Shoulder Muscle Loading and Task Performance for Overhead Work on Ladders versus Mobile Elevated Work Platforms

Denis Phelan[1] and Leonard O'Sullivan[2]

[1] Jacobs Engineering

[2]Leonard O'Sullivan (Corresponding Author)
Ergonomics and Product Design Research Group
Enterprise Research Centre
University of Limerick
Castletroy
Limerick
Ireland
Tel: 00 353 61 234249
Fax: 00 353 61 202913
Email: Leonard.osullivan@ul.ie

Abstract

A high incidence of Musculoskeletal Disorders (MSDs) has been reported in the construction sector. The use of ladders in the workplace has long been identified as a significant risk that can lead to workplace accidents. However, it is unclear if platform types have an effect on the physical risk factors for MSDs in overhead work. The aim of this study is to perform a pilot study on the effects of hand activity on both shoulder muscle loading and task performance while working on ladders versus Mobile Elevated Working Platforms (MEWPs). It is hypothesised that work on ladders would result in greater muscle loading demands, increased levels of discomfort and reduced performance due to the restrictions on postures that could be adopted. A field study (n=19) of experienced electricians on a construction site found that workers spent approximately 28% of their working time on ladders versus 6% on MEWPs. However, the durations of individual tasks were higher on MEWPs (153 seconds) than on ladders (73 seconds). Additionally, maximum levels of perceived discomfort (on a VAS 0-100) were reported for the shoulders (27), neck (23), and lower regions of the body (22). A simulated study (n= 12) found that task performance and discomfort were not significantly different between platform types (ladder vs. MEWP) when completing either of three tasks: cabling, assembly and drilling. However, platform and task had significant effects ($p<0.05$) on median and peak electromyograpic (EMG) activity of the anterior deltoid and upper trapezius. EMG amplitudes were higher for the deltoid than the upper trapezius. For the deltoid, the peak percentile amplitudes were, on average, higher for ladder work over MEWP work for the hand intensive cabling (32 vs. 27% Maximal Voluntary Exertion (MVE)) and the assembly task (19 vs. 6% MVE). Conversely, for drilling the peak percentile EMG amplitudes were marginally lower for ladder compared to the MEWP (3.9 vs. 5.1% MVE). The general implication was that working on the MEWP involved lower shoulder muscle loading for cabling and assembly task. A difference due to platform type was not present for drilling work.

1. Introduction

Musculoskeletal Disorders (MSDs) describe a wide range of inflammatory and degenerative diseases and disorders which can result in pain and functional impairment of the neck, shoulders, elbows, forearms, wrists and hands (Buckle & Devereux 2002). The European Foundation for Living and Working Conditions report that MSDs are the most common occupational disease suffered by European workers (EU-FOUND 2007). A recent report from the European Survey on Working Conditions highlighted that 24.7% of European workers complain of backache as a result of performing work, with a further 22% complaining of muscular pains (Eurostat 2010). An EU study on risk factors associated with MSDs concluded that construction workers were more likely to be exposed to a number of risk factors including work at high speeds, repetitive hand movement, carrying heavy loads, standing or walking, painful or tiring positions, or vibration, when compared to other sector workers (Eurostat 2010).

Brenner and Ahearn (2000) report data on numbers of construction trade workers that retired due to ill health over a period from 1981-1996 in Ireland. Sheet metal workers, floor layers and electricians represented the more frequent occupations of retirees under fifty years of age. During this period, it was estimated that 24,428 years of working lives were lost due to premature retirement from the industry. However, the report only considers employees who are members of the regulated environment of the Irish Construction Industry Federation pension scheme.

Anderson (1988) details trade worker activities that may be associated with MSDs. Many of these activities include typical construction activities such as sanding, grinding, hammering, carpentry, overhead work, turning screws, soldering, welding, use of hand tools, wiring, use of pliers, polishing, sawing, operating finger triggers, jack hammering, use of vibrating tools and working in a cold environment. It is not surprising that the incidence of MSDs in this industry is particularly high (Schneider, 1997). Albers et al. (2004), in a study of ergonomic interventions to reduce musculoskeletal loading in building installation tasks, identified a number of high risk tasks associated with the electrical and mechanical trades. These included pulling cables/wires, attaching raceway to ceilings, positioning fixtures and connecting wires.

However, no reference is made to the variety and effects of the many access platforms used in the industry.

The use of ladders in the workplace has long been identified as a significant risk factor leading to workplace accidents. The safety concerns relating to ladders have been well documented and include the absence of fall protection for the user and the difficulty in securing fall restraints in the event of a fall. In the US, it was reported that 133 fatal ladder related falls occurred in 2004, with ladders accounting for 16% of workplace fall related fatalities (Lombard et al., 2011). Previous ergonomic studies on ladders have focused on climbing/handling of ladders (Bloswick et al. 1990, Imbeau et al. 1998, Hoozemans et al. 2005). Ladder handling was identified as a significant risk hazard for MSDs within the telecommunication sector (Imbeau et al. 1998). This included loading/unloading of ladders from vehicles and the positioning of ladders onto the shoulder. Overexertion was considered a risk factor in the handling of ladders (24-31 kgs). However, no reference is made to ergonomic risks of work on ladders. Bloswick et al. (1990) examined the ergonomic implications of ladder climbing activities using EMG of the erector spinae muscle group with biomechanical modelling of compressive and shear forces at L5/S1. They concluded that fast climbing resulted in 35% greater EMG activity than slow climbing for the torso muscles, and that erector spinae EMG activity almost reached the maximum during a fast climb but no data was presented on the shoulder muscle activity. Hoozemans et al. (2005) examined the effect of differing rung separation on perceived exertion, discomfort, safety and mechanical loading of the lower joints during ladder ascending and descending, but the study did not include the effects of performing tasks using the ladder as a platform.

