Abstract

Peak isometric strength was measured from 10 adult Indian construction workers in eight different field-simulated (FS) postures. This peak-strength data in these FS postures were compared with symmetric postures. In symmetric postures, the vertical load positions were kept the same as FS postures and the points of force exertion were fixed at 40 cm distance in front of the subject. From both symmetric and FS static strength data, it was shown that the maximum peak strength occurred at medium vertical height level and decreased with both increase and decrease of the vertical height level. The maximum and minimum peak strengths were obtained in different FS postures as 222.85 \( \pm \) 61.15 N and 85.65 \( \pm \) 19.89 N, respectively. It was observed that the lifted weight in the field was 12.0 kg, which corresponds to 54.54% and 137.3% (i.e., >100%) of these maximum and minimum peak-strength values. This result indicated the prevalence of high risk factors in the field. During this study, surface EMGs from four different muscles (i.e., trapezius, external oblique, rectus abdominis and erector spinae) were collected while exerting the peak isometric strength. From ANOVA analysis, it was shown that the erector spinae and trapezius activities were significantly \((p \leq 0.05)\) related to the peak-strength value, whereas external oblique and rectus abdominis activities were not. It was also observed that RMS of erector spinae activity increases with ipsilateral increase of asymmetry angle along with the decrease in maximum static peak-strength level in FS postures.

Relevance to industry

The peak static strength and EMG activities were measured in FS postures to highlight the potential risk factors in building construction industry. This study was conducted on adult female building construction workers, where the female construction workers were not well represented in the literature. Moreover, from this study, it is very clear that the actual field postures are of more complex in nature than the simulation studies, as mentioned in earlier studies.

Keywords: Static strength; MVC study; Asymmetric posture; Surface EMG; Female construction workers

1. Introduction

Since 1930, scientists have tried to identify the ‘safe’ lifting method; as in industries, the workers are generally engaged in repetitive lifting jobs in
different postures. The most common prevailing occupational health hazard related to manual load lifting operation is low-back pain (LBP) syndrome. According to Holbrook et al. (1984), in the working population, LBP injuries often arose from too much stresses and/or over-straining the muscles. This over-strain injury is mainly due to awkward movement, repetitive postures, etc. in the actual field and primarily depends on the workers’ muscular strength. Muscular strength denotes the brawn of a person; therefore, more muscular strength indicates better adaptability to the work. It varies from subject to subject depending on their physical strength, physique, sex, working habits, inhabited environmental parameters, etc. Moreover, it is generally agreed that asymmetric posture is more hazardous to the musculoskeletal system than symmetric exertions (Kumar, 1980; Snook, 1988; Kumar and Narayan, 2001). Garg and Badger (1986) studied the maximal voluntary isometric strength in three asymmetric lifting postures, and reported that this strength was reduced by 12–31%. In another report, Mital and Fard (1986) considered the effect of asymmetry in laterally placed loadings and observed a corresponding reduction in muscular strength by 8.5%. Gallagher et al. (1994) reported that with the increase in plane asymmetry demanded more recruitment of the ancillary muscles, which increased the risk of injury. Garg and Beller (1994) showed a decrease of maximum static strength by 14% and 25% occurred as a result of increase in horizontal distance 23% and 31%, respectively. According to Kumar (1995), vertical lifting distance also determined the peak isometric strength of a person. Hence, these results imply that different lifting parameters affect the physical strength output of a person.

Harder physical activity required more muscular activity (Kumar and Mital, 1996). Awkward postures and repetitive movements are identified as risk factors in work places (Winkel and Westgaard, 1992). While lifting the load, muscle generates an internal reactive moments to counteract this load effect and maintain the posture. Any kind of unwieldy posture causes gradual over-exertion to the contra-lateral muscles to maintain the body balance and that contributes as a risk factor during manual load-handling operation. Asymmetric lifting is associated with complex trunk motion (Ferguson et al., 1992; Sommerich and Marras, 1992), and is very common in industries (Marras et al., 1993, 1995). Relationship between the torsion loading due to asymmetric work posture and incidence of LBP was reported by epidemiological studies (Kelsey et al., 1984; Marras et al., 1995). Therefore, the study of trunk muscle activity is major issue in analysing the risk factor related to industrial working postures.

