Effects of upper arm articulations on shoulder-arm discomfort profile in a pronation task

Running title: Upper arm articulations affecting shoulder arm discomfort

Prabir Mukhopadhyay#

Leonard W.' O Sullivan*+

T.J.Gallwey*

Post Graduate Campus, National Institute of Design,GH-0 Extension Road, Gandhinagar 382007, Gujarat, India.

+*Ergonomics Research Centre, Department of Manufacturing and Operations Engineering, University of Limerick, Ireland,
Corresponding author, Leonard.osullivan@ul.ie , Tel: +353 61 234 249, Fax +35361202913.

Abstract

Twenty right-handed male university students performed a full factorial experiment, consisting of three forearm rotation angles (60% prone and supine, and neutral), two elbow angles ($45^0$and 90^0), three humeral rotation angles (45^0, 90^0 and 135^0), and two upper arm angles (45^0 flexion and neutral). The task was a one-second pronation torque of 20% Maximum Voluntary Contraction (MVC) relative to MVC at the standard position of the arm, 15 times per minute for 5 minutes**,** at each postural combination. Discomfort rating after the end of each five minute exertion was recorded on a visual analogue scale. A repeated measures ANCOVA on discomfort score indicated that endurance time was a significant covariate. Other significant factors were upper arm flexion angle, forearm rotation angle, and the interactions of upper arm*elbow and humeral rotation*forearm*endurance time. A supplementary experiment showed that in some of the deviated postures combinations the subjects required additional muscle force to achieve the 20% MVC from the original testing posture. Such data can be helpful for designing workplaces and developing biomechanical models, especially for assessment of designs in virtual environments.

Key words: Humeral Rotation, Pronation, Supination, Musculoskeletal Disorders, Discomfort, Torque MVC.

1. Introduction:

Work related musculoskeletal disorders (WMSDs) are described as the wide range of inflammatory and degenerative diseases/disorders, which can result in impairment. Such conditions of pain and functional impairment may also affect besides others, the neck, shoulders, elbows, forearms, wrists and hands as per Akesson et al. [1]. In spite of numerous attempts at control, WMSDs are still on the rise [11]. The Bureau of Labour Statistics (USA) [2] reported 522, 528 total cases of WMSD in 2002. Of these 55, 119 affected the shoulder, 265, 018 affected the back and there were 60, 099 cases of injuries linked to repetitive movements. Hagberg and Wegman [10] found that materials handling, and force/torque exertion with the aid of human powered hand tools, account for approximately 45% of all industrial overexertion injuries in the United States. Yun et al. [34] reported 51.4% cases of shoulder musculoskeletal problems among VDT workers in banks in Korea. In an epidemiological investigation of WMSD according to Smith et al. [30] among nursing students in Japan, the shoulder was the most affected part (14.9 %). Similarly, among rural Australian nursing students, Smith and Leggat [29] observed prevalence rates of 23.8% for shoulder WMSDs, while Chyuan et al. [4] reported rates of 58% for WMSDs among Taiwanese hotel restaurant workers.

Different causes were put forward for such WMSDs. Putz –Anderson [24] states that it was due to an increase in service and high- tech jobs, an ageing workforce, and a reduction in worker turnover. Kilbom and Persson [13] indicated a high prevalence of shoulder and neck disorders in the electronics industry, due to repetitive, manual short cycle tasks with the arms at 60^0 to 90^0 abduction. Sjogaard et al. [28] observed tasks in the woodwork industry that involved neck flexion/rotation, and repetitive arm movements requiring static contraction forces of 5% to 10% maximum voluntary contraction (MVC), including grip force. Similarly Hagberg and Wegman [10] found awkward postures involving upper arm abduction, and repetitive movement of the forearm contributed to WMSDs among assembly line workers, shop assistants, slaughter house workers, scissor makers and data entry workers. Kilbom and Persson [13] demonstrated the relation of upper arm abduction to the onset of symptoms for WMSDs. Grieco et al. [9] reported that, along with other postural problems, pronation and supination of the forearm were related to upper extremity disorders. Coury et al. [6] observed upper arm flexion in the range of 0^0 to 90^0 in pencil packaging assembly. In a hand made brick manufacturing plant, Trevelyan and Haslam [32] indicated 45^0 medial rotation of the humerus accompanied by 45^0 abduction and 45^0 forward flexion of the upper arm. Coury et al. [6] in a Brazilian industry reported movements such as inward rotation of the humerus, and humeral forward flexion. Silverstein et al. [27] found repetitive and forceful work involving the arms and hands, and requiring pronation and supination, in a variety of industries. From the above it is evident that, in an industrial scenario, forward flexion of the upper arm along with forearm rotation and elbow flexion is common. In most instances this is accompanied by lateral/medial rotation of the humerus. Similarly, in assembly line work internal and external rotation of the humerus takes place coupled with forearm rotation and upper arm flexion as per Melin [19].