The stepladder is a very common feature on the majority of construction sites in Ireland, used by craft when performing work at height. The popularity of the stepladder is likely to be influenced by its versatility and low relative economic cost. The use of Mobile Elevated Work Platforms (MEWPs) on construction sites is also very common. MEWPs are self propelled machines that are capable of raising a working platform to the desired working height. Irish health and safety legislation (HSA 2007a) recognises that work at height can be performed safely using a wide range of work equipment, but guidance favours the use of MEWPs over ladders (HSA

2007b). On MEWPs, the risk of an operator falling is minimised as the operator is contained within a double handrail. Additionally, in the event of a fall, the operator is secured if a body harness is worn. It is clear that MEWPs are a preferred method for accessing work at height compared to ladders due to their safety features in preventing falls from height. However, it is unclear if MEWPs are also preferable in preventing MSDs during overhead work. A review of the literature indicated no previous studies comparing the use of MEWPs to ladders on risks of MSDs for overhead work. The user of a ladder is restricted to the position of the ladder and can only move up or down as per the rung separation distance. The MEWP provides a working platform, typically approximately 1.0 x 2.0 metres, thus allowing the user a stable base to move while performing construction tasks. Additionally, the height of the platform can be adjusted with ease as per the user's preference.

The purpose of this study was to compare work on a ladder versus a MEWP and three types of work tasks on shoulder muscle loading and discomfort, and also task performance. Part I reports on platform type usage on a commercial construction site at a point in time. Part II was a simulated study of commercial electrical work to compare the effect of working on ladders versus MEWPs on shoulder EMG, discomfort, and task performance. The hypothesis of this study was that work on ladders would lead to greater muscle loading demands, increased discomfort and lower levels of performance than on a MEWP due to both the posture and balance constraints required for ladder work and the stable platform and reduced balance requirements on MEWPs.

2. Method

The research methods were approved by the University of Limerick Research Ethics Committee.

2.1 Part I: Field study of discomfort

The survey was performed at a construction site of a large pharmaceutical plant in Ireland. Site management approved the study. Manpower levels peaked at approximately 400 personnel with up to 60 electricians at any one time. The electricians on site (all male) were presented with details of the survey during their morning meetings and invited to participate. Twenty electricians agreed to participate in the one day study from a workforce of 30 on the day of sampling. One had to leave the site during the day giving a sample size of 19.

The survey comprised a simple checklist of broad work activities and location by time segment (15 minutes) which the participants completed as the day progressed. The work activities on the checklist were as follows:

- Working on ladder
- Working on a MEWP
- Working on other access platform
- Electrical work from ground
- Completing safety documentation/retrieving materials
- Other (please state)

A modified version of the Corlett and Bishop (1976) body part discomfort rating method was used to record perceived discomfort at the end of the working day in the neck, shoulders, upper arms, lower arms, lower trunk and upper trunk. The main difference was the use of a 100mm visual analogue scale with anchors of no discomfort on the left and extreme discomfort on the right, as per Carey and Gallwey (2002, 2005).

2.2 Part II EMG study of overhead work

2.2.1 Treatment details and experimental design

Twelve qualified electricians (all male) with a minimum of 4 years work experience in the company volunteered to participate in the experiment, none of which participated in Part I of this study. The mean age was 43 yrs (SD 6.11), mean body mass 88.8kg (SD 5.80) and stature 1.81metres (SD 0.05). There were no female electricians in the company at the time of the study available to participate in the experiment.

The experimental design was full factorial. The independent variables were Platform (2 levels: MEWP and ladder) and Task (3 levels: drilling, cabling and assembly) combined giving six treatments. The dependent variables were discomfort, task performance and EMG amplitude during the task (50^{th} and 90^{th} percentile MVE). Orders were balanced using a 6x6 Latin Square (Montgomery 1991). Participants 7-12 did the reverse treatment orders of the first six participants.

The treatments were simulated tasks comprising combinations of three electrical construction tasks (drilling, cabling and assembly), with both access platforms (ladders and MEWP) in a workshop environment. None of the participants had participated in the site study. The tasks selected were identified as routine electrical activities during the field study. Participants were instructed to perform each task for a period of 5 minutes followed by a rest period of 5 minutes between tasks, as per Carey and Gallwey (2002, 2005) and Mukhopadhyay et. al. (2007). In order to represent the actual practice as performed on construction sites, the participants were instructed to set the ladder/MEWP position to suit their individual preference. Figure 1 is a photograph of a participant on the MEWP.

[Insert Figure 1 about here]

Drilling task:

The drilling task required participants to drill a 100mm medium density concrete block using an electric drill and a 14 mm masonry drill bit. Performance was measured from the amount drilled in mm. A new concrete block was used for each participant.

Cabling task:

The cable task involved feeding a 10mm diameter power cable through a series of brackets mounted on a wall. The length of cable pulled (metres) during 5 minutes was the measure of performance.

Assembly task:

A 10 mm threaded bar was fixed to the wall for the assembly task. Participants used their dominant hand to move a nut from the outside edge of the bar towards the wall. The distance each nut was threaded (mm) during the 5 minutes was the measure of performance.

