Chapter 3

Experiment 2: Effects of upperarm abduction combined with elbow flexion on discomfort for repetitive isometric gripping
3 Effects of upperarm abduction combined with elbow flexion on discomfort for repetitive isometric gripping

3.1 Problem formulation

The repetitive uses of the arm above the horizontal level is very common in jobs like carpentry, assembly line tasks and also in sports as swimming and tennis or those involving throwing and pitching, they causes fatigue and have a high incidence of injuries, as impingement of ligaments or tendons at the shoulder level. Ciriello et al. (2002) reported that clockwise and counter clockwise screw driving task with ulnar deviation have maximum acceptable torques ranging from 0.33 to 0.65 Nm without arm abduction or torque exertion. In all these investigations it was evident that discomfort and fatigue of different body parts were important indicators of stress and are responsible for rated musculoskeletal disorders in the long run. Therefore, it was noticed that postural combination of shoulder, upperarm, and forearm, are important in task design to reduce risk of WMSDs. Several studies have been reported in this regards (NIOSH, 1997).

There is still a big need to ascertain the effects of posture and repetition on the origins of upper limb WMSDs. Straker et al. (1997) reported that the performance was poor and discomfort and fatigue were significantly greater at 30° upper arm flexion compared to 0°. Similarly, Kilborn and Persson (1987) conducted laboratory experiment and reported that abduction of upper arm to more than 30° led to upper arm WMSDs. Herberts et al. (1980) found that the combination of elbow flexion and upper arm abduction increased the localised muscle fatigue as abduction increased from 45° to 90°. Kattel et al. (1996) reported that the maximum grip strength occurred with upper arm at 0° abduction, elbow flexion at 135° and wrist at neutral. Coury et al. (1998) studied the shoulder adduction strength in various body postures and reported the discomfort, pain and reduction in grip strength at different postures of elbow and shoulder flexion, but they did not considered the upper arm abduction effects.

Using intermittent torque exertion in their study, O’Sullivan and Gallway (2005) reported that discomfort for pronation torques were considerably higher than supination torque, and for both supination and pronation torques there was a significant forearm rotation effect that resulted in increasing discomfort for non-neutral forearm rotations. However their study did not include the effect of upper arm abduction. Mukhopadhyay et al. (2003) used intermittent torque along with grip force, and reported an increase in discomfort with an increase in upper
arm abduction angle from $0^\circ$ to $90^\circ$, while the elbow angle was fixed at $90^\circ$ abduction. Factors such as postural angle of shoulder and the magnitude of applied load showed the influence on the relative activation of shoulder muscles (de Groot et al., 2004; MacDonell and Keir, 2005). Au and Keir (2007) had reported that hand gripping increased the activity of some shoulder muscles and decreased the activity of others. In order to know the effects of upper limb deviation and to prevent upper limb injuries associated with deviated upper arm, it was necessary to further investigation compared to the previous studies (Carey & Gallway, 2005; Mukhopadhyay et al., 2007a; O’Sullivan & Gallwey, 2005 and Khan et al. 2009a), so that the posture causing more pain, strain and more discomfort should be avoided in jobs of repetitive nature in industrial tasks.

Based on the above literatures, it was, however, found that there is a lack of investigations about the combination of upper arm abduction with forearm rotation and elbow flexion angles and frequency of exertions in gripping task. Therefore the experiment-2 was designed to investigate the effect of upper limb posture on discomfort for repetitive isometric gripping.

3.2 Method

3.2.1 Participants

In this experiment a total number of eighteen right-handed male college students volunteered. The participants were of mean age $\mu = 22.9$ year ($\sigma = 4.5$ years) height $\mu = 168.2$ cm ($\sigma = 4.3$ cm) and Mass $\mu = 64.8$ kg ($\sigma = 5.2$ kg). They were called by departmental notices, and emails. The prior approval was taken from the ethics committee of the department to conduct the experimental investigations.