There have been quite a few studies to establish the effect of posture and repetition on the genesis of upper limb WMSDs. In an EMG study, Straker et al. [31] found that performance was poor, and discomfort and fatigue significantly greater, at 30^0 upper arm flexion compared to 0^0. Ludewig and Cook [16] reported that lateral rotation of the humerus shows great variability among subjects but, in spite of that, not many studies have included humeral rotation in their experiments. Likewise the effects of upper arm flexion on WMSDs have not been investigated extensively, particularly in combination with forearm rotation and elbow angle, despite various studies on operator discomfort. Similarly Kilbom and Persson [13] demonstrated, in a laboratory experiment, that abduction of the upper arm to more than 30^0 led to upper arm WMSDs. Grieco et al. [9] reported that upper extremity disorders were most commonly associated with pinching and deviated postures like excessive flexion, extension, and radial deviation of the wrists. Awkward elbow postures due to extreme pronation or supination of the forearm were one of the many factors contributing to such disorders, according to them. Mukhopadhyay et al. [21] reported a laboratory based discomfort study of pronation torque with various combinations of elbow angles, forearm rotation angles, force and frequency. The results indicated significant effects for forearm and elbow posture, and force and repetition. However, this study did not include the study of upper arm postures as are typical in many industrial tasks.

Kee and Karwowski [12] reported that body part discomfort is associated with biomechanical factors such as joint angles, muscle contraction, and pressure distribution that produce feelings of pain, soreness, numbness or stiffness. So the warnings provided by body discomfort can be valuable indicators of mismatches between the job and the human operator [5]. Thus, discomfort score has been used by various researchers [3, 5, 12, 22] but there are between-subjects differences in pain tolerance. O' Sullivan and Gallwey [22] and Carey and Gallwey [3] used static endurance time of specific upper arm limb strengths as covariates and the results were mixed.

In order to understand and prevent upper limb injuries associated with deviated upper arm articulations, such as those described above, it was necessary to conduct a study to extend the approach of Carey and Gallwey [3], P. Mukhopadhyay, et al. [21] and O' Sullivan and Gallwey [22] to posture combinations involving deviated upper arm, forearm and wrist postures.

2. Method

2.1. Terminology

The term pronation torque has been used in this research to denote torque exertion in the anticlockwise direction for the right hand only. The terms prone and supine are used to denote the rotational position of the forearm only.

A datum posture is referred to which was a combination of the upper arm vertical, by the subject's side and with the forearm and wrist neutral.

2.2. Subjects

Twenty right-handed male University students, with no previous history of musculoskeletal disorders participated. Their mean age was 23.5 years (SD=9.4). The mean stature was 177.7cm (SD=9.4) and body mass was 70.7 kg (SD=10.1). The subjects received a written explanation of what needed to be done. The Ethics Committee of the University of Limerick approved the experimental procedure.

2.3. Apparatus

2.3.1. Seat fixture

A steel fixture (Fig. 1) with hinge and height adjustment was fabricated in-house to maintain the upper arm flexed at different angles, and to keep the elbow flexion/extension angle and the humeral rotation angle constant for each treatment combination. The entire fixture was attached to a chair, the height of which could be adjusted to the sitting height of the subject. The fixture could be moved back and forth around a fixed point so as to support the upper arm (including the humerus, elbow and forearm) in different combinations to reduce the effects of static load.

[Insert Fig. 1]

2.3.2. Torque meter

Forearm torque was measured using a meter built in-house (Fig. 1). The meter comprised a shaft and handle (diameter 25mm) in a T-bar configuration identical to that used by O'Sullivan and Gallwey [22]. The shaft was attached to a height adjustable bench, which allowed rotation of the shaft to various forearm rotation angles as dictated by the treatments.

2.3.3. Goniometers

A Penny and Giles Biometrics electro-goniometer (model Z180) was used to record the forearm rotation angles. Voltage readings from the goniometer were amplified and zeroed using a Biometrics K100 amplifier.

2.3.4. Data acquisition (computer interface)

Signals from the goniometers were interfaced with the PC using a National Instruments data acquisition and A/D converter board (model PCI-MIO-16XE-50) with a BNC adaptor board (model BNC2090). Voltage signals from the strain gauge amplifiers were interfaced with the PC using the BNC adaptor board. Virtual Instruments (VIs) were written using G code in LabVIEW (V.6i) to control the experiment.

2.4. Design of experiment

The treatments (experimental conditions) comprised two levels of elbow angle ($45^0$and 90^0), three levels of forearm rotation angle (0, +/-60% Range of Motion), two levels of upper arm angle (45^0 flexion and neutral) and three levels of humeral rotation angle (45^0, 90^0 and 135^0) which were kept in place by the fixture. The humeral rotation angle of 90^0 corresponded to having the forearm perpendicular to the chest. The torque was constant at 20% MVC as for O' Sullivan and Gallwey [22] and frequency of exertion was constant at 15 per minute as per Carey and Gallwey [3]. The cycle was 1 second of static exertion followed by 3 seconds of relaxation. These cycles lasted for 5 minutes followed by 1 minute of rest. McKenna and Gallwey [18] reported a similar short cycle time in an electronic assembly task, and Trevelyan and Haslam [32] reported one only slightly longer while Corlett and Bishop [5] reported a similar work-rest cycle.

Modified Latin Square orders were used to determine the order of treatment combinations. But, as it took some time to adjust the fixture and in order to reduce inconvenience to the subjects, the treatments were set in blocks of the same upper arm angles. Under each block the other treatment combinations were also ordered by means of a Latin Square design.

