The effect of ladder climbing on forearm function

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ABSTRACT

Wind energy technicians are required to be capable of manual ascent of turbines before conducting essential maintenance. This mandates vertical ladder ascent which involves considerable forearm exertion which may have implications for such maintenance tasks. This study aimed to quantify the effect of a simulated and continuous climb of an 80m turbine on: grip strength; a pegboard test assessing fine motor control; and a hand-tool dexterity test. These were performed prior to and immediately post-climb and 15 minutes post-climb for the data collection. A convenience sample of ten healthy adults was recruited and underwent two familiarisation sessions with ladder climbing and manual tests. Results displayed wide inter-individual variability and indicated significant loss of grip strength (21-25%) and a tendency towards a loss of fine motor control (pegboard, mean 5% loss, NS) although hand-tool test data were equivocal. The scores acquired 15 minutes post-climb suggest task learning was incomplete, and that this may have masked an immediate post-climbing loss in function. Taken together these results have implications for: tasks expected of wind technicians; recruitment to a burgeoning wind energy industry; and for the design of future studies which will fully quantify these factors and thereby increase the effectiveness of individuals undertaking manual tasks after vertical ladder climbing.

KEYWORDS

Vertical ladder climbing, forearm function, fatigue

Introduction

In a burgeoning wind energy industry which underpins the UK's stated green energy policy and targets, and also in other growing professions such as offshore oil installation decommissioning, there is an unprecedented number of individuals whose duties include prolonged repetitive ladder climbing. While ladders are not new to industry, more traditional industries and professions have undertaken ladder climbing on pitched and shorter vertical ladders than some typical of the energy industry today. Maintaining wind turbines involves accessing the nacelle (the elevated housing containing the gearing and equipment) which, in a large onshore turbine is typically 80m high and may be up to double this height offshore. Despite lift access in some newer turbines, wind energy technicians routinely scale vertical ladders of this height up to three times per day. Lifts will not operate when technical issues or adverse weather conditions mandate, and anecdotal evidence suggests some workers prefer to climb manually even when the lift is operational.

Moving the body vertically is profoundly more energetic than most other types of movement. For a given height gained, climbing a vertical ladder demands a greater effort and physiological response than a pitched one (Barron et al., 2017). While the requirement for accelerating and raising the centre of mass may be relatively similar, a pitched ladder enables a person to 'stand in balance' where the area of the base of support contains the vertical projection of the centre of mass. This is not the case for vertical ladders where the centre of mass projected vertically falls outwith the base of support. This exerts a turning moment on the body, and so to prevent it pivoting backwards, a much greater isometric contraction of the forearm flexors and extensors is needed to grip the ladder rungs or rail. By comparison to the postural muscles of the legs, these relatively small muscles work disproportionately hard and fatigue more rapidly when climbing vertically.

It has been understood for a long time that fatigue is a peripheral concept. In his landmark paper on hand strength and fatigue, Merton (1954) observes that maximum voluntary strength equates to maximal tetany, and that when strength fails, no amount of electrical stimulation of the motor nerve can restore it. He also notes that recovery from fatigue does not occur if circulation to the muscle is arrested. Contemporary physiology suggests adaptation of muscle is mediated through: signal transduction pathways which respond to energy turnover, hypoxia, muscle contraction, systemic exercise and stretch receptors (Wackerage et al., 2011); and an efficient technique which may relate to optimisation of motor unit discharge (Korantz et al., 2005). This science leads us to expect those who climb regularly to quickly develop forearm strength and efficiency at climbing because of adaptive processes.

Above-average fitness has been deemed appropriate for UK wind technicians by the industry abstracting a fitness score of 35 ml/kg/min as a minimum (Renewable UK, 2013). While aerobic fitness remains fundamentally important, consideration is also required for aspects of grip strength and fine motor control. These are not tested formally as a part of the medical screening procedures. Such screening seeks, among other factors, to uncover existing musculoskeletal issues which ladder climbing may exacerbate. However, the research base which underpins our understanding of risk factors for ladder climbing is generally scant, diverse and dated. A systematic review conducted on the limited available evidence (Cooper et al., 2013) recognised ladder climbing to be associated with an increased risk of musculoskeletal disorder, specifically low back pain and knee osteoarthritis; and that this was exacerbated by adopting stooped or kneeling postures and by workers having a high body mass index.