2.2.2 EMG equipment and data reduction

Muscle activity from the upper trapezius and anterior deltoid muscles was measured using bipolar surface EMG. A Nexus 10 portable EMG system (Mind Media) with Bluetooth connectivity recorded the EMG signals. The sampling frequency was set at 1024Hz with a band pass filter set to 20-500Hz in the software. The sampling window was set at 0.5 seconds (512 samples) with a 25% overlap. The Root Mean Square (RMS) calculation was applied to the raw EMG to determine signal amplitude.

Maximal Voluntary Exertions (MVEs) were performed for both muscles at the start of the experiment and signal amplitudes from these recordings were used to convert the signals from experimental treatments to percentages of MVE. Percentiles (50^{th} and 90^{th}) of the % MVE data from the Amplitude Probability Distribution Function (APDF) were determined for each recording, as per Vasseljen and Westgaard (1995). The 50^{th} percentile is indicative of the median EMG activity amplitude during the treatment whereas the 90^{th} percentile is indicative of peak EMG activity.

2.2.3 Procedure

The participants completed the informed consent form and were briefed on the nature of the experiment and what it involved. The EMG electrodes were attached over the upper trapezius and anterior deltoid muscles on their dominant side. The guidance of SENIAM (1999) was followed in preparing the skin and the guidance of Delagi et al. (1980) was followed in positioning the electrodes. The signal quality was tested and EMG signals were recorded for MVE exertions of both muscles. The participants familiarised themselves with the tasks prior to commencement, including operation of the MEWP and positioning of the platform as per the task. Participants self selected their preferred working height on both platforms. It was necessary to control the pace of the simulated work as it is known to affect discomfort for the upper limb in simulated tasks (Finneran and O'Sullivan, 2013). As such, the participants in repetitive tasks were instructed to "perform the task at a pace they felt they could maintain for an eight hour day" (as per Finneran and O'Sullivan, 2010). This was expected to approximately result in an activity equating to a Methods-Time Measurement (MTM) pace rating of 100%.

Each treatment lasted five minutes, followed by a five minute break. At the end of each treatment discomfort was rated using the same scale as in Part I above. Performance was measured using a tape measure for the drilling and assembly task, and a measuring wheel for the cabling task.

2.2.4 Statistical analysis

The Statistical Package for the Social Sciences (SPSS V16) was used for the statistical analysis. A paired sample t-test was used to compare average cycle times on ladders versus MEWPs for the field study data. In the simulated study the discomfort data were not normally distributed so the Wilcoxan Signed Ranks test was used to test effects for Platform (2 levels) and the Friedman test used to test effects of Task (3 levels). A two way ANOVA (Platform X Participant) was used to analyse the performance data for each task separately. ANOVA was used to analyse the median and peak percentile MVE data (recorded from the treatments) for both the deltoid and upper trapezius data. Hence there were four separate analyses: two per muscle. The ANOVA main effects were Platform, Task and Participant. Due to insufficient degrees of freedom, the three way interaction was not included in the analysis.

3. Results

3.1 Part I Discomfort and work activities

As illustrated in Figure 2, a number of body regions had high average levels of discomfort. The neck, shoulders and lower trunk values were in excess of 20 (on the 0-100 scale). Highest discomfort was recorded for the shoulders (27.9), with the upper trunk (7.6) recording least discomfort. Mean levels of discomfort were almost 50% greater for the right shoulder (16.6) than for the left (11.3). Additionally, discomfort was greater for the right arm and leg (58.5) versus the left arm and leg (23.7).

A breakdown of the work activity and work locations performed by the electricians is shown in Table 1. The average length of time on MEWPs was 153.3 sec versus 73.7 seconds for ladders. Hence the duration of tasks on MEWPs was on average more than double the time spent on ladders on any one instance but ladders were used more frequently. These differences were statistically significant (paired sample t-test $p < 0.05$).

[Insert Figure 2 about here]
[Insert Table 1 about here]

Generally, the data indicate that the electricians performed approximately 37% of their typical day working at height. On average, 28% of the work day was spent working on ladders, with 6% on MEWP's. In excess of 35% of each electrician's working day was spent completing electrical work on the ground. The data also showed that 3% of their time involved using other access platforms excluding MEWPs and ladders. This would include fixed scaffolds, mobile aluminium towers and hop-ups.

3.2 Part II

3.2.1 Effects of platform and task on discomfort

Mean discomfort for the upper body was slightly higher for ladders (25.2) than for MEWP (24.3). These differences were not significant (Wilcoxon signed rank p= 0.693). Ratings of upper body discomfort were significantly different between tasks (Friedman test, $p<0.001$). The mean ranks showed least discomfort for the assembly task (1.4), compared to the drilling (2.3) and cabling (2.3).

3.2.2 Task performance data

ANOVA performed on the data showed that Platform did not have a significant effect on task performance for the drilling, cabling and assembly tasks (p=0.052, p=0.070 & p=0.070 respectively). While not significant, the majority of participants were better able to perform the drilling task on the ladders than the MEWP.

3.2.3 Effects of platform and task on EMG data: Anterior Deltoid

The log calculation was applied to the EMG data to transform it to a normal distribution. Average raw (R) and log transformed (T) EMG activity data for the anterior deltoid are show in Table 2. ANOVA performed on the median percentile EMG activity data for the anterior deltoid, identified significant effects for Task ($p<0.001$), Platform (p=0.007), Participant (p=0.02) and for a two way interaction between Task x Platform (p=0.004). For the peak percentile EMG activity data the same factors were significant and at similar levels, with one exception which was platform (p = 0.07).