2.5. Procedure

2.5.1. Preliminary data collection

Maximum pronation torque strength was recorded at the standard position with the wrist and forearm at neutral and the arms abducted at 0^0 as per Mogk and Kier [20], followed by a ten-minute rest break. Next endurance time at 50% MVC torque in the above position was recorded as per O'Sullivan and Gallwey [22] and Carey and Gallwey [3] as a possible covariate, to account for individual differences in pain tolerance. It was followed by a break of ten minutes to minimise any cumulative fatigue effect. Maximum range of motion of the forearm was measured with the elbow at 90^0. In all cases the subject was guided by the LabVIEW programme. When the subject exerted 50% MVC the counter turned green and any overshoot or undershoot caused a beep to warn him and the pointer also turned red.

2.5.2. Experiment

Each of the 36 treatment orders was presented to the subject using another VI (Fig. 2). This also controlled the frequency and level of exertion for each treatment during testing. After the five minutes exertion, the subject rated discomfort on a 100mm Visual Analogue Scale (VAS) using the cursor on the VI. The VAS had verbal anchors of "No Discomfort", "Moderate Discomfort" and "Extreme Discomfort" as shown in Figure 2. During the one-minute rest the subject indicated the zone of maximum discomfort on a body part discomfort map. The entire experiment lasted for about five hours with a 30 minutes break in the middle, thus mimicking more than half a shift in industry.

[Insert Fig. 2 here]

3. Results

All data were recorded in text file format on the computer hard drive during testing and imported into the statistical analysis software (SPSS: Statistical Package for Social Sciences, SPSS V.11) subsequently for analysis.

3.1. Maximum torque and endurance time

The mean pronation torque strength was 6.4 Nm (SD=1.4). The average holding time (endurance) for 50% of the maximum torque was 65.9 seconds (SD=32.0).

3.2. Discomfort Score

As in previous experiments by Carey and Gallwey [3] and O' Sullivan and Gallwey [22] the score was standardized using the min-max procedure of Gescheider [8] for each subject as follows:

$$\text{Standardised Discomfort Score (SDS)} = \frac{\text{Raw Data- Minimum Data}}{\text{Maximum Data- Minimum Data}} \times 10$$

This was to reduce between subject differences in perception of discomfort and for comparing the pattern of SDS with the data existing in the literature. But SDS was not normally distributed and could not be normalized using different types of transformation. The Raw Discomfort Scores (RDS) were also not normally distributed, but the natural logarithm transformation was successful (Levene's test, p=0.345) and this transformed data was used to perform all statistical analysis including Analysis of Covariance (ANCOVA), and is referred to as the Transformed Discomfort Score (TDS).

For comparison purpose the mean and standard deviation (SD) of RDS, SDS and TDS at different articulations are presented in Table 1. Maximum discomfort occurred at 135^0 humeral rotation, 45^0 upper arm flexion, 45^0 elbow angle with the forearm prone. The values were RDS (5.0), SDS (7.2) and TDS (0.8) respectively. Minimum discomfort was at 90^0 humeral rotation, neutral upper arm angle, 90^0 elbow angle, with the forearm at neutral. The values were RDS (1.8), SDS (1.3) and TDS (0.4) respectively.

[Insert Table 1]

Mauchly's test of sphericity [17] was performed on the TDS. Some of the factors violated the sphericity tests i.e. forearm rotation angle, forearm rotation* endurance time, humeral rotation*upper arm angle and humeral rotation*upper arm*endurance time. Hence the repeated measures ANCOVA (Table 2) was performed using the Greenhouse-Geisser Correction with torque endurance time as covariate. Endurance time was a significant covariate (p=0.01). The other significant effects were upper arm flexion angle (p=0.01), forearm rotation angle (p=0.024) and the interactions of upper arm*elbow (p=0.01), upper-arm*endurance time (p=0.05) and humeral *rotation*forearm*endurance time (p=0.01).

[Insert Table 2]

To differentiate between the levels of factors in ANCOVA, the Student Newman Keuls test was performed. Forearm rotation angles of neutral and supine were significantly different from prone. Neutral and supine forearm angles were not significantly different from one another.

3.3. Interactions

Transformed discomfort score (TDS) was plotted. Figure 3 shows a general increase in discomfort at a prone forearm compared to neutral but no real difference between neutral and supine. It also makes clear that elbow angles of 45^0 and 90^0 resulted in similar levels of discomfort. The combination of forearm rotation and upper arm angle (Figure 4) shows a similar increase of discomfort with the forearm at prone compared to neutral, and by a similar amount. Again the discomfort scores at neutral and supine are about the same. It can be seen (Figure 5) that there was little difference in discomfort with a change of humeral rotation from 45^0 to 90^0, but a notable jump from 90^0 to 135^0. Again the greater discomfort in prone is very clear and the increase is roughly the same at each angle of humeral rotation.

[Insert Figure 3]

[Insert Figure 4]

[Insert Figure 5]

3.4. Body part discomfort mapping

Total responses in each different part for all the subjects are presented in Figure 6. Forearm had the highest discomfort, followed by upper arm and elbow joint.

[Insert Fig. 6]

4. Discussion

4.1. MVC value and endurance time

The maximum value of pronation torque (7.4 Nm) was close to that recorded by Salter and Darcus [25] (7.2 Nm) but lower than the 12.4 Nm reported by Kramer et al. [14]. The endurance time had a high coefficient of variation (48.6%) which might be due to the fact that the subject profile was a mixture of physically active as well as completely sedentary individuals. Subjective exertion levels, motivation and other personal factors might also be responsible.