In India, our indigent labour groups are regularly selling themselves for a pittance, i.e. around Rs. 60–70 (i.e. 1.5 USD ($) for 8–10 h job without any quibble. In 1994, it was reported (Singh, 2000) that out of a total 68,484 industrial injuries (not included service sector and agriculture), 9283 were caused during handling different objects. It was also mentioned that the most injury prone areas are where the labours are forced to manually handle the heavy weights (~100 kg). In our country, most of the load-handling operations are executed manually, specially, in small-scale industries, like the building construction industry, garment industry, etc. These workers adopt different varieties of unwieldy postures in the working field to perform the tasks with a bare infra-structural investment. In general, these labours are employed temporarily by a labour-contractor, not as employers of organizations. As a result, industrial accidents occurred among these groups are never encountered. In a recent study (Joshi et al., 2001), it was claimed that the existing Factory Act (1946) was not sufficient to take care of the Indian workers.

Snook (1982) first identified that the activities associated with construction industries are a highly occupational risk area. Since then only few studies were conducted to highlight different adverse effects on physique of the construction workers (Wickström, 1978; Stubbs and Nicholson, 1979; Grandjean, 1983; Damlund et al., 1982; Wickström et al., 1985; Burdorf et al., 1991; Sillanpää et al., 1999; Hsiao and Stanevich, 1996; Ciriello et al., 1999; O’Reilly et al., 2000). The earlier studies reported that the risk factors in this industry were mainly related with prolonged standing, inclined postures, repetitive movements,
lifting and forceful movements, exposure of whole-body vibration, monotonous tasks, sudden maximal physical efforts, etc. (Damlund et al., 1982; Anderson, 1980; Andersson, 1981; Burdorf et al., 1991). Ultimately, these factors lead to a high prevalence of back disorder, early retirement and increased risk of injury. In another study (Riihimäki et al., 1989), authors observed that the accident related to microtraumas of the spine occurred four times more in a year among concrete reinforcement workers than the maintenance house painters. During lifting, the total strength on the lower back portion is counteracted by passive stretching of non-muscular tissues, which leads to develop microtrauma or other degenerative changes. Sparto et al. (1997) observed that in repetitive lifting task, a significant decrease in postural stability and force generation capability indicated a high risk of injury. However, the metabolic cost (oxygen uptake) is entirely dependent on the magnitude and duration of physical effort. According to the total amount of metabolic cost, this construction work is under heavy job category. Considering all the risk related to the construction industry, the work postures and muscular strain should be studied thoroughly. Unfortunately, there are no published reports available on the health hazards and general health status of Indian construction workers.

In this report, first a field study is presented on the manual handling operation in building construction area to understand field-working conditions. The aim of the field study was to obtain an overview on work complexity in actual field-working conditions. It was observed that these field postures were a complex combination of different lifting parameters. Therefore, it was decided to study on these field-working postures. A laboratory study was then conducted on field-simulated (FS) postures, as the working postures ultimately affect the lifting capability of a person. In actual field condition, these labours worked with asymmetry angle more than 90°, which was not considered in previous laboratory simulation studies. This study was conducted on adult building construction women workers, who were habituated to do this kind of heavy work regularly. The variations in peak-strength and EMG activity were studied in those FS postures and were compared with symmetric simulated postures to highlight the potential risks associated with this kind of manual handling operations.

2. Methods and materials

This study is described under two headlines: (1) field study and (2) laboratory simulation study.

(1) Field study: Field study was conducted on 11 adult building construction female workers (height, 150.7 ± 4.9 cm; weight, 47.6 ± 5.9 kg; age, 29 ± 4 years), for whole day working period. Within this total working period, they mainly performed two types of work: (1) continuous lifting operation pertaining to concrete the boundary wall of a lift unit, and (2) concreting other structures, where they mainly carried the concrete mixture. In the actual field, the whole concreting work was done manually. A schematic view of field-working condition, while concreting a boundary wall of a lift unit is presented in Fig. 1. This type of fieldwork was selected for laboratory simulation study. The field study was done by continuous observation through visual inspection.
Two electronic stopwatches were operated manually for time-motion study. Few video recordings were collected in the field and analysed off-line for testing those manually recording data. This video data also helped in detailed work-study analysis.

To simulate these field-working postures, eight static FS postures were identified and studied in the laboratory. A typical example of adopted FS posture in the laboratory is depicted in Fig. 2(a) and the 3D locations of eight different force exerting points (i.e. A', B', C', D', E', F', G' and H') in FS posture are described in Fig. 2(b). A brief description of these two figures (Figs. 2(a) and (b)) is discussed later in this section. Here, certain lifting parameters in FS postures are discussed, while describing Fig. 1.