Generic risk factors for musculoskeletal disorders such as epicondylitis or wrist tenosynovitis include posture, force and repetition (Bernard, 1997). Applying the principles of the Rapid Upper Limb Assessment (RULA) tool (McAtamney & Corlett, 2005) to vertical ladder climbing: shoulders are elevated and flexed; lower arms are continuously raised above the horizontal (while upper arms remain near horizontal) and are subjected to repetitive loading for the duration of the climb. Minimum loading equates to the participant's body weight plus personal protective equipment. Climbing styles vary according to the rung or rail grip preference, although many designs of wind turbine ladders do not have side rails, in favour of a central falls-arrest channel and elevated side flanges on each rung. Whatever the configuration may be, protracted repetitive loading is inevitable because the climber has no choice but to alternately grip and release with each hand, although personal style preference and ladder configuration may vary the loading and recovery with each forearm exertion cycle. While this suggests that exposure to a risk of musculoskeletal injury may be inevitable for wind technicians from ladder climbing, there is currently no published evidence of a causal link. As a result, it is not known whether the response to stresses borne by such individuals are cumulative or adaptive.

The problem

After a ladder climb, wind energy industry workers (as well as those of other professions) may be required to undertake specialised skilled work demanding manual dexterity. If forearm muscles are pre-exhausted from the prior activity of ladder climbing, we hypothesise this would logically reduce their effectiveness, and possibly intensify injury risk when subsequently undertaking certain manual tasks. Support for this lies in the prominence of risk assessments which include load magnitude and repetition in their metrics (Li & Buckle, 2004). While little is understood about the effect of prolonged vertical ladder climbing on manual tasks, Tipton et al. (2013) highlighted the importance of work rate on occupational fatigue, presenting the work of Milligan (2010) on climbing a ten rung ladder at three different speeds. Grip strength was shown to be significantly reduced after ladder climbing, and to a significantly greater extent after climbing at a faster speed. The effect on more fine motor coordination may be expected to be similar, but there appears to be no research evidence to support this.

Investigation & analysis

This pilot study sought to address some of these factors by laying the necessary groundwork for designing a larger study using a customised vertical ladder ergometer capable of simulating any climb in a safe laboratory setting.

Method

A convenience sample of five men and five women aged between 18 and 60 with no ladder climbing experience was recruited. After screening for physical activity readiness, two familiarisation visits were undertaken to the ergonomics laboratory for ladder climbing, and practice with all three tests of forearm function. These, in order of their execution, were as follows:

- A handgrip dynamometer test to assess maximum strength, alternately testing three times each for the left and right hands.
- The Purdue pegboard test to assess fine motor control, involving placing pegs in vertically in hole slots in a standard board. This test involved separate assessments for the left and right hands placing pegs in a line of holes within a time limit of 30s.
- A hand tool dexterity test. This required 12 nuts and bolts of differing size to be undone and re-inserted and secured in a standard wooden frame in the minimum time (typically 3 – 6 minutes). These tests are illustrated in Figure 1.