4.2. Humeral rotation

Although humeral rotation itself was not significant its interaction with forearm rotation and endurance time indicated that this combination is a potential risk factor in the genesis of WMSD. This finding is in agreement with that of Savva et al. [26] and is probably due to the fact that the lever arm of the muscle is decreased at this posture and so a higher muscle force is required to maintain 20% MVC, leading to more discomfort. According to Palastanga et al. [23] the glenohumeral capsule, which keeps the glenohumeral joint in position, restricts external rotation of the humerus but not internal rotation to the same extent. Hence any external rotation puts a stress on the capsule which leads to more discomfort.

4.3. Forearm rotation

As the literature contains almost no data on raw discomfort scores (RDS) it could not be compared and the standardized discomfort scores (SDS) value had to be used.

Discomfort was greater with forearm rotation on either side of neutral and the mean SDS value was greater in prone (5.5) than in supine (3.3). These values were close to those reported by O' Sullivan and Gallwey [22] of 6.9 when prone and 4.1 when supine.

The radial and ulnar bones are parallel to each other in supination according to Coury et al. [6]. When the forearm is prone there is crossing of the radial and ulnar bones. An exertion of a pronation torque, with the forearm already in prone, may lead to tendon or ligament strain, thus giving rise to more discomfort. There are many blood vessels supplying the forearm musculatures, and complete or partial blockage of some of these in the prone condition might have caused the effect. Some connective tissue strain also cannot be ruled out as indicated by Wiker et al. [33], which might have caused more discomfort at prone when compared to the supine or neutral positions.

4.4. Upper arm flexion

This involves active participation of the deltoid, clavicular head coracobrachialis, and biceps muscles. Increased activity of these muscles due to poor biomechanical advantage resulting from deviated postures might have led to more discomfort.

4.5. Elbow flexion

There was increased discomfort with the elbow flexed at 45^0. As reported by Lieber and Frieden [15] many of the behaviours of the skeletal muscles can be explained in the light of their muscle architecture. Ettema et al. [7] reported that the moment arm of the pronator teres (PT) muscle (the prime muscle in pronation) was a maximum at 95^0 elbow flexion (25mm) and gradually decreased from this as the elbow was flexed more.

At 70^0 elbow flexion the moment arm of the muscle had decreased to 21.4 mm, but no values were reported for smaller angles, by the group or others in the literature. It could be inferred from this data that at 45^0 elbow flexion, the moment arm of the PT muscle would decrease further and, with the forearm prone, the moment arm of the PT muscle becomes least (at 30^0 pronation the same group reported it to be 6.1 mm). Thus at this articulation, with the least moment arm of the prime muscle, the entire shoulder arm system is at a disadvantage and, to exert the requisite torque, it has to do more work and hence becomes more stressed, leading to more discomfort.

4.6. Endurance time

The high significance of this factor was helpful as it confirmed the initial supposition. This result contrasts with some other experiments where endurance time was not a significant covariate. In O'Sullivan and Gallwey [22] pronation torque endurance time was not significant but this may have been due to using SDS values which would in themselves have reduced the effect of individual differences. In an earlier experiment Mukhopadhyay et al. [21] used grip strength endurance time as a covariate but it was not significant. It seems that in the present case the significance is due to the fact that the endurance test mimicked the actual exertion in the experiment, and that there was no standardizing of the scores relative to the actual strength at each articulation.

4.7. Body part discomfort

That the maximum number of discomfort responses was in the forearm area was to be expected, as the forearm muscles (flexors and extensors) are very active in such tasks. This suggests that the subjective ratings were relevant to the task performed. However the high number of responses in the elbow, upper arm and shoulder area is indicative of the activity of the biceps, triceps and brachioradialis muscles in these types of postures.

4.8. Supplementary experiment

It appeared that some of the increase in discomfort at non-neutral positions could be due to reduced MVC torque at these positions. A supplementary experiment was carried out to measure pronation MVC torque at each of the articulations on eight subjects (mean age 20.8 years, SD=1.9). Table 3 presents percentages of MVC torque data and in addition RDS values (from the main experiment) relative to their mean values in the datum posture. It is notable that the biggest increase of RDS (by 172.7%) corresponded to a decrease in MVC by 51.5% and roughly similar results are evident at other postural combinations. But the pattern is mixed. For example, with respect to the standard position of the arm, the MVC increased by 12.7% at 90^0 elbow angle with the forearm supine and a humeral rotation of 90^0, but RDS increased by 3.7%. This may indicate an interaction between posture and MVC that affects discomfort but it needs more investigation.

[Insert Table 3]

5. Implications of the results

The focus of the majority of researchers so far has been on different articulations of the upper arm without much attention to humeral rotation. It is now clear that humeral rotation, coupled with other articulations in assembly line work, is a potential risk factor for upper arm WMSD. The results suggest that working with the forearm prone should be avoided, and that supine and neutral are somewhat safer. Similarly, elbow flexion of 90^0 is preferable. Furthermore, it confirms that jobs should be designed for work with the upper arm close to neutral. Humeral rotation of 135^0 (lateral) was the most stressful position and so it should be avoided in assembly line work. The results confirm that work should be designed to keep the arm close to the midline of the body and to avoid activities involving movement of the hand away from the body.