Figure 3 shows a plot of the average transformed median EMG data where anterior deltoid activity was highest overall for the cabling task on both platforms, with values higher for Ladder than MEWP (Ladder T0.93, R 8.51%, MEWP T0.78, R6.03%). Assembly task muscle activity was also higher for Ladder than MEWP (Ladder T0.86, R7.24%, MEWP 0.21, R 1.65%). Across all conditions, the treatment with the lowest overall activity was Assembly task on the MEWP (0.21, R 1.65%). The EMG activity data for Drilling followed an opposite trend as for Cabling and the Assembly task with muscle activity slightly higher for work on a MEWP (T0.42, R2.63%) than on a Ladder (T0.35, 2.24%). This illustrates the significant two way interaction for Task x Platform ($p=0.004$).

For the peak percentile data (Figure 4), the same general trend was present as for the median values. The data were highest for Cabling, although the differences between MEWP and Ladder were less than for the assembly task. Again Drilling followed an opposite trend with values lower for Ladder than MEWP. Overall the lowest values were for drilling on a ladder.

[Insert Table 2 about here]

[Insert Figure 3 about here]

[Insert Figure 4 about here]

3.2.4 Effects of platform and task on EMG data: Upper Trapezius

ANOVA on the upper trapezius median percentile EMG data indicated significant effects for Participant ($p=0.005$), Platform ($p=0.047$) and Task ($p<0.05$). Median EMG activity was higher for all tasks completed on ladders compared to MEWPs. Interactions between Platform x Participant, Task x Platform, & Task x Participant were not significant ($P>0.05$). Table 3 shows higher EMG activity for the cabling task compared to the other tasks for all participants.

ANOVA on the peak EMG data revealed that Task was significant ($p <0.01$) but that Platform was not ($P=0.526$). Participant was significant ($p<0.05$). No significant interactions between Participant x Task ($p=0.404$), and Participant x Platform ($p=0.680$) were recorded.

Median and Peak EMG activity (Figure 5 and Figure 6) were higher for cabling and assembly tasks performed for ladders, compared to MEWP However, drilling recorded lower peak EMG activity for ladder.

[Insert Table 3 about here]

[Insert Figure 5 about here]

[Insert Figure 6 about here]

4. Discussion

4.1 Working platform types and durations

37% of the electricians work activities surveyed on site were performed above ground level on some type of access platform with overall duration of work on ladders (28%) being most common. Work on MEWPs accounted for only 6% of time in this study. Individual cycle times were longer on MEWPs (153 seconds) than on ladders (73 seconds) but ultimately the electricians used the ladders more frequently. The extensive requirement to perform work at height can be expected for electrical installation work as many services are installed on ceilings and walls. It was noted that the use of ladders varies during the lifecycle of a construction project. It is the experience of one of the current authors (DP), specifically from commercial construction sites, that as a project nears completion, it is often difficult to use MEWPs due to reduced access, particularly when partitions are erected. It is also the experience that ladders are often favoured during the latter stages of projects because they are less likely to cause damage to the finished structure.

The average length of task duration on ladders was on average half that of work on MEWPs. The general inference is that, often for short duration activities, the ladder was preferred for short duration tasks over a MEWP. Other factors that may have influenced the access method used include availability, training requirements, access difficulties, and costs. In practice, when an electrician was required to perform a task at height, the decision to use a MEWP required that it will be available, that the operator had adequate training, and that the MEWP could gain access to where it was required. The cost difference between platform types is substantial with ladders costing €200-300 and MEWPs up to several thousand Euros.

NIOSH (1997) highlights the strong evidence of a relationship between posture and MSDs of the neck and neck/shoulder region. Higher incidence of shoulder elevations was likely to be more evident on ladders as the worker commenced work straight away once they ascended the ladder. Ladder work required the electrician to carry all materials or tools. On MEWP work, materials can be carried in the MEWP allowing the worker more time to assess the task. MEWP work also allowed the user to raise the working height above the task height thus reducing the incidence of neck extension. During the field study, it was noted that workers were more likely to look down on a task when in a MEWP.

This survey approach involved workers logging their platform use throughout the working day. A more precise way to estimate the frequencies would be to use systematic work-study sampling methods by an independent observer. But the construction site used in this case study was very large, making it particularly difficult to locate workers. As such, work-study sampling was considered unpractical.

4.2 EMG and discomfort study of overhead work on ladders and MEWPs

4.2.1 Platform and task effects on upper limb discomfort

It was expected that the use of ladders would result in greater levels of discomfort and reduced performance due to the restrictive posture associated with ladder use. MEWP platforms provide for greater flexibility allowing the user to adopt a variety of postures to suit the task being performed. But the results indicated that platform type did not have a significant effect on upper limb discomfort in this study. It was anticipated that the MEWP platform would provide a more stable base to allow the user to perform the work in a variety of positions, as advocated by Kroemer (2009). While Platform did not a significant effect on the discomfort data, it did on the EMG data (with the exception of peak upper trapezius). The effects were more pronounced for the Deltoid. If the treatments were of a longer duration than those tested (five minutes), then fatigue differences and increasing discomfort may have been more pronounced. However, it is not possible to confirm this in the absence of a trial with more participants and longer duration treatments.

Task had a significant effect on upper limb discomfort. Discomfort ratings were highest for the cabling task followed by the drilling and assembly tasks. This could be expected given the differing physical demands of the tasks. The cabling task required vigorous movement of the arms to pull the cable, an explanation supported by the higher muscle activity levels for the cabling task. Methta and Agnew (2010) performed a laboratory study on the effects of a drilling task on muscle activity. It found that fatigue was shown to influence discomfort ratings for all body parts measured. This included the hand, lower and upper arm, and upper and lower back.