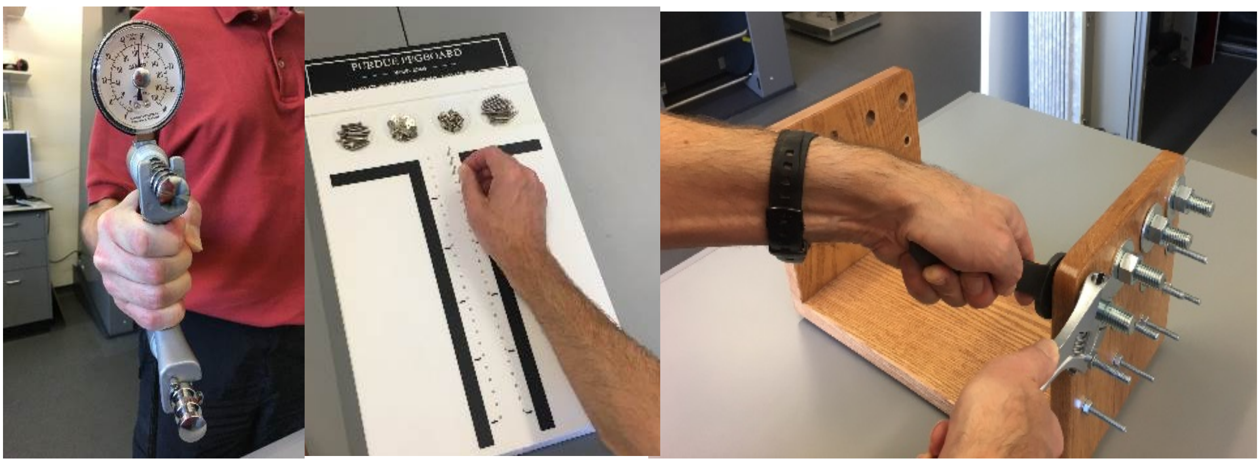

Figure 1: Left: Grip strength dynamometer; Centre: Purdue Pegboard; Right: hand tool dexterity

After familiarisation visits, at least two full days were required to elapse before the testing day to ensure full recovery. The test protocol involved the forearm tests being completed before, immediately after and 15 minutes after a continuous 80m climb on the ladder ergometer (simulating the ascent of a large onshore turbine). The protocol is illustrated in Figure 2.

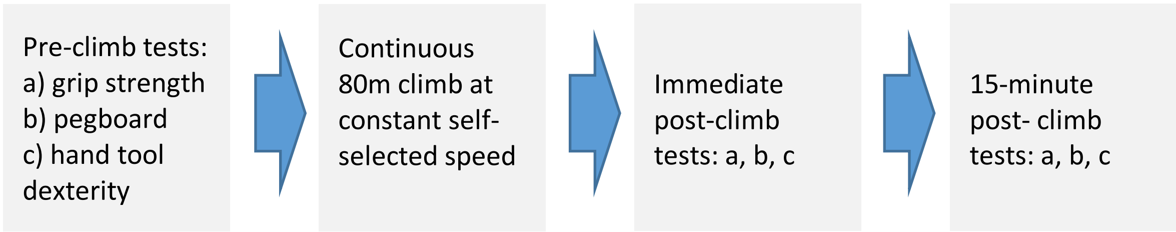

Figure 2: Protocol

Heart rate was continuously monitored during the ladder climbing task as a precaution, so that any participant achieving a theoretical maximal heartrate (220 – age) would be prevented from continuing. The rating of perceived exertion was recorded each minute throughout the climb. The outcome variables were as follows: grip strength (L and R; best of three attempts in succession); number of pegs placed in 30s (L and R); total time to remove and re-secure all 12 bolts on the wooden frame. Stature and mass were also obtained from participants using standard procedures (Stewart et al., 2011).

Results

Participants were aged 32.9 ± 12.0 y, had stature 172.4 ± 10.3 cm and body mass 78.7 ± 21.3 kg (mean ± SD; n= 10, data pooled for men and women). There was a correlation between grip strength and body mass ($r = 0.79$, $P<0.01$), but neither of these correlated with rating of perceived exertion for the last minute of climbing. Grip strength results are depicted in Figures 3 and 4.