6. Relevance to industry

There is a lack of sufficient usable data on avoiding musculoskeletal disorders for the upper arm in typical industrial jobs, especially with complex postures involving humeral rotation, upper arm flexion, and elbow flexion at different forearm rotation angles. Industrial jobs involving such static postures are strongly associated with injury as operators must often perform their tasks for long duration of time. In practice the effects of non-neutral postures will be worse, since the experimental subjects had arm supports to reduce the problems due to static load. These data can be used to identify and control high-risk tasks in industry well before they develop into musculoskeletal disorders, especially at the design stage e.g. when using biomechanical models.

7. Limitations

Task duration of 5 minutes with a rest of 1 minute is typical of some industrial jobs as observed by Corlett and Bishop [5]. But the subjects performing this task were all students and their subjective rating of discomfort might be different from industrial workers. The total experiment lasted for about five hours with only half an hour break in the middle thus representing almost half a shift in industry. Hence it is arguable that the conditions that applied to this task were close to real working condition. Nevertheless the aim was merely to indicate the relative differences in discomfort between different combinations of postures, and thus these results cannot be used to estimate absolute discomfort levels. Provided that these limitations are borne in mind, the results should be useful for predicting the relative probabilities of injury at the workplace, especially in assembly line work.

8. Conclusions

Based on this investigation, the following conclusions are made:

1. Maximum standardized discomfort score (SDS) (7.1) was recorded at 135^0 lateral rotation of humerus, neutral upper arm 45^0 elbow and forearm prone and this posture should be avoided.

2. Minimum SDS (1.3) was recorded at 90^0 humeral rotation, neutral upper arm, 90^0 elbow and neutral forearm so work should be designed to implement such a posture.

3. Discomfort reports were most frequent in the forearm region indicating the role of the forearm flexors and extensors while discomfort reports in the shoulder and upper arm

indicated the increased activity of the biceps and brachioradialis in the respective articulations.

4. A task-specific endurance time test was a significant covariate and such tests should be included in future experiments of this type if standardized scores are not used.

