# The influence of gender and individual differences on risks of injury due to layout in assembly work

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**Abstract:** This paper examines variation in elbow and shoulder joint angles between genders for a simulated light assembly task within normal reach at three bin distances. Joint angle ranges were estimated for 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile values pooled from males and females for each of the seventeen task elements. Large differences in risk levels were found between the 5$^{th}$ and 95$^{th}$ percentile estimates. Male elbow angles were smaller than the females, but the male shoulder angles were greater than the females, on average. These results have important implications for workplace design.

**Keywords:** RSI, Injuries, Gender, Variation, Elbow, Shoulder, Layout.

**NOMENCLATURE**

Elbow flexion: The angle of the upper limb relative to a neutral datum i.e. 90$^0$ included elbow angle

Shoulder flexion: The angle of the upper arm relative to the vertical from side view. Positive angles are forward from the vertical and vice versa.

## 1. INTRODUCTION

The human component in manufacturing, especially in assembly tasks, remains considerable. The high costs of automation, and often its inability to adapt to new products and small batch sizes, result in it being prohibitive. High injury rates for highly repetitive tasks often indicate a deficient match between what is expected of the operator and the ability of the body to cope. If the musculoskeletal system is overloaded, even by small amounts, injuries propagate over time as a result of repeated micro injuries. In time these result in chronic injury that, at a minimum, requires medical attention but sometimes requires surgery. In addition, techniques such as Predetermined Motion Time Standards (PMTS) are used in the design of workplaces that may not be suitable for both genders. The injuries that result cause absenteeism and legal claims for compensation.

The World Health Organisation [1] estimates that in 1992 such compensation costs in the EU reached 27,000 million Euro. The International Labour Office [2] reported that musculo-skeletal injuries accounted for 40% of the direct costs of work related injuries. It should be noted that the total cost of injuries can include personnel replacement, retraining, disruption, and lost production, which may result in a figure that is two to three times the compensation cost [3]. It follows that Work-related Musculo Skeletal Disorders (WMSDs), also known as Repetitive Strain Injuries (RSI) and Cumulative Trauma Disorders (CTDs), are major concerns for all manufacturers.

However, these are not the sole reasons for ergonomics interventions. For example, Eklund [4] studied an automotive company, and noted that several quality problems were due to deficiencies in the work situation, and 30% of the quality deficiencies arose from ergonomically demanding tasks. Hendrick [5], on the other hand, compiled case material that showed big financial benefits. Examples included leg protectors, tractor-trailer redesign, materials handling, CRT displays, installation of mainframe computers, and organisational issues. Benefit to cost ratios were of the order of 10 to 1, and therefore worthy of serious attention.

There are four main factors that contribute to WMSDs i.e. tasks with joint deviations from neutral, high repetition, high force, and/or insufficient rest pauses. Evaluation methods and biomechanical models are based on these factors but do not account for the predisposition of some individuals to injuries e.g. accommodating various sizes of individual. Differences in body dimensions, including limb lengths and stature, are often considerable so it is not sufficient simply to place components within normal reach, as the task may yet induce stressful joint angles. Das and Behara [6] showed a highly significant relationship between maximum reach and upper limb dimensions. Hence it follows that a standard task layout will induce different upper limb joint angles, especially at the elbow and shoulder, for individuals of different sizes. Joint angles also differ within and between genders but the extent is unknown. Hence it was decided to collect elbow and shoulder flexion joint angle data, for different layouts, for a typical assembly task.

## 2. EXPERIMENTAL METHOD

Ten right handed student volunteers, five female and five male (mean age 23.5 years) participated in the experiment. The mean stature of the females and males was 1644 and 1775 mm respectively. These values are similar to those reported by Pheasant [7] for british adults in the 19 to 25 age group ( mean female stature 1620 mm, male stature 1760 mm)

To ensure the realism of the workplace, its layout mimicked that at a local company that completed contract assembly work of small electrical components for mainly the automobile industry. The experiment involved the assembly of domestic 3-pin electrical plugs at three reach distances, so as to examine the effect of component layout on upper limb joint angle variations. Six components were positioned in bins on the table surface on an arc about the fixture of radii 300mm, 350mm and 400mm for near, mid and far reach distances respectively (Figure 1).

[Insert Figure 1 about here ]

The remaining two components, Pins 2 and 3, were placed in bins attached to the front of the table, as observed in the contract assembly company. The table surface height was set at 790 mm and the seat height at 600 mm, based on the industrial data. Subjects sat with 25mm clearance between their abdomen and the bins at the front of the table.