3.2.2 Experimental Design

Three (Upper Arm Abduction angle) x Three (Elbow Flexion angle) custom design was used for the repeated measures Analysis of Variances (ANOVA). The perceived discomfort score on 100 mm Visual Analogue Scale (VAS) was recorded as dependent variable. The equation of the model used in ANOVA, was as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \epsilon_{ijk}$$

Where, $\epsilon_{ijk}$ is the deviation of the observed value $Y_{ijk}$ from the population mean $\mu_{ijk} (\mu + \alpha_i + \beta_j + \alpha\beta_{ij})$.
\( \alpha_i \) and \( \beta_j \) are main effects, and,
\[ \alpha\beta_{ij} \] is the two-way interaction of Upper arm abduction with Elbow flexion.

### 3.2.3 Postures

In the present study the three levels of upper arm abduction angle \((0^\circ, 45^\circ, \text{and } 90^\circ)\) with three levels of elbow flexion angle \((45^\circ, 90^\circ, \text{and } 135^\circ)\) were taken based on the previous studies (Kattel et al., 1996; O’Sullivan and Gallwey, 2002; Mukhopadhyay et al., 2007a) to investigate the effect of posture on discomfort score for a repetitive torquing task. Kattel et al. (1996) investigated the effect of upper arm abduction \((0^\circ)\), and elbow flexion \((90^\circ, 135^\circ \& 180^\circ)\) on grip strength. O’Sullivan and Gallwey (2002) took up upper arm abduction \((0^\circ)\) elbow flexion \((0^\circ, 45^\circ, 90^\circ \text{and } 135^\circ)\) and fore arm rotation (75% prone, neutral and 75% supine) to find the effect on discomfort for repetitive torquing task. The postural angles used in this experiment-2 are shown in Figure 10.

![Figure 10 Postural angles used in Experiment - 2](image)

### 3.2.4 Apparatus

For the experiment a chair was used to attach experimental rig. This rig was designed according to the requirement of the Experiments -1 & 2 and which was comprised of five main components (as Numbers for each of the adjustments marked in Figure 11). The
adjustments for shoulder abduction angle and elbow flexion angles were provided in the rig. There, a support was also provided at the end of the rig, to keep grip meter in line with the wrist with respect to the forearm rotation.

**Figure 11 Experimental Setup**

1) the vertical adjustment to bring the rig level to underneath the shoulder.
2) the rotary adjustment for the upper arm abduction support.
3) the rotary adjustment for elbow flexion angle.
4) provided to keep the angular control of the forearm rotation.

**3.2.5 Task**

A task of 150N grip force, at the frequency of fifteen exertions per minutes (15/minute) was given to each participant for Five minutes duration. This was in line with the repetitive tasks chosen for experimental simulations in previous researches (Lin et al., 1997; Mukhopadhyay et al., 2007a; Carey and Gallwey, 2002; Khan et al., 2009a). The main difference from these above mentioned studies were of the type of force in this task, in this experiment gripping tasks was the main aim for investigation. There were nine experimental conditions for each
subject. The conditions were completely randomised in unique order for each subject (Appendix -4).

3.2.6 Preliminary Data Collection

The participants were briefed about the experiment, and then experiment started to investigate the effect of upper arm abduction and elbow flexion on discomfort for the repetitive gripping task. Participants were asked to fill the consent form and their demographic data were recorded. Participants were accustomed with the discomfort scale by performing a trial run before the actual start of the experiment for all predefined treatments.