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List of Figures

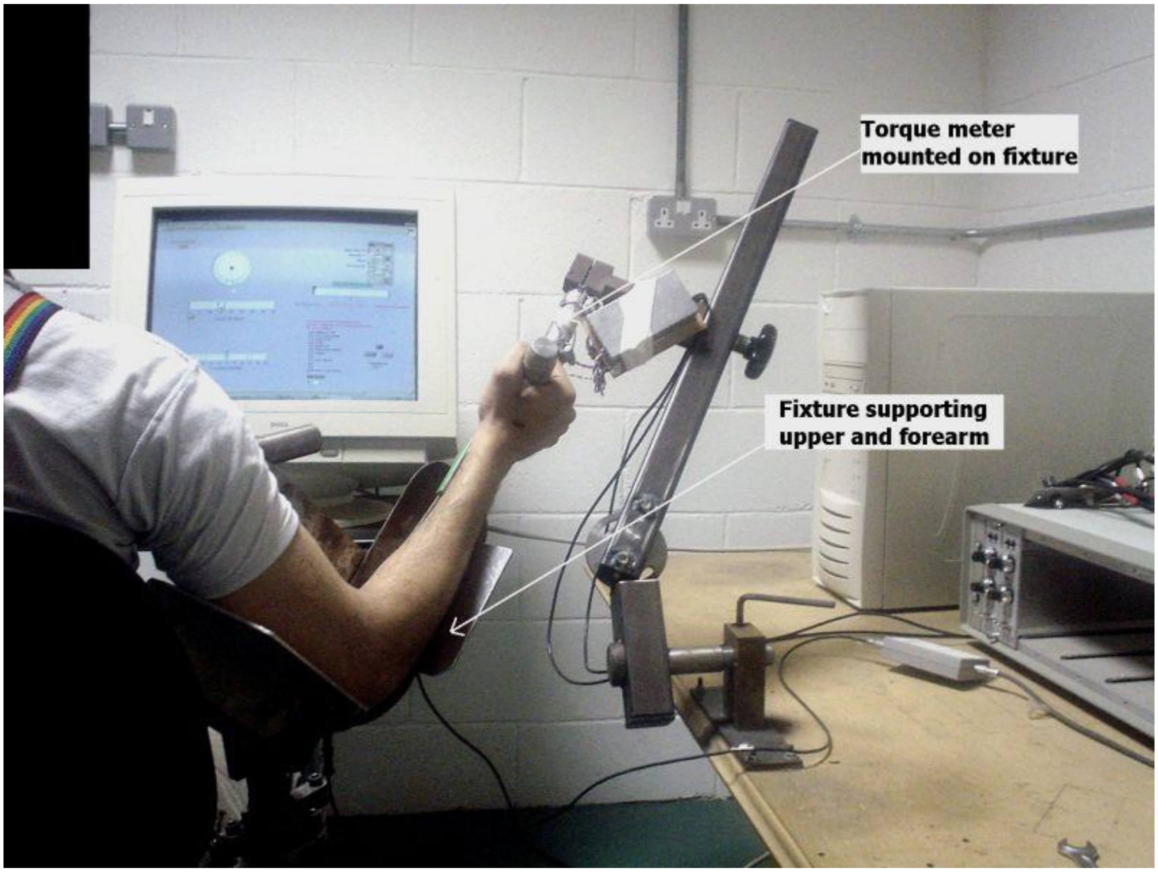

Fig. 1. Fixture for keeping the shoulder arm system in position

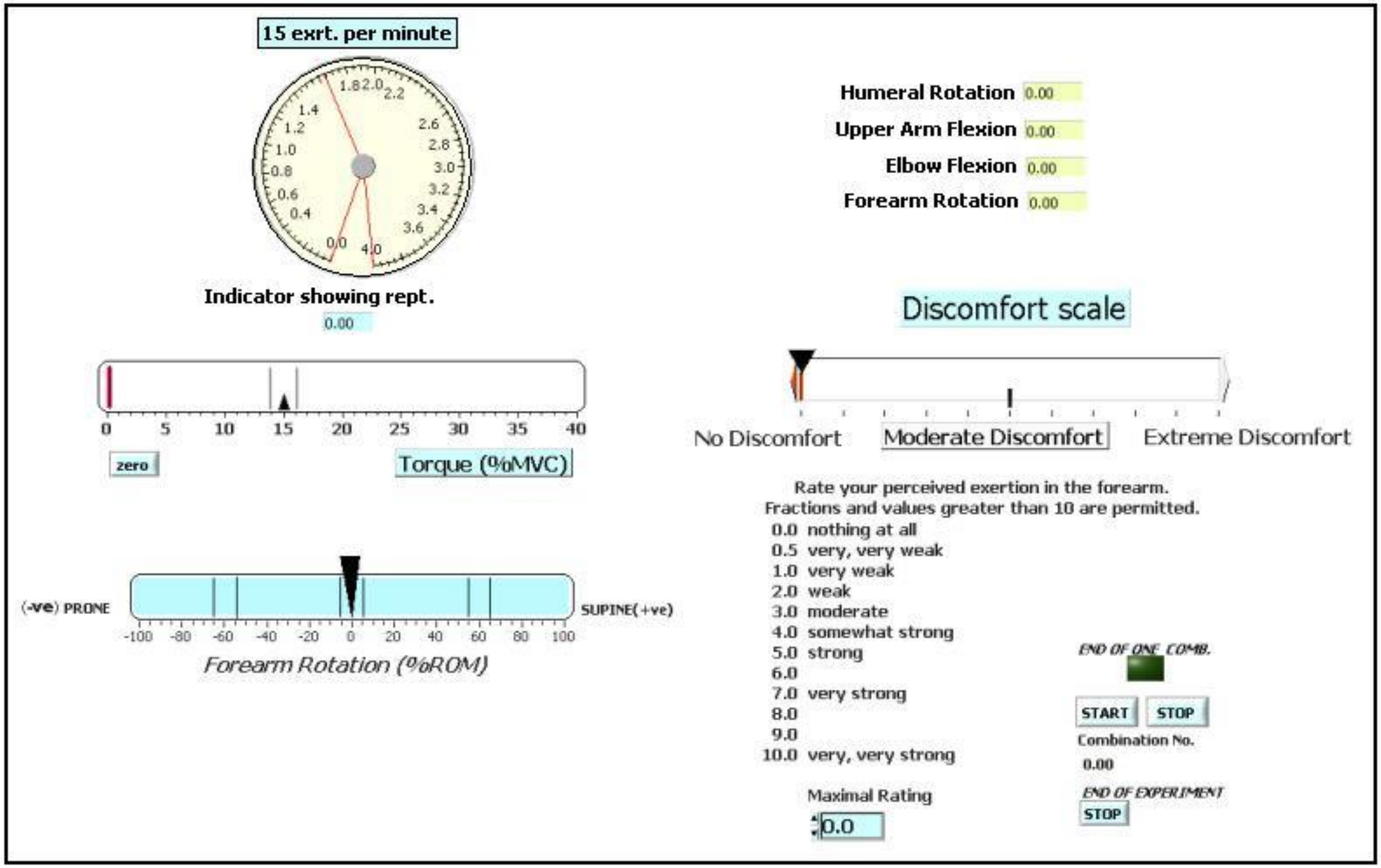

Fig.2. Screen shot of LabView VI for discomfort recording

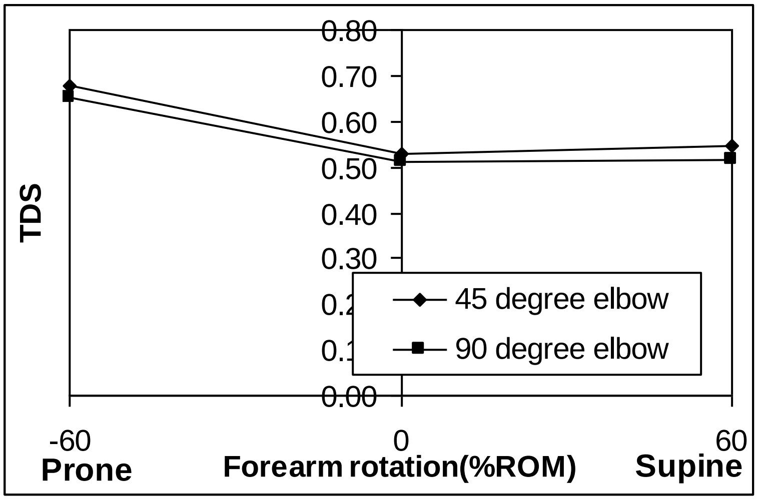

Fig.3. Transformed discomfort score (TDS) versus forearm rotation angles (%ROM) at different elbow angles