In the field, two female workers were engaged together in asymmetric lifting (mentioned as target group in Fig. 1). They stood on one working platform at (140±5) cm height above the floor level. This working platform was of a fixed structure and made up of wood. The final unloader was standing on a fixed platform, located at the other side of the shutter (Fig. 1). Therefore, the horizontal locations during peak-strength measurement in FS postures in laboratory were kept constant (A–H points in Fig. 2(a)) for all the subjects. It was observed in the field that the workers generally choose their partners for this lifting operation based on their body height. Considering this fact, in the laboratory simulation study, the vertical positions of the force exerting point (A'–H' in Fig. 2(b)) were determined based on subject’s body anthropometry. In the actual field, these target workers used to collect the load from the head of a ground-level load-carrier, which was at ~40 cm in front of the subject. The

![Diagram](image-url)

Fig. 2. A graphical representation of sequential static load positions during manual lifting operation in the field. (a) Showing one example of static adopting posture, where the subject stands outside the centre-squared margin, keeping their feet with a 30 cm gap. The horizontal distance from A to B is 15 cm, G to H is 10 cm and the horizontal distance from A–H is 93 cm. The anterio-posterior distance from AB level to GH level is 65 cm. These A–H are fixed for all the subjects and marked beforehand. (b) Represents the trajectory of different lifting positions; for both FS postures (A’–H’) and symmetric postures. For symmetric postures, the vertical heights of load exertion are marked as b–h, while the horizontal locations are kept constant, marked as K (filled circle).
simulated position was marked by A′ in Fig. 2(b). While collecting the load, these two workers jointly dragged the load towards them for about 15 cm with the help of ground-level workers, which was equivalent to the distance A′B′ in Fig. 2(b). Then they lifted the load to their ear level and moved 15 cm posterior from their centre of location for transferring the load, simulated at G′ in Fig. 2(b). Again, while releasing the load, with the help of a final un-loader (Fig. 1), these workers further pushed the load again by about 10 cm towards the person, which was equivalent to G′H′, shown in Fig. 2(b). As a result, the load travelled a total of 65 cm in antero-posterior direction (corresponding to the vertical distance between AB and GH levels in simulation study, mentioned in Fig. 2(a)). During this lifting operation, a considerable number of external risk factors were experienced along with their physical exhaustion; such as, the workers sometimes felt giddiness while looking down, asynchronous load handling during either collection or releasing the load, slippage of load, etc. Moreover, their load container was made up of steel plate, as well the concrete mixture was semi-solid in nature; therefore, the coupling was poor. During this field study, different field environmental parameters and workers’ physiological parameters were collected and discussed in Section 3.

(2) Laboratory simulation study: Based on the field study, a simulation study was conducted in the laboratory. Eight positions were selected from the field postures as mentioned above and peak static strength was measured to identify the workers’ maximum load-handling capacity in those postures. To compare the effect of asymmetry postures, the peak strength was also measured from symmetric exertion at the same vertical height levels. Along with the peak-strength parameter, their muscular responses were also collected in those postures. In this study, to compensate inter-subject variations of individual muscle response, the EMG responses were normalized in terms of maximum voluntary contraction (MVC), as suggested by Marras and Sommerich (1991). The details of the laboratory parameters are given below.

2.1. Subjects

Static strength was measured from 10 normal adult female construction workers. The related anthropometric results from these subjects are given in Table 1. The subjects were categorized with no history of chronic or acute illness, not having hypertension and no acute rheumatic problem. They were also screened on the basis that they were not currently consuming any medications and not pregnant. These subjects were instructed not to take any stimulant for at least 2 h prior to participation and during this study. They were clothed in their traditional loose garments during the experiment. Before starting the actual experiment, proper demonstration was given and then ample time was allowed for the subjects till they became familiar with the experimental protocols and adopted lifting postures. In this experiment, all the participating workers were Maharashtrians, residents of Maharashtra state, India.