3.2.7 Procedure

The participants were asked to sit on a fully adjustable chair at which the rig was integrated. The adjustments were made for each treatment as per the random order of respective participants. For that the upper arm abduction angle, and elbow flexion angle was fixed with the required other adjustments as per the Participant anthropometry. Then, participant was asked to squeeze the grip meter to a grip force level of 150N for a second in 4 second cycle shown in the Clock (Figure 12) for five minutes duration for each treatment. A ‘beep’ signal and the blinking of green light underneath the clock were programmed in the LABVIEW8.6 code (Appendix -5). The whole experiment was controlled by the screen shot of the LABVIEW code (Figure 11). Once the five minute exercise was over Participant was asked to stop repetitive exertions and requested to fill in the perceived discomfort level of hand arm system in the Visual Analogue Scale (VAS) shown in the Screen shot (Figure 12). A VAS was labelled with three important marks as ‘no discomfort’, ‘moderate discomfort’ and ‘extreme discomfort’. A rest of at least 2 minutes or till the participant felt no discomfort, was given between each task for the respective treatment (Carey and Gallwey, 2002; Khan et al., 2009a).
3.2.8 EMG recordings

To support the levels of discomfort recorded VAS, a supplementary part of this experiment was designed to see the development of fatigue in Extensor Carpi Radialis Brevis (ECRB) and Flexor Carpi Radialis (FCR) muscles for three levels of elbow flexion angles ($45^0$, $90^0$ and $135^0$) for no deviation in wrist without abduction of upperarm. The selections of the muscles were in line with the study of Khan et al. (2009a). The datalink of M/s Biometrics ltd (UK) was used to record the data of Electrical activity of the muscle. The same rig, as described above, was used to obtain the postural angle of elbow joint. To EMG preamplifier (SX230 EMG sensor) was interfaced using DATAlink of M/s Biometrics Ltd. (data acquisition system), that was able to record at 1024 samples per second. The EMG activity was recorded for 30 seconds every time: at the beginning of the repetitive exercise, then after 2 minutes and at the end after 4.5 minutes. This part of the experiment was performed for four subjects to record ECRB data and three subjects for FCR data, the number of subjects...
were small due to difficulty in convincing for the skin preparations for surface EMG. The consent was taken prior to the observations from each participant.

3.2.9 EMG data Analyses

The EMG signal was analysed using Fast Fourier Transformation using the DataLink software (M/S Biometrics Ltd. UK) that was used for the recording the electrical activity of muscles. Initially obtained raw EMG signal for each of the three sets of 30 seconds durations. These data were further transformed to Root Mean Square values (RMS) by doing the averages at every set of 256 samples collected and the spectrums were plotted.

3.2.10 Statistical analysis

The data of VAS and EMG recordings were analysed using the repeated measures Analysis of Variances (ANOVA) and then Post hoc tests (SNK test) were applied to see the significant difference in the effects of the levels of each variable on the dependent variables. Later on, the graphical analysis using profile plots was carried out to further investigate the effects of postures on discomfort for repetitive gripping task of the present study. The details of the analyses were presented in the next section. All statistical analyses were performed using SPSS.

3.3 Results

3.3.1 Discomfort Score

The data of raw discomfort score (Appendix -6) were found to be normally distributed, hence satisfied the assumption to implement ANOVA on the data. The summary of the data is presented in Figure 13 as bubble plots with standard deviations.

The results of repeated measures ANOVA for the effects of main factors and their interactions on dependent variable (i.e. discomfort score) are presented in Table 5. The results showed that the effects of Elbow flexion angle was highly significant (<0.001 respectively). The effect of upper arm abduction was not found significant. The two way interaction was also not significant on discomfort score.
Figure 13 Bubble plots of the mean Raw Discomfort Score for three levels of elbow flexion at different levels of upper arm abduction.

Table 5 The results of the ANOVA performed on Raw Discomfort Score

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>degrees of freedom</th>
<th>Mean Square</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow Flexion angle (EFA)</td>
<td>68.3</td>
<td>2</td>
<td>34.2</td>
<td>10.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Upperarm Abduction angle (UAA)</td>
<td>3.5</td>
<td>2</td>
<td>1.7</td>
<td>0.5</td>
<td>0.604</td>
</tr>
<tr>
<td>EFA * UAA</td>
<td>9.4</td>
<td>4</td>
<td>2.3</td>
<td>0.7</td>
<td>0.606</td>
</tr>
<tr>
<td>Error</td>
<td>736.3</td>
<td>153</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>817.4</td>
<td>161</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Post Hoc Test:** To differentiate the levels of elbow flexion angles, the Student-Newman Keuls test was performed on the data of discomfort score. There was no significant difference
between discomfort levels at elbow flexion angles of $90^\circ$ and $135^\circ$, but at $45^\circ$ discomfort was found significantly different from both of the other levels of elbow flexion angle.

