Fig. 4, the task with lower frequency loading (2 x 10 s, i.e. 10 s holding and 20 s rest, and repeated two times in a one min cycle) produces less discomfort than the higher frequency loading task (4 x 5 s, i.e. 5 s holding and 10 s rest, and repeated four times in a one min cycle). Even loading is the same, the discomfort feeling reduces with a longer rest time.

In summary, the study’s main contribution is to develop nine regression models based on task factors for predicting the discomfort in whole body, shoulder and upper arm areas. The models explained at least two-third of the variations. Moreover, the study finds shoulder flexion angle is the most important factor affecting whole body discomfort for all participants; arm reaching frequency is the second dominant factor for affecting female
participants’ whole body discomfort. Holding weight is the second dominant factor affecting male participants' whole body discomfort.

On the other hand, this experiment design involves four independent variables. To reduce experiment time and cost, three of the four variables only have two levels, and the fourth one has three levels. The application of the study results would be limited between these experimental levels. Therefore, future studies could include more levels in each variable for more detailed evaluations.

5. Conclusions

Conclusions from this study are as follows:

(1) Shoulder flexion, holding weight, reaching frequency and holding duration affect discomfort rating. This experiment elevates muscular effort of the upper limb to support greater shoulder flexion and heavier weight, causing greater discomfort. Higher arm reaching frequency and longer holding duration causes disturbance of potassium homeostasis on upper limb muscles and increases discomfort accumulation.

(2) Females’ subjective discomfort ratings are significantly greater than males under the same task condition.

(3) The shoulder flexion, holding weight, holding duration and reaching frequency are the significant factors involved in whole body discomfort, and shoulder and upper arm discomfort regression models. Shoulder flexion is the most important factor affecting whole body discomfort for all participants, after which reaching frequency is the dominant factor for female participants' whole body discomfort. Holding weight is the dominant factor for males' whole body discomfort. These results can be used as task design guidelines to reduce the incidence of work-related musculoskeletal discomforts and disorders.

References


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