2.2. EMG study

Four groups of muscles were considered in this study, namely, trapezius, external oblique, rectus abdominis and erector spinae. Roy et al. (1989) observed that the L5 location of EMG study was most suitable to denote the low-back strain injury.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Description of different body dimensions (Mean ± SD)</th>
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<tbody>
<tr>
<td>Body dimensions</td>
<td>Measured value</td>
</tr>
<tr>
<td>Height</td>
<td>151.0 ± 2.84 cm</td>
</tr>
<tr>
<td>Weight</td>
<td>40.5 ± 2.77 kg</td>
</tr>
<tr>
<td>Age</td>
<td>29.6 ± 3.28 yr</td>
</tr>
<tr>
<td>Eye height</td>
<td>142.1 ± 2.1 cm</td>
</tr>
<tr>
<td>Knee height</td>
<td>41.2 ± 3.12 cm</td>
</tr>
<tr>
<td>Shoulder height</td>
<td>127.6 ± 10.4 cm</td>
</tr>
<tr>
<td>Trochanteric height</td>
<td>79.2 ± 18.4 cm</td>
</tr>
<tr>
<td>Functional arm reach</td>
<td>81.2 ± 17.3 cm</td>
</tr>
<tr>
<td>Biacrominal width</td>
<td>30.1 ± 4.5 cm</td>
</tr>
<tr>
<td>Upper arm circumference (relaxed)</td>
<td>19.8 ± 3.2 cm</td>
</tr>
<tr>
<td>Upper arm circumference (contracted)</td>
<td>23.4 ± 3.2 cm</td>
</tr>
<tr>
<td>Upper thigh circumference</td>
<td>44.2 ± 3.1 cm</td>
</tr>
<tr>
<td>Calf circumference</td>
<td>32.5 ± 5.1 cm</td>
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</table>
Therefore, in this study, L5 location of erector spinae was considered. The detailed conditions are presented below.

2.2.1. EMG site preparation

The locations of the electrode positions with corresponding muscles are presented in Table 2. All the electrodes were placed at the right side of the body. The site was first rubbed gently with a piece of alcohol soaked cotton to reduce the skin resistance. Two Ag–AgCl surface electrodes of 1.0 cm diameter were then placed on each muscle by using double-sided adhesive tape with an inter-electrode distance of 0.3–0.5 cm. Site preparation was deemed acceptable when the skin impedance reached below 5 kΩ. The ground electrode was attached to the left earlobe of the subject. These bipolar electrodes were anchored firmly on the skin with another adhesive tape. The outputs of the electrodes were amplified by a Tektronics differential amplifier (model-AM502) with a single-pole filter of a bandwidth frequency of 10–1000 Hz and stored into a magnetic cassette by an FM recorder (TEAC SR-70). This recorder tape speed was 4.76 cm/s with a frequency bandwidth of 0–1250 Hz. Signals were first digitized by 12-bit A/D conversion (driver software was built in-house) with a sampling frequency of 2.88 kHz and then were analysed off-line to calculate the RMS response. After securing all electrodes on the skin, a series of MVC was performed in order to record the EMG response at their maximum voluntary capacity. The defined postures for simulating the MVC condition are explained here.

2.2.2. Posture identification for maximum voluntary contraction study

To adopt a particular posture for generating MVC for above four groups of muscles (Fig. 3(a)–(d)), the experimental rig of a Takei kiki kogyo (Tokyo) dynamometer was used along with two other Velcro straps (made in-house). One was used to fix upper chest movements, while the other was applied to restrict the foot movement of the subject by strapping at the hip level, whenever required. To achieve the MVC condition for the above muscles, the corresponding adopted static postures were identified in the following ways.

For the trapezius muscle, the subject was asked to stand straight and extend her right hand laterally, as shown in Fig. 3(a). The load cell was chained vertically down on her wrist. The subject pulled the cable forcibly in the upward direction, as the maximum static horizontal arm abduction at the shoulder joint resulted in MVC of trapezius muscle (Bao et al., 2001).

For the external oblique muscle, the load cell was connected to the chest strap near the armpit level from the backside of the subject, as shown in Fig. 3(b). The subject pulled the load cell in maximum force with her right shoulder by axial rotation of the trunk. It helped to generate the maximum axial twisting of the upper body segment around the hip joint causing maximum response from the external oblique muscle.

For the rectus abdominis muscle, the load cell was fastened with chest strap from the back of the subject, as shown in Fig. 3(c). The hip angle was made ~160° in posterior. The subject was asked to pull the cable in forward direction to adopt the upright position. In this study, the forcible flexion of trunk against load was chosen for peak muscular activity of rectus abdominis muscle.