**Profile plots:** The graphical Analysis (based on box plots) of the Elbow flexion angle vs. the raw discomfort score; upper arm abduction vs. discomfort score for repetitive gripping task are shown in Figures 14 and 15. From Figure 14, it was observed that the discomfort was maximum when elbow was flexed at an angle of $45^\circ$ and then it reduced towards $90^\circ$ and $135^\circ$ and minimum discomfort was found at $135^\circ$ elbow flexion angle. Figure 15 showed that the discomfort was maximum when the upper arm abducted at $45^\circ$. It was noticed that there was almost no difference in discomfort between elbow angles of $90^\circ$ and $135^\circ$, but at $45^\circ$ it was significantly different from both the others.

![Figure 14](image_url)  
**Figure 14**  Discomfort score vs. Elbow flexion angle for repetitive gripping task
3.3.2 EMG activity

The sample graph of the raw data of EMG activity, were presented in Figures 16. The EMG data were analysed using Power spectral density analysis using Triangle and Bartlett method to evaluate the median frequency of the EMG signal for during the first and the last exertion of the five minute cycle of each level of elbow flexion angle (45°, 90° and 135°). The summary of the data was presented in Table 6. The data showed that there was no effect of elbow flexion angle for repetitive gripping task on the electrical activity of ECRB muscle. There were differences in the starting Median Frequency of EMG signal of FCR muscle compared to the ending Median Frequency of the same signal (i.e. low compared to the earlier one). One more thing was found that the reduction in the mean Median Frequency was more for 45° elbow flexion angle, but the comparatively less difference was noticed for the 90° and 135° elbow flexion angles.
Figure 16  The raw EMG signal of FCR muscle of Participant-1 for the first 30 seconds during the repetitive task of 150 N at 15 exertions per minute for the experimental cycle of five minutes duration.

Table 6  The summary of the Electromyographic activity of ECRB and FCR muscles for the repetitive gripping task of 150 N at the frequency of 15 exertions per minute

<table>
<thead>
<tr>
<th>Elbow flexion Angle (degrees)</th>
<th>%MVC</th>
<th>Median Frequency of first exertion (Hz)</th>
<th>Median Frequency of last exertion (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>7.1±5.5</td>
<td>105±18.7</td>
<td>107±13.8</td>
</tr>
<tr>
<td>90°</td>
<td>5.6±1.4</td>
<td>114±22.1</td>
<td>104±14.4</td>
</tr>
<tr>
<td>135°</td>
<td>6.4±2.4</td>
<td>101±12.2</td>
<td>99±6.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical activity of FCR muscle for three participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexion Angle (degrees)</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>45°</td>
</tr>
<tr>
<td>90°</td>
</tr>
<tr>
<td>135°</td>
</tr>
</tbody>
</table>

- %MVC: percentage of Maximum Voluntary Contraction, ECRB: extensor carpi radialis brevis, FCR: flexor carpi radialis
- All data are indicated as μ±σ
3.3.3 Normalisation of EMG data

Further data of the EMG of both muscles were normalised using the following formula to get percentage of Maximum Voluntary Contraction (%MVC) of the electrical activity of muscle:

\[
%\text{MVC} = \frac{(\text{RMS EMG} - \text{RMS EMGmin})}{(\text{RMS EMGmax} - \text{RMS EMGmin})} \times 100
\]
as presented in Table 6. ANOVA was also performed on these data but there were no significant effect of elbow flexion angle was found. However the mean values of %MVC showed that there were comparatively more efforts required to do the task at 45° elbow flexion compared to 90° and 135° elbow flexion as the %MVC was found more 45° elbow flexion for both muscles.