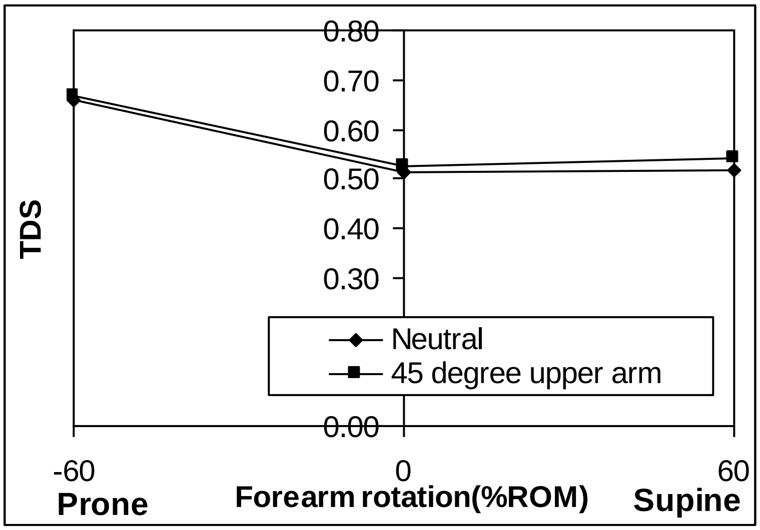

Fig.4. Transformed discomfort score (TDS) versus forearm rotation angles (% ROM) at different upper arm angles

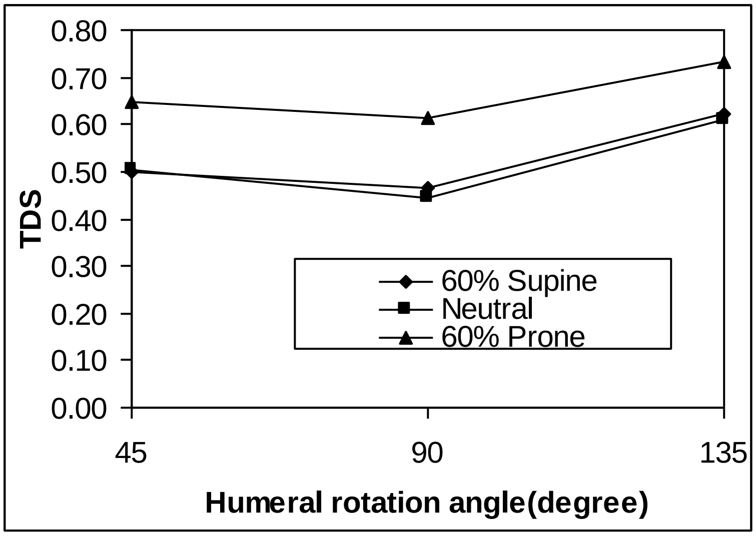

Fig. 5. Transformed discomfort score (TDS) versus humeral rotation angle at different forearm rotation angles

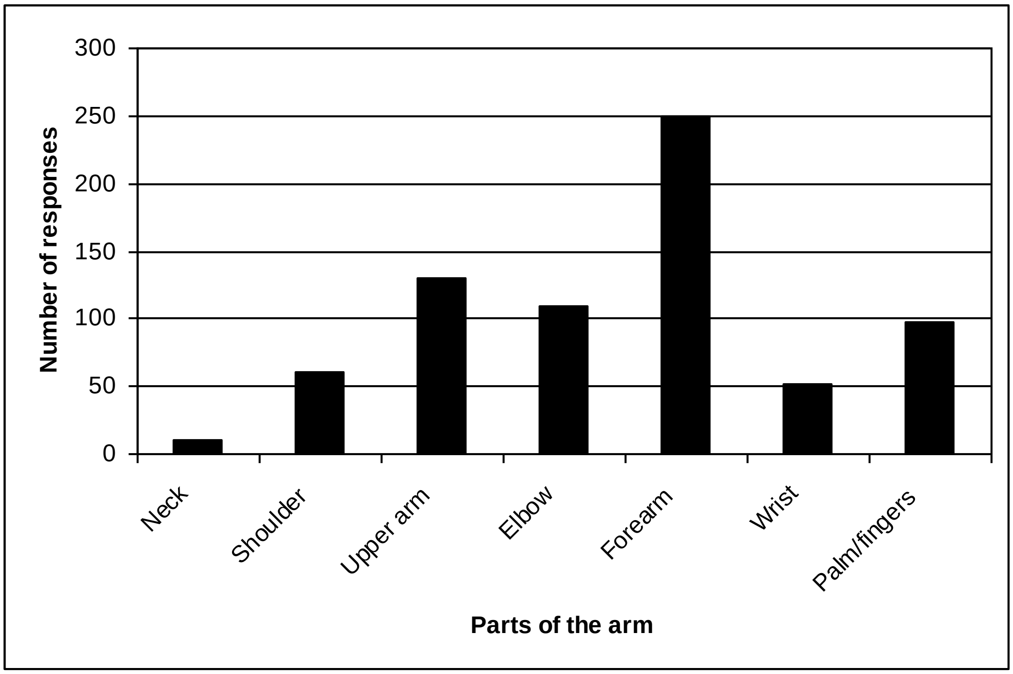

Fig.6. Discomfort profile in different parts of the arm. As there were multiple responses the total add up to more than 100.