4.2.2 Platform effects on task performance

It was expected that the MEWP would allow the participant to adopt a wider range of postures to suit the physical demands of each task, thus leading to higher task performance. However, Platform did not have a significant effect on performance. While not significant, the plot of average values indicated that for the majority of participants, performance improved when on ladders which was counter to expectations. One explanation is that participants felt more stable and comfortable on the platform to take micro breaks between work cycles, whereas on the ladder they were focused on completing the task so as to return to ground level. For the drilling task, the result approached significance ($p=0.052$). If the task was of a longer duration or if more participants were included then this result may have been significant.

Previous reports on task performance and muscle fatigue show conflicting findings. Methta and Agnew (2010) found that task performance in a simulated drilling task in a laboratory was not influenced by task difficulty. The report compared a fatigue and a no fatigue condition, and while the report did not observe any effects of task difficultly on performance, the authors acknowledge the level of difficulty may have not been sensitive to changes in fatigue.

4.2.3 Platform and task effects on muscle activity

The Platform main effect was significant for median EMG activity for both the anterior deltoid and upper trapezius. Generally, shoulder muscle activity was greater on ladders compared to MEWPs and as such the results would suggest that ladder use required greater levels of force and thus increased biomechanical demands on the user. While NIOSH (1997) concluded that there was insufficient evidence to link force of exertion on its own and MSDs of the shoulder, they also note that high shoulder muscle requirement can increase muscle contraction activity, which may lead to an increase in both muscle fatigue and tendon tension, and impair microcirculation.

Regarding the peak EMG data, the values were marginally higher for the upper trapezius for cabling and the assembly task on the MEWP than the ladder, which was counter to the findings generally for the deltoid. Both the cabling and assembly tasks involved more dynamic shoulder movements than for the drilling task, which was largely static for the duration of the treatments. An explanation for the platform differences for the peak upper trapezius data is that, on the ladder, the participants used less dynamic movements than on the MEWP because of the ladder's effects on balance. A detailed motion analysis study is necessary to verify this explanation.

Veiersteda et al. (2013) studied full day EMG recordings of the upper trapezius which included a group of electricians (n=14). They reported mean 50th percentile APDF values of 5%MVE and 90th percentile Amplitude Probability Distribution Functioning (APDF) of 15.4% MVE which are comparable to the values from the mean values across the three tasks in the current study (50th percentile: 4.8% ladders, 6.8% MEWP, 90th percentile: Ladders 8.7, MEWP 9.8. But the 90th percentile ADPF values were highest for cabling on the MEWP (15.1% MVE) is very similar to the same parameter reported for the electricians by Veiersteda et al. (2013).

This study has demonstrated that higher upper trapezius and deltoid muscle activity was present when performing overhead work on ladders compared to MEWPs. However, this study only considered two muscles and they were studied separately. Previous studies indicate patterns of redistribution of forces in shoulder muscles due to fatigue or repetitive exertions. This may result in recruitment of other muscles (Cote et al 2002; Selen et al 2007) in the exertion. Antony and Keir (2009) concluded that performing a simultaneous shoulder exertion and hand grip led to posture specific redistribution of shoulder muscle activity for both isometric and dynamic conditions. The effects of hand activity, specifically the use of tools, have been shown to influence shoulder muscle activity. Antony and Keir (2009) examined the effects of loading on shoulder muscle activity and concluded that a 0.5 kg load increased shoulder muscle activity by 4% MVE. Sporong et al. (1998) reported an average increase in muscle activity of 22% of the resting state when light precision work was introduced to a task. EMG activity was higher for the cabling and assembly tasks on ladders but the drilling task had lower peak EMG activity even though participants had to hold and control the tool. In this experiment, the tasks required low to moderate levels of precision. In practice, some work by electricians, such as connecting wires in components, requires high levels of precision. If high precision tasks are performed on a ladder rather than a MEWP this may increase the differences in shoulder muscle activity between the two platform types. A separate study is necessary to verify this.

The interaction between Platform and Task was similar across both muscles. Drilling resulted in lower peak EMG activity for ladder than MEWP for the upper trapezius and vice versa for the deltoid, but the magnitude of the differences is marginal. As such, platform could be considered as not having an important effect on the EMG data overall for the drilling task. This may be due to the overall static nature of drilling once the task commences. This was not the case for the cabling and assembly tasks. As mentioned previously, these tasks involved performing more dynamic movements. The assembly task provided the greatest contrast with the largest increase in EMG levels when completed on ladders. The significant effect for participants is to be expected given individual strength differences.

4.3 Limitations

Part I of this study involved a survey of a single construction site during a specific phase of the construction. As such, the results indicate the discomfort and work practice by those workers at that phase of the construction project only. Future research studies should repeat this survey on other construction sites throughout the life cycle of the project to more accurately capture the work practices, especially the ladder versus MEWP use patterns. The actual postures used by the workers to perform their work were also not recorded during the field study and this is also a limitation of this work.

The sample size in the experiment (Part II) was relatively small (n = 12) and this limits the generalisability of the results. It is necessary to test a larger number of participants and for longer durations to confirm if these findings would be representative of the larger populations of electricians working for full day durations on site.

The treatments in Part II were of a relatively short duration. Others have completed laboratory based discomfort studies of simulated tasks to study wrist, forearm and shoulder posture effects (Carey and Gallwey, 1999, 2002; O’Sullivan and Gallwey, 2005; Mukhopadhyay et al., 2007; Khan et al., 2009). Further research studies are necessary performing these types of simulated tasks for longer durations than five minutes to ensure the findings reflect the actual cumulative fatigue effects as experienced in the course of a working day. Solutions include repeating the treatments as performed here but for longer durations (up to 8 hours with rest breaks) or performing site surveys using posture analysis with EMG and discomfort studies with workers performing individual tasks similar to the treatments studied here for long durations.