3.4 Discussion

3.4.1 Elbow flexion

From the results of Experiment -2, it was observed that discomfort score was not significant at the elbow flexion of 90° and 135°, but when the elbow flexed at 45° there was a significant change in discomfort score, this is in line with Mukhapadhyay et al. (2007a) that, with the upper arm abduction of 90° and elbow flexion of 135° and 90°, there was no effect of elbow flexion. An earlier experiment was done by Mukhopadhyay et al. (2003) and showed that the increase of discomfort with change of abduction from 0° to 90° was not very high, which is also supported by Herberts et al. (1980). Discomfort in general was maximum at 45° elbow angle compared to 90° and 135° indicating extreme conditions for operators having work at such postures. This was further validated using the supplementary experiment in that electrical activity of FCR muscle showed that there was steep fall in the median frequency for 45° elbow flexion compared to minimal reduction noticed for 90° and 135° elbow flexion angles as per Table 6. Studies (Farina and Merletti, 2000; Hägg et al. 2000) have found that the change in muscle fatigue is indicated by the reduced median frequency of the EMG signal. However, there are several issues as address by Hägg et al. (2000) such as, rise in EMG amplitude may be indicate of muscle fatigue of the change in applied force. Therefore, it was an indication of muscle fatigue if RMS EMG rises or median frequency decrease with time in the EMG signal. Although that may not be only indication of the muscle fatigue, only it could be correlated or predicted the significance of EMG signal analyses in accordance with the discomfort score.
During the course of experiment, many of the participants complained about the higher perceived discomfort in the whole arm at 45° elbow angle compared to 90° or 135°. Dempster (1964) reported that the movement of the humerus bone reaches its maximum with the elbow pointed backward, upward and outward at 45°. Possibly this extreme was reached in this experiment at this particular angle. It has been reported that after this angle the shoulder sinus limits the motion of the joint structure, which might partly explain increased discomfort at 45° elbow angle compared to 90° and 135° elbow angle. Salter and Darcus (1952) reported that when the elbow was flexed at 30° there was a fall in pronation torque, this might be due to the fact that elbow flexed at such a low angle might shorten the length of the muscles pronator teres (PT) and pronator quadrates (PQ). Thus, the participant had to apply more force at 45° elbow angle, thus causing more discomfort. Such relationship between discomfort and strength has been reported by Coury et al (1998). The increase in discomfort score at different postures, especially at extreme postures of 45° elbow flexion angle with upper arm abduction at 90°, the exertion was maximum. It has been observed from this experiment that in industrial task such postures should be avoided for the betterment of workers as well as for the work place.

3.4.2 Upper arm abduction

Upper arm abduction was not significant on discomfort for repetitive gripping task of the present experiment. However, few studies have reported that abduction was found significant for repetitive torquing task (Mukhpadhyay et al., 2007a &b). Roman-Liu (2003) also stated that the experimental conditions make difference in the strength of subjects differentiated by factors such as cross-section area of the arm, body mass, occupation. The difference may be because the task was completely different as in this experiment it was repetitive gripping of 150 Newton at 15 exertions per minute. It was well known that different muscle groups are activated in torquing task (O’Sullivan & Gallwey, 2002) as compared to gripping task (Mogk and Keir, 2003). O’Sullivan and Gallwey (2002) observed the effect on muscle loading of pronator teres (PT), pronator quadratus (PQ), biceps brachi (BB), brachioradialis (BR), mid deltoid (DT) and the extensor carpi radialis brevis (ECRB) during maximum torque exertions. Although Mogk and Keir (2003) reported the electrical activities of flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), flexor digitorum superficialis (FDS), extensor carpi radialis (ECR) extensor carpi ulnaris (ECU), and extensor digitorum communis (EDC) for gripping task. Also, Finsen et al. (1998) revealed that no significant difference in elbow
angle was found between the highly abducted (median 122° range 106°-130°) and moderately abducted (median 109° range 105°-120°) posture. There was a significantly higher shoulder abduction moment in the highly abducted posture compared with the moderately abducted. Regarding the parallel to the humerus, the mean outward upper arm twisting moment of the humerus in the glenoid cavity was significantly higher (100%) in the highly abducted posture.