List of Tables

Table 1 Mean values of Raw, Standardized and Transformed Discomfort Scores (RDS, SDS and TDS) at different articulations (standard deviation)

			Forearm rotation (%ROM)								
Humeral rotation angle	Upper arm angle	Elbow angle	**60 Supine**			**Neutral**			**60 Prone**		
			RDS	SDS	TDS	RDS	SDS	TDS	RDS	SDS	TDS
45^0	45^0	45^0	2.7 (1.7)	3.1 (2.3)	0.5(0.2)	2.7(1.8)	2.9 (1.8)	0.5(0.2)	4.0 (2.1)	5.5 (2.5)	0.7(0.2)
		90^0	3.0 (1.9)	3.4 (2.3)	0.6(0.2)	2.7 (1.8)	2.9 (2.0)	0.5(0.2)	4.0 (3.0)	5.0 (2.7)	0.7(0.2)
	0^0	45^0	2.6(1.9)	2.8 (2.1)	0.5(0.2)	2.6(1.8)	2.7 (1.9)	0.5(0.2)	3.8 (2.1)	4.9 (2.6)	0.6(0.2)
		90^0	3.0(1.6)	2.2(2.3)	0.4(0.2)	2.4 (1.7)	2.6(1.7)	0.5(0.2)	3.7 (2.0)	5.0 (2.7)	0.6(0.2)
90^0	45^0	45^0	2.3(1.6)	2.1 (1.8)	0.5(0.2)	2.3 (1.6)	2.4(2.0)	0.5(0.2)	3.7(2.2)	4.8 (2.8)	0.6(0.3)
		90^0	2.3(1.4)	2.4 (2.4)	0.5(0.2)	2.3(1.5)	2.4 (2.3)	0.5(0.2)	3.5(2.2)	4.2 (2.9)	0.6(0.2)
	0^0	45^0	2.5(1.5)	2.6 (1.6)	0.5(0.2)	2.1 (1.3)	2.1 (1.7)	0.5(0.2)	4.1 (2.3)	5.5(3.2)	0.7(0.2)
		90^0	1.9 (1.4)	1.7(2.3)	0.4(0.2)	1.8 (1.4)	1.3 (1.4)	0.4(0.2)	3.5 (2.3)	4.4 (3.0)	0.6(0.2)
135^0	45^0	45^0	3.5 (1.9)	4.6 (2.3)	0.6(0.2)	3.3(1.7)	4.0 (2.0)	0.6(0.2)	5.0(1.8)	7.2 (2.3)	0.8(0.2)
		90^0	3.4(1.7)	4.5(1.8)	0.6(0.2)	3.2 (1.4)	4.2 (1.4)	0.6(0.1)	4.8(1.9)	6.7 (2.2)	0.7(0.2)
	0^0	45^0	4.0(2.0)	5.4 (2.7)	0.7(0.2)	3.7(1.6)	5.0 (2.0)	0.6(0.2)	5.0 (2.3)	7.0 (2.4)	0.7(0.2)
		90^0	3.3(1.7)	4.2 (2.3)	0.6(0.2)	3.2 (1.6)	4.2(2.0)	0.6(0.2)	4.4 (2.1)	6.0 (2.6)	0.7(0.2)

Table 2 Repeated measures ANCOVA on Transformed Discomfort Scores (TDS) with Greenhouse Geisser Correction factor for factors violating sphericity

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Endurance time (ET)	7.94	1.000	7.937	15.866	0.001
Upper arm (U)	0.07	1.000	0.066	7.583	0.013
Forearm rotation (F)	0.39	1.346	0.288	4.120	0.043
U * ET	0.04	1.000	0.038	4.395	0.050
U* E	0.05	1.000	0.047	7.812	0.012
H* F * ET	0.17	4.000	0.042	3.186	0.018
Residual	20.45	648.000			
Total	41.60	719.000			

E= Elbow angle

H= Humeral rotation angle

Table 3 Maximum Voluntary Contraction (MVC) and Raw Discomfort Scores (RDS) at different articulations as % of standard position of the arm (0^0 abduction/adduction/upper arm angle, elbow angle at 90^0, forearm and wrist at neutral)

			Forearm rotation angle (%ROM)					
Humeral rotation angle	Upper arm angle	Elbow angle	**60 Supine**		**Neutral**		**60 Prone**	
			MVC	RDS	MVC	RDS	MVC	RDS
45^0	45^0	45^0	94.2	148.0	72.1	146.0	40.7	221.1
		90^0	101.7	163.1	61.9	146.5	41.3	218.7
	0^0	45^0	95.1	139.5	75.0	139.4	38.9	206.1
		90^0	108.0	113.6	84.5	131.4	53.9	202.5
90^0	45^0	45^0	99.9	123.7	77.1	125.2	48.2	199.5
		90^0	102.4	124.5	92.7	122.7	56.4	186.7
	0^0	45^0	102.7	134.0	84.8	114.6	63.8	222.8
		90^0	112.7	103.7	**100.0**	**100.0***	58.5	192.3
135^0	45^0	45^0	104.1	191.2	83.0	177.7	54.2	268.5
		90^0	110.2	182.5	81.8	174.6	48.5	255.6

	0^0	45^0		99.7	215.4			84.8	198.8
52.2	272.7								
		90^0		108.7	178.5			80.9	175.5
		52.8	239.8						

* Datum posture combination