For the erector spinae muscle, the load cell was cabled with the chest strap, as shown in Fig. 3(d). The chain length was adjusted in such a way that the hip angle was made around 135° to hyper-flex the lumbar joint and helped to stretch the intervertebral ligaments (Adams and Hutton, 1982). Thereafter, the subject was instructed to develop the maximum static trunk extension with respect to the hip joint against load, which helped to

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Identified positions</th>
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<tbody>
<tr>
<td>Trapezius</td>
<td>2 cm above the annulus superior scapula</td>
</tr>
<tr>
<td>External oblique</td>
<td>10 cm from the mid-line of the abdomen and 4 cm above the ilium at an angle of 45° to the middle of the abdomen</td>
</tr>
<tr>
<td>Rectus abdominis</td>
<td>3 cm lateral to the umbilicus</td>
</tr>
<tr>
<td>Erector spinae</td>
<td>2–3 cm lateral from the mid-line of spine at L5/S1 level</td>
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</table>
produce the acute response of erector spinae muscle.

2.3. Peak static strength study

In this study, the sequential changes of dynamic body movements during lifting operation in the field were simulated at eight different static postures. In the field, the workers lifted the load by free-style lifting process chosen by them, which is better than any set lifting postures (Stevenson et al., 1990). In this simulation study, the subjects were asked to adopt the posture as they adopted in the field.

2.3.1. Field-simulated postures

From Fig. 2(a), it is shown that the subjects exerted their maximum force keeping the legs 30.0 cm apart and in free-style lifting posture. 3D locations for different force exerting positions in FS postures are outlined in Fig. 2(b), which were selected as follows. Within a total horizontal distance of 93.0 cm, the distances AB and GH were 15.0 and 10.0 cm, respectively (Fig. 2(a)). The calculated diagonal distance, \( BG = \sqrt{65^2 + 68^2} = 94.06 \) cm, was divided equally into five segments (corresponding to BC, CD, DE, EF and FG in Fig. 2(a)) and were marked beforehand on the platform. These marked points (i.e. A–H in Fig. 2(a)) were the corresponding horizontal
locations of force exerting positions A'–H' of the FS postures shown in Fig. 2(b) and their vertical locations were selected as below. The vertical heights for the points A' and B', were fixed at knee height level, whereas for G' and H', were at ear height level (Fig. 2(b)). To calculate the vertical positions of C', D', E', F' and G' points, first the difference between knee height and ear height was taken for individual subjects and then divided into five equal divisions. These levels were approximately at knee level, halfway between knee and hip level, hip level, below chest level, shoulder level and ear level. According to these load positions (A'–H'), the corresponding body parameters are identified in the text as position 1 to position 8.

2.3.2. Symmetric simulated postures

These FS peak-strength data were compared with those obtained from the sagittally symmetric lifting postures. In this symmetric posture, peak strength was measured at six vertical height levels (b–g in Fig. 2(b)), which were at the same vertical heights as in FS postures (i.e. B', C', D', E', F' and G' in Fig. 2(b)). The horizontal distance was kept constant at 40 cm from the centre of the workers body location (marked as K) as in the same line of A'B' (Fig. 2(b)). In the text, these positions are identified as position ‘b’ to position ‘g’.

At these reference points, each subject was asked to pull the cable vertically upward smoothly and as hard they could without any jerk and sustained for 3–6 s with the same posture. During peak-strength development, the subject was told to sustain the voluntary exertion for (3–6) s and between two successive exertions 5 min rest was allotted. Three trials with almost the same values were accounted, and their average was considered (Chaffin, 1975). The voltage output of the load cell was fed to a processing unit, where the time-averaged peak signal value was displayed.

3. Results and discussion

3.1. Parameters obtained in the field study

In the field study, it was observed that the construction workers generally worked for an average of ~5 h in a day. Within this total working period, they performed continuous lifting operation for 48.2 ± 10.7% pertaining to concrete the boundary wall of a lift unit, which was selected for this laboratory simulation study. The percentage of average work, rest and pause durations for the whole-day activities were 18.5%, 23.2% and 58.3%, respectively. The weight of the concrete mixture, which they used to lift, was 24.04 ± 3.11 kg. This load lifting frequency was of 6.5 ± 1.1 lifts min⁻¹ with an average single lifting time of 1.5 ± 0.6 s. In the field study, field environmental parameters and the worker’s physical parameters were measured.

3.1.1. Field environmental parameters

The average values of ambient environmental parameters in the field were as follows: wet-bulb temperature 26.8 ± 0.65 °C, dry-bulb temperature 33.3 ± 1.6 °C, globe temperature 46.7 ± 5.0 °C (under the Sun) and 33.3 ± 2.8 °C (under shade). This field environment results indicated that these workers were working in positive heat load condition.