Table 7. Ranges of raw discomfort score recorded for different types of repetitive tasks in experimental investigations.

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of exertion</th>
<th>Raw discomfort score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mukhopadhyay et al.,</td>
<td>Torque of 20% MVC Torque at frequency of 10-20 per minute for 5-minutes duration</td>
<td>(\mu 1.0(\sigma 0.9) - \mu 5(\sigma 2.4))</td>
</tr>
<tr>
<td>(2007a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lin et al. (1997)</td>
<td>Two level of forces 15 &amp;45N at two pace 20 &amp; 4 motions per minute for 1hr duration</td>
<td>(\mu 1.0 - \mu 6.8)</td>
</tr>
<tr>
<td>Mukhopadhyay et al.</td>
<td>Torque 6.4Nm at a frequency of 15times per min for 5 minutes duration</td>
<td>(\mu 1.0(\sigma 1.4) - \mu 5.0(\sigma 2.3))</td>
</tr>
<tr>
<td>(2007b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carey et al., (2002)</td>
<td>ROM 45° and a frequency of 10 or 20 exertions per min. And the level of exertions 10%-20% of MVC.</td>
<td>(\mu 1.5 - \mu 5.0)</td>
</tr>
<tr>
<td>Carey et al.,(2005)</td>
<td>Force of 10N at frequency of 15times per min. For Five minutes duration</td>
<td>(\mu 1.58(\sigma 0.78) - \mu 3.32(\sigma 2.26))</td>
</tr>
<tr>
<td>Khan et al.,(2003)</td>
<td>Grip force at 10 N at 10 &amp; 20 exertions/minute</td>
<td>approx. (\mu 2.0) to (\mu 5.8)</td>
</tr>
<tr>
<td>Khan et al., (2009a)</td>
<td>Wrist flexion force of 10 N at frequency of 15 exertions per minute</td>
<td>(\mu 2.09(\sigma 1.11)) to (\mu 4.46(\sigma 1.90))</td>
</tr>
<tr>
<td>Khan et al., (2009b)</td>
<td>Wrist flexion of 10 and 20% MVC wrist flexion at frequency of 15 exertions/minute</td>
<td>(\mu 1.13(\sigma 0.82)) to (\mu 6.53(\sigma 2.70))</td>
</tr>
</tbody>
</table>

3.4.3 Range of perceived discomfort

The important point seen in the results of present study was the range of the mean discomfort score compared to previous researchers (Carey and Gallwey, 2002, 2005; O’Sullivan and Gallwey, 2002; Khan et al., 2003; Mukhopadhyay et al., 2007a, 2007b; Khan et al., 2009a, 2009b). They used different types of exertions (e.g. flexion force, torque, and grip force) for
evaluating the effect of posture on discomfort for repetitive tasks. The mean Raw Discomfort Score (RDS) recorded in this experiment was ranged from 3.46 (sd 1.87) to 5.69 (sd 2.45) for repetitive gripping task of 150 Newtons at 15 exertions/minute for Five minutes duration. Although, previous researches have shown the similar trend but the levels of force/type of force/frequency of exertions were different. However the time duration for the given experimental task was same. The summary of the previous researches are given in Table 7.

3.5 Conclusions

There was significant effect of elbow flexion angle on discomfort for repetitive gripping task. However, there was not significant difference in discomfort for the similar task for 90° compared with 135° flexion of elbow joint (p>0.05). The repetitive gripping at 150N was giving the approximately similar range of the perceived discomfort compared to the repetitive flexion task of 10N.