Many upper limb muscles are active in performing the exertions involved in the experiment, yet in this study, only two were evaluated. As such, the results only reflect loading on these two specific muscles. This is a further limitation of the study.

5. Conclusions

Part I Field Study

- High levels of perceived discomfort in the neck, shoulders and lower body, were reported by the small group of electricians surveyed.
- Thirthy seven percent of the electricians' days were spent working at height, using ladders, MEWPs or other access platforms. Ladders were used much more extensively than MEWPs in this study at 28% compared to 6% respectively.
- Average cycle time durations were significantly longer on MEWPs at 153 sec compared to 74 sec for ladders. Ultimately, the electricians used the ladders a lot more frequently. A larger survey involving a greater number of participants across multiple sites is necessary to more accurately reflect the actual practice of platform use in the construction sector.

Part II: Simulated Study

- Platform type did not have a significant effect on performance or on perceived discomfort. These findings must be taken in context of the short duration treatments (5 minutes) and the small sample size (n = 12).
- Anterior deltoid and upper trapezius median (50^{th} percentile) EMG activity were significantly affected by Platform and Task, and the Task by Platform two way interaction (each $p<0.05$). But for the peak (90^{th}) EMG data only

Task was significant; Platform was not. The main finding was that muscle activity (50th and 90th percentile EMG data) was considerably higher for hand intensive work (cabling and assembly) on the ladder versus MEWP. But for drilling, the only power tool treatment, the differences in platform effects were considerably lower, and sometimes reversed (compared to cabling and assembly) suggesting ladder work to be more suitable.

- Working on a MEWP was not found to increase task performance or lower discomfort in this study. But the EMG data show that MEWP work involved lower shoulder muscle loading for cabling and assembly task in particular. It is necessary to study these conditions in longer duration treatments to better understand fatigue effects as they would apply in an actual workplace.

6. References

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Figure 1 Photo of a participant on the MEWP cabling