3.1.2. Worker’s physical parameters

The workers’ resting physiological parameters like heart rate was 79.0 ± 4.7 beats min⁻¹ and blood pressure was systolic 112.5 ± 7.2 mmHg and diastolic 71.6 ± 8.6 mmHg. These body parameter values indicated that they were physically normal and not suffering from hypertension. The mean working heart rate was observed to be 123.7 ± 12.5 beats min⁻¹ (i.e. 46.1% of their VO₂max). Therefore, the physiological cost was more than the NIOSH recommended value, i.e. 33% of VO₂max (NIOSH, 1981).

3.2. Laboratory simulation study

3.2.1. Variations of peak static strength in different MVC simulated postures

The static strength is very much dependent on the body posture and reference active group of muscles as well the part of the body segments are used to generate the maximum static strength in that particular posture. The static strength output from different muscular MVC conditions is
presented in Table 3. One-way ANOVA result showed that the peak-static strength levels in different MVC simulated postures were significantly different ($F$ ratio = 54.69 and $p = \ll 0.0001$).

From this result (Table 3), it was observed that trapezius MVC posture produces the least amount of strength, as only the right-hand abduction is used to generate the peak strength. The other three muscular MVC postures were engaging the whole trunk action. Among them, the external oblique muscular MVC elicited the least amount of static strength as it was related to the axial rotation of the trunk. In comparing the peak static strength during developing MVC for rectus abdominis and erector spinae, trunk extension generated more strength than trunk flexion.

3.2.2. Comparison between the peak static strength in FS and symmetric simulated postures

The variations obtained in peak static strength in different FS postures and symmetric simulated postures are shown in Fig. 4(a). In case of FS postures, the peak-strength data were resultant of three lifting parameters, e.g. asymmetry angle, lifting height and working plane (either frontal or lateral). The maximum and minimum peak strengths in FS postures were observed as 222.85 ± 61.15 N and 85.65 ± 19.89 N, respectively. From Fig. 4(a), it was inferred that the maximum peak strength occurred at position 4, at around waist level, while the strength gradually decreased in other conditions, as observed by Kumar (1995).

While comparing the peak strength in FS postures between positions 1 and 2 and 7 and 8, it showed that the lift strength reduced by 27.8% in front plane asymmetry (between positions 1 and 2) and 18.66% in lateral plane asymmetry (between positions 7 and 8), which were similar as reported by Kumar et al. (1995). Moreover, positions 1 and 2 were at knee level and positions 7 and 8 were at ear height level. Therefore, in accordance with asymmetry angle and plane, the vertical height also could play an important role as the forces were exerted at two different body height levels. A decrease in peak-strength value of 27.86% and 9.03% at positions 1 and 2 in FS posture was observed when those compared with symmetric peak exertion at knee level (position b). This was mainly because of 51.9° and 41.9° of frontal plane asymmetry angle. Peak strength was decreased by 7.16% and 18.13% at 7 and 8 positions in FS posture while compared with symmetric peak exertion at ear height level (position g). At the 3rd position (41.63%) 4th position (56.99%) and 5th position (63.62%), more peak strengths were observed in FS postures than symmetric peak-strength exertion (i.e. positions c, d and e). In the above positions, though the effect of postural asymmetry resulted a slight reduction of peak strength, but the decrease in horizontal distance (by 32%, 65% and 97.5%, respectively) as compared with symmetric posture (horizontal distance was fixed at 40cm) caused more peak strength in case of FS postures. Garg and Beller (1994) reported the similar kind of results, where the maximum static strengths were decreased by 14% and 25% with increase in horizontal distance by 23% and 31%, respectively. While comparing the peak-strength values at positions 3, 4 and 5 in FS postures, position 4 was more symmetric and more nearer than the others. Therefore, at this position maximum peak strength occurred.

3.2.3. Variations in muscular activity

Figs. 4(b) and (c) depict the nature of EMG activities from four different muscles at different static postures. It was observed that the rectus abdominis and the external oblique contracted at around 20% of their MVC level, whereas the erector and the trapezius mainly participated to generate a force and maintain the stability of posture.