Each plug assembly operation consisted of seventeen elements (Figure 1). Subjects completed ten plug assemblies at each of the three bin distances, preceded by five practice assemblies at the start. To avoid problems of simultaneous tasks with naïve subjects, the task was performed with the right hand only. A strain gauge type electro-goniometer measured elbow flexion, data for the shoulder was measured from video recordings.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

### 3.1 Postural risks from pooled joint angle data

Estimates were made for 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile elbow and shoulder flexion angles for bins at the mid distance, for each element (Table 1). Risk levels were obtained using Drury's Technique [8] with ratings from 0 to 3, depending on the joint deviation from neutral, for negligible, low, moderate, and severe injury risk levels respectively.

For all but two elements, there was a minimum difference of one zone score between the 5$^{th}$ and 95$^{th}$ percentiles, and for some it was two zones, e.g. element 2 shoulder score. However for elements 3 and 9 there was no change in the risk level for shoulder flexion i.e. some task elements induced stressful postures for some individuals, but safe postures for others, not unexpected with pooled gender data.

O'Sullivan and Gallwey [9] found that shoulder angles were strongly related to stature and body mass, while elbow angles were strongly related to trunk dimensions. These explain some of the larger variation in shoulder values. As a further point, MTM is often used in work design but its standards do not differentiate between genders. Garg and Saxena [10] found that MTM over-estimated the maximum acceptable frequencies for light transfer tasks by as much as 18% compared to results from psychophysical data. These points illustrate the need for caution when designing tasks for use by both genders.

[Insert Table 1 about here]

3.2 Gender differences in joint angle data

Table 2 values indicate that male elbow angles were on average 14%, 15% and 11% less than the females for the near, mid and far conditions, whereas the male shoulder angles were on average 2%, 29% and 45% greater than the females. For each of the Place elements, the differences in elbow flexion between genders were between -18 and -25 % in most cases. Male elbow flexion for the Pick elements was less than for females except for element 1. There is little data to relate physiological and discomfort properties of the elbow to such joint angles, but changes in elbow posture can result in large changes in its moment arm and in muscle cross sectional area. When combined with nerve compression at greater elbow flexion [11], and lower strength for females, they may explain some female propensity to injury.

Bin distances affected shoulder differences more than the elbow. For most elements, the difference between genders increased with an increase in bin distance, but three of the elements are difficult to interpret (see note). The greater difference in shoulder angles for males is probably due to differences in body dimensions, and the extent of the differences (average $45^0$ for far condition) is quite large. It shows the need for adjustable workplace designs e.g. raising the table height to a suitable level for males.

3.3 Effect of bin distance on joint angles

Elbow flexion increased by almost 50% between the near and far distance for both females and males, even though the distance changed by only 100 mm. It could result in substantially greater moment arm values at the shoulder but shoulder flexion was not affected as much by the distance of the bins, rather by their configuration.

3.4 Workplace layout

These results accentuate the need for good layout and unfortunately many people who design workplaces do not have extensive knowledge of postural issues. However, very practical advice is available for a variety of situations, which should result in significant improvements [12]. More detailed explanations of the anatomy and physiology aspects permit a more in-depth understanding of the mechanisms [13]. As explained earlier such steps can result in significant improvements in quality and productivity levels.

[Insert Table 2 about here]

**5. CONCLUSIONS**

There was a large variation in the pooled joint angle data that resulted in considerable differences in the risks of WMSDs for each element. On average male elbow angles were less than for females but male shoulder angles were greater. The effect of increasing reach distance, on the differences between genders, was greater for the shoulder than the elbow such that a 100mm change in bin arc radius resulted in an increase in elbow flexion of 50%. Thus differences both between and within genders are rather significant and need to be accommodated in both the design and evaluation of workstations.

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Table 1

Drury zones* for percentile estimates for pooled male and female data at mid distance

| | | Elbow Flexion | | | Shoulder Flexion | | |
|---|---|---|---|---|---|---|---|
| **No** | **Element** | **5th** | **50th** | **95th** | **5th** | **50th** | **95th** |
| 1 | Pick base | 0 | 1 | 2 | 1 | 2 | 2 |
| 2 | Place base | 2 | 2 | 3 | 0 | 1 | 2 |
| 3 | Pick Pin 1 | 0 | 1 | 3 | 2 | 2 | 2 |
| 4 | Place Pin 1 | 2 | 3 | 3 | 1 | 1 | 2 |
| 5 | Pick Pin 2 | 2 | 3 | 3 | 0 | 0 | 1 |
| 6 | Place Pin 2 | 2 | 3 | 3 | 0 | 1 | 2 |
| 7 | Pick Pin 3 | 2 | 3 | 3 | 2 | 1 | 0 |
| 8 | Place Pin 3 | 2 | 3 | 3 | 0 | 1 | 1 |
| 9 | Pick Clip | 0 | 1 | 2 | 2 | 2 | 2 |
| 10 | Place Clip | 2 | 2 | 3 | 1 | 1 | 2 |
| 11 | Pick Fuse | 0 | 1 | 1 | 2 | 2 | 3 |
| 12 | Place Fuse | 2 | 2 | 3 | 1 | 1 | 2 |
| 13 | Pick Grip | 1 | 1 | 2 | 0 | 1 | 2 |
| 14 | Place Grip | 2 | 3 | 3 | 0 | 1 | 2 |
| 15 | Pick Cover | 1 | 1 | 2 | 1 | 2 | 2 |
| 16 | Place Cover | 2 | 2 | 3 | 1 | 1 | 2 |
| 17 | Place Plug | 2 | 2 | 3 | 1 | 0 | 0 |