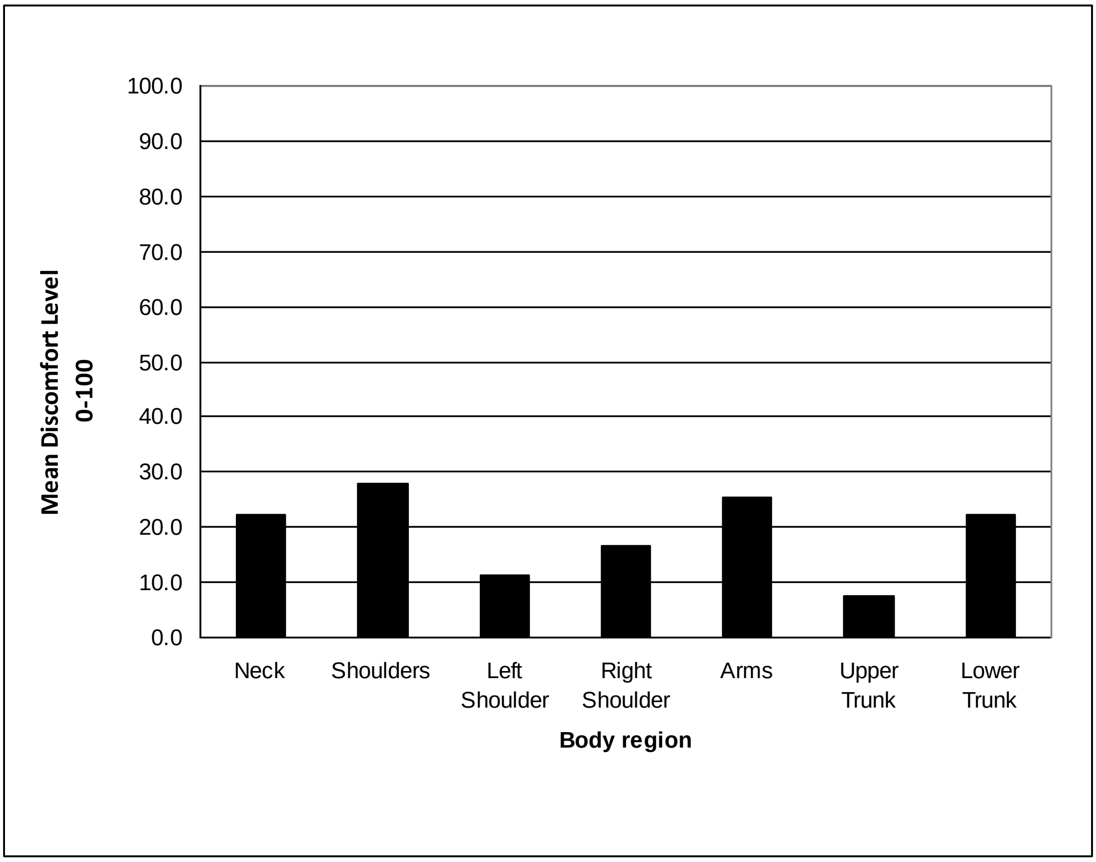

Figure 2 Mean discomfort by body region

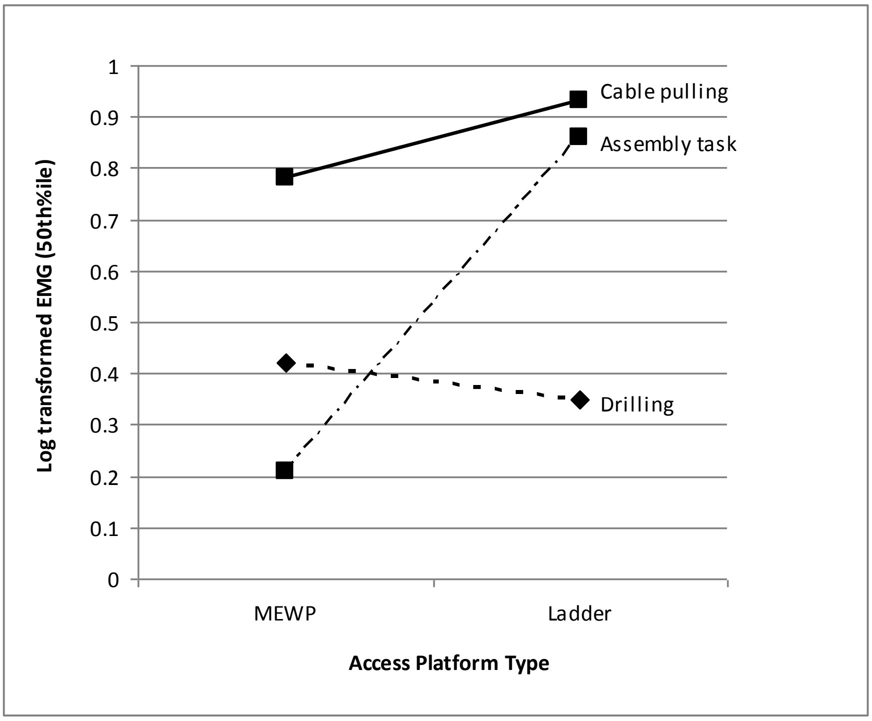

Figure 3 Transformed average 50th percentile EMG activity for the Anterior Deltoid for Platform versus Task. Task, Platform and Task X Platform were significant at min $p<0.01$

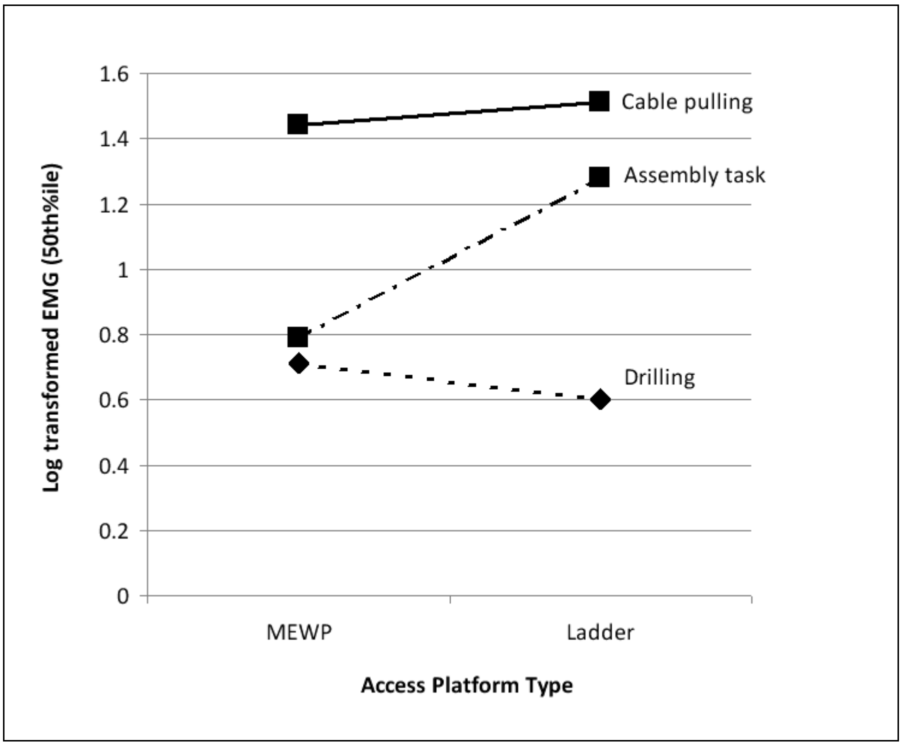

Figure 4 Transformed average 90th percentile EMG activity for the Anterior Deltoid for Platform versus Task. Task and Task X Platform were significant at $p<0.01$, Platform was not significant $p = 0.07$.