3.2.3.1. Trapezius and erector spinae. During symmetric force exertion (Fig. 4(b), upper panel), at knee level (position b), the trapezius was active at

<table>
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<th>Table 3</th>
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<tr>
<td>Amount of peak strength developed from different body segments during maximum voluntary contraction</td>
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<tr>
<td>Most active muscle</td>
</tr>
<tr>
<td>Trapezius</td>
</tr>
<tr>
<td>External oblique</td>
</tr>
<tr>
<td>Rectus abdominis</td>
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<tr>
<td>Erector spinae</td>
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84.9%, whereas the erector spinae EMG level was at 46.9% of MVC level. At position c, the subject hyper-extended the hip joint, therefore the erector spinae EMG activity increased and trapezius was less active than in previous postures. Thereafter at positions d and e, trapezius action gradually increased, as the subject pulled the cable in an erect posture and the maximum force was developed at position e. On the other hand, the erector spinae was relatively less active in these positions. At positions f and g, as the arm was elevated during pulling, the trapezius EMG levels were slightly reduced than at position e, but remained higher than at positions b and c. Therefore, muscular load on the trapezius was more in higher lifting heights, as observed by Nielsen et al. (1998). On the other hand, at positions f and g, the erector spinae was slightly more active to maintain the

Fig. 4. (a) Peak strength responses at eight different FS postures (marked with solid bar) and bi-symmetric posture (marked with opened bar) from the same vertical lifting heights levels are presented side by side. For the FS postures, the load positions are described as position 1 to position 8, whereas for symmetric exertion positions load are denoted as position b to position g (marked in the x-axis). A graphical representation of RMS values obtained from four different muscles in (b) symmetric postures and (c) different FS postures are plotted. T.R.—trapezius; E.R.—erector spinae; E.O.—external oblique and R.A.—rectus abdominis.
trunk stability. A trade-off property was observed between erector spinae and trapezius action (Nielsen et al., 1998); i.e. when one was high, the other one was low.

In FS postures, as shown in Fig. 4 (c, upper panel), it was observed that trapezius activity was less at position 1 than 2, whereas the erector spinae was almost at the constant level. At position 1, the anterior trunk deviation was larger and the trapezius was stretched. Therefore, reduced trapezius activity was observed. Comparing the results, shown in Figs. 4(b) and (c) (upper panel), at positions b and 2, the plane asymmetry caused an increase in muscular activity both in trapezius and erector spinae. At position 3, though the load was nearer to the subject in comparison to the symmetry posture (position c), the plane asymmetry caused a slight increase both in trapezius and erector spinae EMG activities. At position 4, the plane asymmetry was almost zero. So, in this FS posture (position 4), the erector spinae EMG was almost at the same level as obtained at position 3, but the trapezius EMG was reduced, as the arms were spanning out laterally to adjust the load position, nearer to the subject. At position 5, as the hand abduction angle was almost zero (the related posture typically presented in Fig. 2(a)), therefore trapezius activity again increased as compared at position 4. At positions 6, 7 and 8, the ipsi-lateral trapezius activity gradually decreased (as the load position and electrode positions were at the same right side) with the increase in plane asymmetry. On the contrary, at the same above locations, as the asymmetry angle approached or crossed 90°, a trunk-rotation occurred to adjust the asymmetric load location. As a result, more activation of ipsi-lateral erector spinae muscle occurred. This result also supported the fact that erector spinae muscles were recruited in bending postures to maintain the postural stability. Marras and Davis (1998) studied the effect of asymmetry angle limited up to 60° and reported that the contra-lateral erector spinae was more active. In this study, it was seen that when the asymmetry angle near or more than 90°, then more activation of ipsi-lateral erector spinae took place. However, Garg and Bannag (1988) reported that the participant’s perceived stress level would increase with more twisting of the trunk because of poor postural stability and unequal loading on arm, back and leg.

3.2.3.2. External oblique and rectus abdominis. In Fig. 4(b) (lower panel), it was observed that from the knee height level (position b), the external oblique EMG level gradually decreased with the increase in vertical height of load exertion up to position e and started to increase positively with vertical heights, which helped to maintain the stability of the posture, along with the co-activation of erector spinae muscle. From Fig. 4(c) (lower panel), plane asymmetry caused more activation of this muscle, therefore, at position 4 the EMG level was the least. As the electrodes were placed at the right side of the body, at positions 1, 2 and 3, this EMG showed a contra-lateral side response. In these positions, plane asymmetry caused more activation in contra-lateral side, as similarly observed by Marras and Davis (1998). With further increase in plane asymmetry (at positions 6, 7 and 8) showed an increase in ipsi-lateral muscular activity for maintaining the trunk stability. At position 8, the highest muscular activity occurred as hyperflexion of the body occur with plane asymmetry.

From Fig. 4(b) (lower panel), it was observed that the rectus abdominis was slightly more active up to position c, and then started to decrease up to position f. At position g, again its activity increased. Maximum muscular activity was observed at position c for symmetric load exertion. Comparing the results in Figs. 4(b) and (c) (lower panels), it can be concluded that the plane asymmetry causes a slight increase in this EMG level as mentioned by Kumar and Narayan (2001).