* Notation for Drury posture injury risk levels [8]

Zone 0 Negligible risk

Zone 1 Low risk

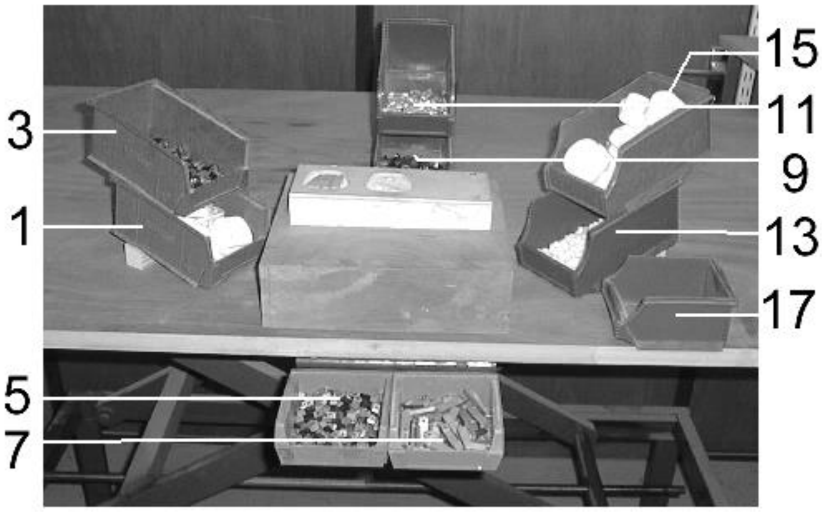
Zone 2 Moderate risk

Zone 3 Severe risk

Table 2 Percentage differences in joint angles between males and females*

| | | Elbow | | | Shoulder | | |
|---|---|---|---|---|---|---|---|
| | No. | Near | Mid | Far | Near | Mid | Far |
| 1 | Pick base | 14 | 20 | 35 | -4 | 8 | 29 |
| 2 | Place base | -18 | -18 | -14 | 11 | 24 | 65 |
| 3 | Pick Pin 1 | -3 | 7 | -1 | -6 | 9 | 28 |
| 4 | Place Pin 1 | -21 | -20 | -16 | 31 | 34 | 64 |
| 5 | Pick Pin 2 | -8 | -10 | -10 | 503** | 137** | 281** |
| 6 | Place Pin 2 | -23 | -23 | -16 | 8 | 41 | 55 |
| 7 | Pick Pin 3 | -10 | -11 | -8 | -91 | 5 | -55 |
| 8 | Place Pin 3 | -22 | -25 | -20 | 1 | 39 | 62 |
| 9 | Pick Clip | -17 | -32 | -15 | -3 | 15 | 30 |
| 10 | Place Clip | -25 | -25 | -18 | 5 | 34 | 59 |
| 11 | Pick Fuse | -5 | -9 | -15 | -7 | 4 | 23 |
| 12 | Place Fuse | -31 | -29 | -18 | 12 | 50 | 72 |
| 13 | Pick Grip | -19 | -20 | -25 | 17 | 102 | 70 |
| 14 | Place Grip | -22 | -23 | -18 | 65 | 45 | 95 |
| 15 | Pick Cover | -9 | -5 | -2 | -7 | 20 | 25 |
| 16 | Place Cover | -18 | -17 | -15 | -8 | 2 | 59 |
| 17 | Place Plug | -8 | -9 | -8 | -230** | 122** | -80** |
| | Mean | -14 | -15 | -11 | 2 | 29 | 45 |

* positive % difference indicates greater male values than females and visa versa.
** values not included in mean as % differences are not suitable due to large values




| No | Task element |
|---|---|
| 1 | Pick base |
| 2 | Place base |
| 3 | Pick Pin 1 |
| 4 | Place Pin 1 |
| 5 | Pick Pin 2 |
| 6 | Place Pin 2 |
| 7 | Pick Pin 3 |
| 8 | Place Pin 3 |
| 9 | Pick Clip |
| 10 | Place Clip |
| 11 | Pick Fuse |
| 12 | Place Fuse |
| 13 | Pick Grip |
| 14 | Place Grip |
| 15 | Pick Cover |
| 16 | Place Cover |
| 17 | Place Plug |

Figure 1 View of simulated task with Pick element numbers (near bin reach condition)

## Figure Captions

Figure 1 View of simulated task with Pick element numbers (near bin reach condition)