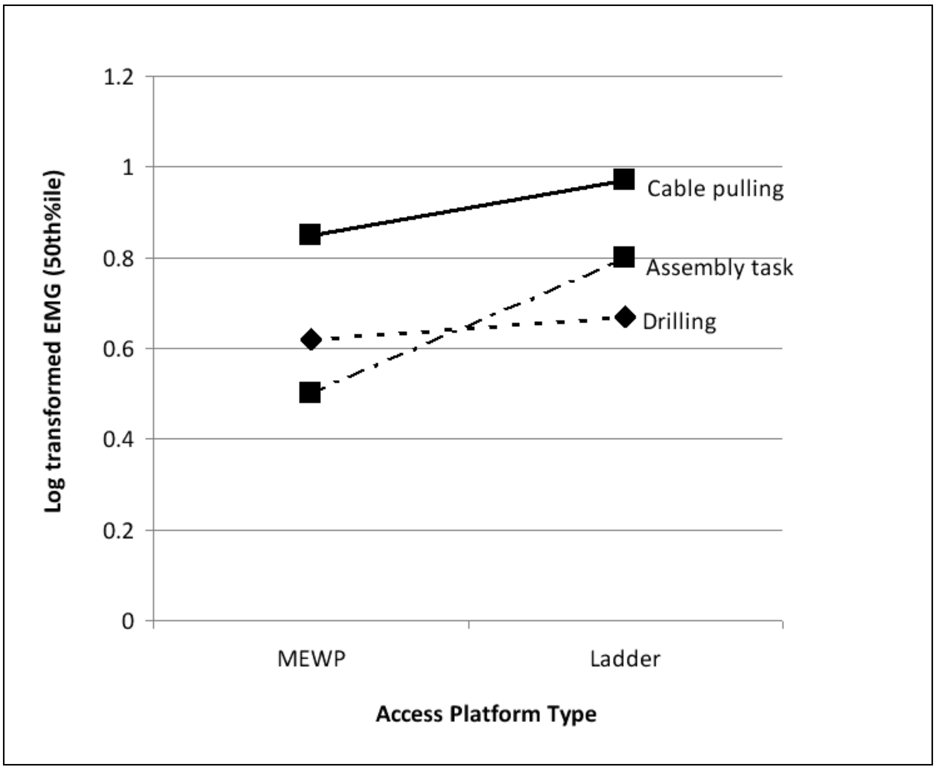

Figure 5 Transformed average 50th percentile EMG activity for the Upper Trapezius for Platform versus Task. Platform and Task were signficant at $p < 0.05$)

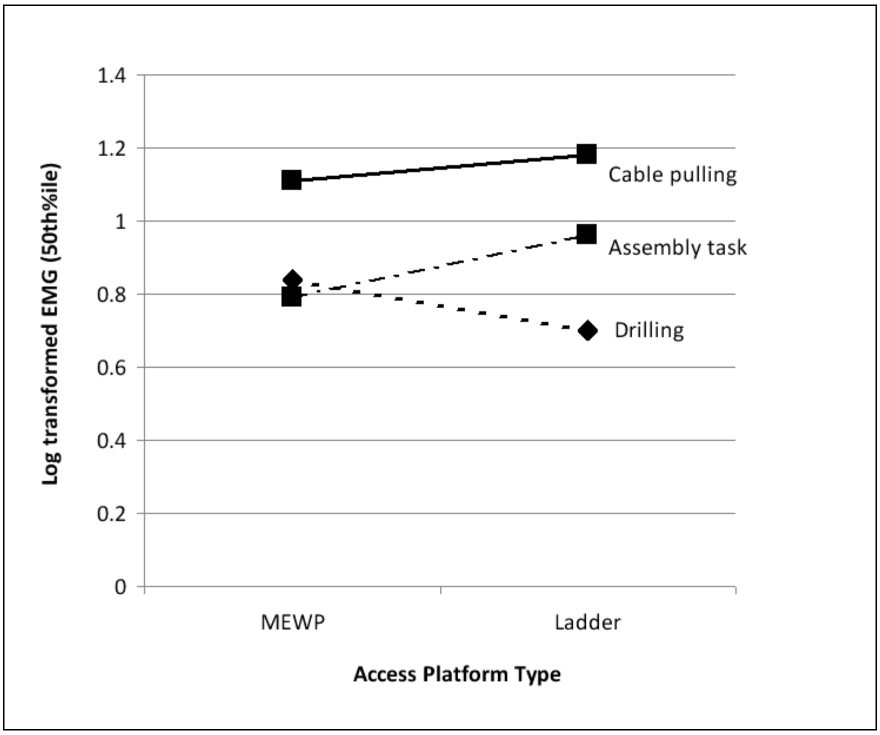

Figure 6 Transformed average 90th percentile EMG activity for the Upper Trapezius for Platform versus Task. Task was significant ($p<0.01$) but Platform was not ($P=0.5$)

Table 1 Percentage time on working platforms and other activities (n = 19)

Activity	**Mean**	**Std Deviation**
Working on a ladder	27.9%	13.5
Working on a MEWP	5.8%	8.5
Working on other access platform	3.3%	7.0
Working on ground	37.0%	14.9
Completing safety documentation	10.4%	3.4
Other (retrieving materials etc)	15.6%	7.5

Table 2 Average raw and transformed % MVE data (50th & 90th percentiles) for the Anterior Deltoid

	Raw				Log transformed			
	50th %ile		90th %ile		50th %ile		90th %ile	
	Ladders	MEWP	Ladders	MEWP	Ladders	Mewp	Ladders	MEWP
Drilling Task	2.24	2.63	3.98	5.13	0.35	0.42	0.6	0.71
Cable Pulling Task	8.51	6.03	32.36	27.54	0.93	0.78	1.51	1.44
Assembly Task	7.24	1.62	19.05	6.17	0.86	0.21	1.28	0.79
Mean	6.00	3.43	18.47	12.95	0.71	0.47	1.13	0.98

Table 3 Average raw and transformed % MVE data (50th & 90th percentiles) for the Upper Trapezius

	Raw				Log transformed			
	50th %ile		90th %ile		50th %ile		90th %ile	
	Ladders	MEWP	Ladders	MEWP	Ladders	Mewp	Ladders	MEWP
Drilling Task	4.17	4.68	6.92	5.01	0.62	0.67	0.84	0.7
Cable Pulling Task	7.08	9.33	12.88	15.14	0.85	0.97	1.11	1.18
Assembly Task	3.16	6.31	6.17	9.12	0.5	0.8	0.79	0.96
Mean	4.8	6.8	8.7	9.8	0.7	0.8	0.9	0.9