In present study, each FS posture was a complex combination of different lifting parameters. From statistical analysis, it was shown that trapezius and erector spinae activities were significantly (p ≤ 0.05) related with the peak-strength outputs, whereas external oblique and rectus abdominis outputs were not (p = 0.51 and 0.17, respectively). This relation might improve with the consideration of both ipsi- and contra-lateral EMGs. This result showed that the increase in trunk axial rotation showed a significant impact on trunk muscular activity (for both trapezius and erector spinae).
3.3. Risk factors related to the load handling

From Fig. 4(a), it was observed that the increase in asymmetric plane during load handling caused a decrease in peak strength. In the field, the average amount of load lifted by two female workers was 24.04 kg. It was mentioned in *Maharashtra Factory Act* (Rule 66 (2)), “if the lifting is performed with conjunction with other person(s), the maximum permissible weight limit (30 kg for individual adult female workers) will be thereof the sum of weight permissible for each person separately” (Dwivedi, 2000). In this context, it was assumed that the above lifted load (i.e. 24.04 kg) was distributed equally among those two workers, and each worker would handle around 12.0 kg. According to Chaffin and Park (1973), a sharp increase in the low-back injury rates was expected while performing manual load-handling operations with the required strength greater or equal to their isometric strength values. Later, Chaffin et al. (1977) showed from epidemiological results that this rate of back injury was three times higher in the case of over-strain group. In this study, the amount of load (i.e. 12.0 kg) was expressed in terms of percentage of peak strength to analyse the risk factor associated with this type of load-handling operation (Fig. 5). From this figure, it can be interpreted that the workers always have lifted the load above 50% of their peak static strength. The workers even crossed the safety margin at 1st, 7th and 8th positions. However, in actual field, at the corresponding locations of 1st and 8th FS positions, another worker was also shared the load. But if a mismatch in synchronization occurred during load transferring then there would be a huge strain on the back. Moreover, from Fig. 4(c) (lower panel), it was seen that due to increase in both vertical height of load position and postural asymmetry, the gradation of erector spinae contraction was very high to maintain the body balance, which would cause strain injury. From Fig. 5, while comparing the erector spinae muscular activity in different FS postures, it was shown that the change in erector spinae activity followed the same pattern with the increase in risk factor in terms of percentage of load factor with respect to peak strength, except at positions 1, 2 and 3, as at those three positions, the plane asymmetry was contra-lateral to the electrode. This result also supported the view that due to asymmetric posture the back was paying the cost.

With the application of revised NIOSH lifting equation (1991) for calculating recommended weight limit (RWL) in this lifting condition (from B to G in Fig. 2(b)), the calculated RWL would be 1.2 kg. This will further evident the potential risk factor associated with this kind of lifting operation.

It is observed that in this FS posture, the asymmetry angle was even more than 90°, which was not studied earlier. These FS postures were a combination of wide variations of lifting parameters. It is, therefore, encouraged to study in FS postures for better simulation on field applications. Moreover, there was no data available on the physical strength of this Indian working population. This study will provide the database for this population. This result also showed that the unwieldy postures are the potential risk factors for this type of operation. According to Potvin and Norman (1993), a decrease in strength and significant increase in EMG amplitude for erector spinae and external oblique occurred while performing continuous lifting task. Therefore, this risk factor will further increase in this kind of job operation. A combination of flexion with rotation imposes a high risk factor to these workers in the field.

![Fig. 5. In eight different FS postures, changes in erector spinae muscular activity are plotted with the amount of load handled by the workers as a percentage of their respective mean peak-strength value.](image)
The present study was done on eight static FS postures, but the actual fieldwork was dynamic in nature. The static strength measurement does not account the inertial force. These inertial forces are very much significant if the actual task is dynamic in nature, like the manual load lifting operation. Dynamic human strengths are very much relevant in determining an individual’s actual lifting capacity. Therefore, this result can be improved by measuring the dynamic strength in this FS posture.

4. Conclusion

From the above results, it is shown that in field postural asymmetry with a heavy load causes a considerable stress on the major muscles groups. This ultimately leads to occupational health hazards. In this context, it is pointed that the existing Maharashtra Factory Rules (1975) (Dwivedi, 2000) mentioned the safe load limit for handling materials for the adult female worker is 30 kg. Considering this risk factor, the current Maharashtra Factory rule needs to be evaluated scientifically based on workers’ performance. Otherwise, the work environment has to be modified to care for the welfare of the workers.

References

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