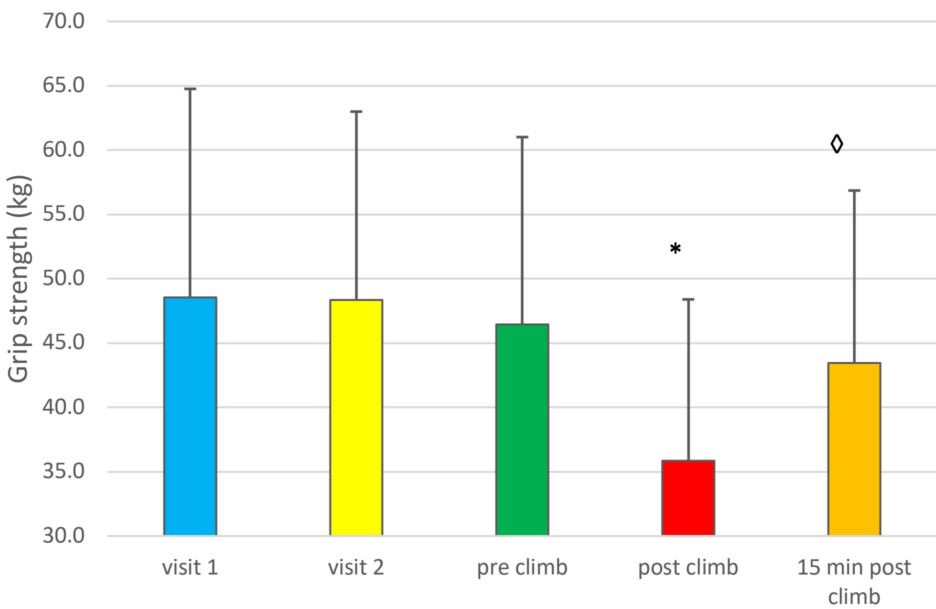

Figure 3: Best grip strength (highest score of L or R)
* Different from pre-climb, P = 0.002; ◊ P = 0.33
Error bars refer to 1 SD

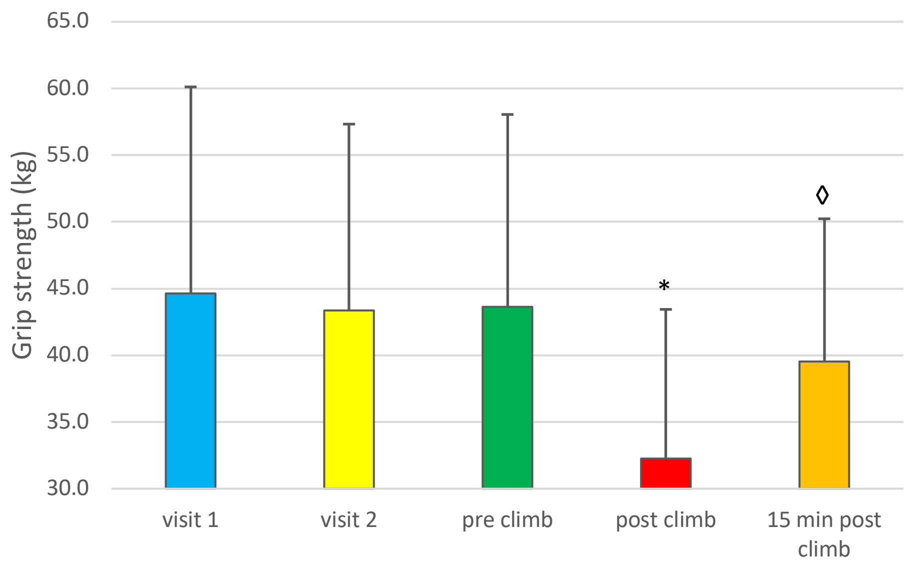

Figure 4: Grip strength average of L and R hands
* Different from pre-climb, P = 0.001; ◊ P = 0.007
Error bars refer to 1 SD

Pegboard results are illustrated in Figure 5.

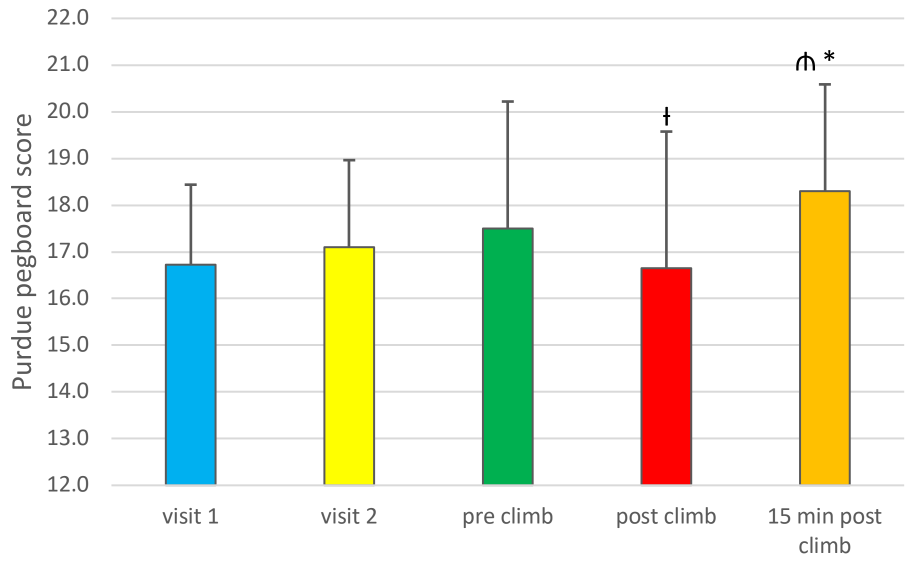

Figure 5. Pegboard test (average of L and R)
Ɨ Not different from Pre-climb, P= 0.13;ᕰ P=0.078; * Different from post climb P = 0.001
Error bars refer to 1 SD

Hand tool dexterity results are given in Figure 6.

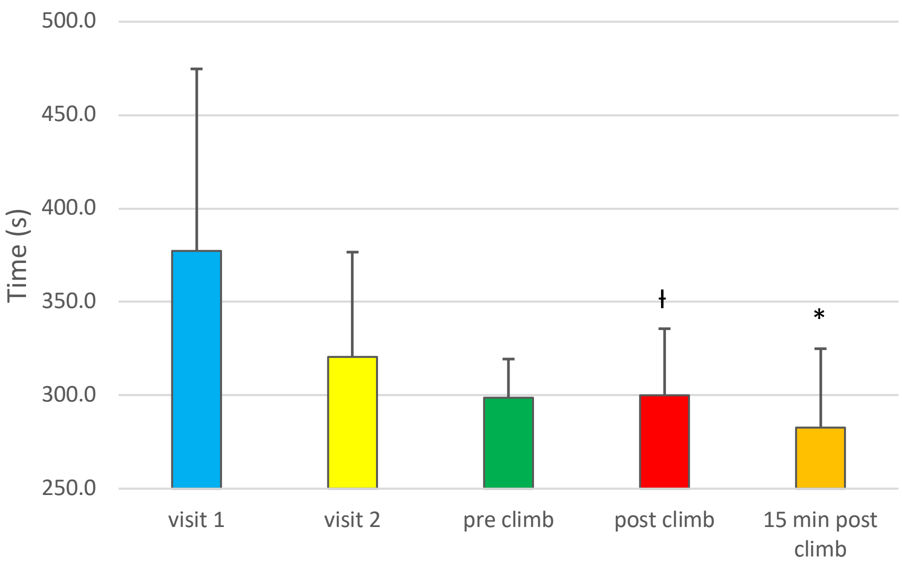

Figure 6: Hand tool dexterity
ɫ Not different from pre-climb, P=0.82; * P = 0.006
Error bars refer to 1 SD

Discussion

These results illustrate a clear effect of ladder climbing on grip strength, which was not fully recovered within 15 minutes after climbing ceased. The observed difference in pegboard test scores did not reach significance post-test, but significantly improved 15 minutes following the climb, underscoring that learning was incomplete for this task. This suggests a measurable effect of ladder climbing on fine motor tasks might be present if either a larger sample was measured or learning had completed. There was no observed effect of ladder climbing on hand tool dexterity immediately post-climb (P = 0.18) for the same reasons, however, scores significantly improved between immediately post-climb and 15 minutes post-climb (P = 0.006) confirming that skill learning was still taking place.

The data from Figures 5 and 6 suggest the learning effect for both pegboard and hand tool dexterity tests may not have been overcome, and that participants were still becoming more adept at the tests at the time the main intervention took place. Consequently, it is proposed that a longer familiarisation for both these is essential. This will inform the protocol for a follow-up study.

Impact and implications

The type of work wind technicians are required to conduct after a turbine climb may be compromised if it involves high grip strength. While the data on pegboard scores did not show a significant effect, it is also possible that a larger study will demonstrate fine motor control is also compromised for several minutes following a climb. To reduce the confounding factors of this study, a continuous climbing protocol was used at a self-selected sustainable speed, identified at two familiarisation trials. However, the reality of climbing wind turbines is such that the climb is generally completed in sections separated by trap doors, although designs vary widely. Further work is necessary to establish the magnitude of the effects of climbing on forearm function with both continuous and intermittent climbing protocols. It is equally important to ascertain whether these findings on healthy and fit young adults without prior experience of ladder climbing apply to industry professionals. Even so, the knowledge base created by such future work must equally inform those whom the industry seeks to recruit.

While little is known about the optimal climbing strategies individuals should adopt to minimise the 'down time' after the ladder ascent, it is clear there is wide inter-individual variability in functional response. A participant also needs to balance whole body fatigue against specific forearm fatigue. Future research should focus on optimising this balance because it could increase the effectiveness of a technician's use of time and reduce injury risk after climbing a wind turbine.

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