An ergonomic assessment
of manual timber extraction

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Summary

Assessment of the manual extraction of first thinnings of a pine plantation indicated a high level of strain being placed on both the cardiovascular and biomechanical systems of the subjects. This task needs to be adjusted in order to avoid accidents resulting from fatigue, as well as to prevent the development of work-related musculoskeletal disorders specifically in the shoulders and lower back. Included in this report is an explanation of the methodology used to assess the task, an in-depth discussion of the results and the provision of some recommendations relating to both cardiovascular and biomechanical strain.
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Introduction

The manual extraction of timber is a biomechanically and physiologically strenuous task resulting in high demands being placed on both the workers' musculoskeletal and cardiovascular systems. A continual mismatch between task demands and worker capabilities results not only in their bodies taking strain, but also a decrease in their work capacity which negatively impacts on their performance ability. The accumulative effect of task demands that repeatedly exceed the biomechanical capacity of the worker while performing a task, will lead to the onset of work-related musculoskeletal disorders (WMSD). Factors contributing to these occupational disorders include poor postures, repetitive motions, forceful movements and heavy lifting. Similarly, physiological demands that exceed worker capabilities will have a deleterious impact on the workers' general and occupational well-being, as they result in the premature onset of fatigue which is associated with decreased cognitive and physical ability. This decreased vigilance and the increased risk taking behavior associated with fatigue exacerbates the likelihood of accidents and injuries (Lilley et al., 2002).

Methodology

In order to conduct a holistic analysis of the manual timber extraction task, both the task demands and worker responses to the task were assessed.

Task requirements

The task assessed was first thinnings of a pine plantation conducted in the Sabie area in May 2006. The workers carrying out this task were required to manually move logs from within the plantation to the roadside, from where they are transported. The task involved lifting, maneuvering, rolling, carrying and lowering of logs averaging approximately 50 – 60 kg, with the heaviest being up to 110 kg. The task was determined by the supervisor at the start of every day depending on the size of the logs to be extracted, the gradient of the terrain and the distance to the roadside.

Subject responses

Twelve workers were assessed. All workers were male and their average age was 29 years, with the youngest worker being 17 and the oldest being 49 years. The workers had been working in the forestry industry for an average of approximately three and a half years. However, on average they had only been employed to carry out manual timber extraction for 18 months (See Table 1). The time for which employees work in this task is expected to be relatively short as a result of the demanding nature of the task.

Basic anthropometric measurements were made including the measurement of stature and mass. These data were used to calculate body mass index (BMI) which gives an indication of the percentage body fat. The BMI of someone with an "ideal" body mass would be between 20 to 24.9; any value below 20 is considered underweight, and a value of above 25 is considered overweight; a value of
above 30 indicates obesity (Pheasant, 1996). As shown in Table 1, the average BMI for the subjects assessed in this study was 22.01, indicating that these workers were generally of ideal body mass, and only one subject had a BMI of less than 20.

Before the start of work the subjects were fitted with heart rate monitors which were used to assess their physiological responses to the task. Reference heart rates ranged from 48 to 69 b.min⁻¹ with an average of 60 b.min⁻¹ (Table 1). These reference heart rates are reasonably low thus indicating that the subjects were reasonably fit in terms of their cardiovascular systems.

Table 1. Basic data for workers in a study of manual timber extraction conducted in Sabie.

<table>
<thead>
<tr>
<th></th>
<th>Mean (Standard Deviation)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.25 (9.36)</td>
<td>17</td>
<td>49</td>
</tr>
<tr>
<td>Months in forestry</td>
<td>44.00 (40.73)</td>
<td>5</td>
<td>144</td>
</tr>
<tr>
<td>Months in task</td>
<td>18.25 (17.14)</td>
<td>2</td>
<td>62</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>175.83 (7.02)</td>
<td>167</td>
<td>189</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>68.13 (6.35)</td>
<td>57.9</td>
<td>82.6</td>
</tr>
<tr>
<td>BMI</td>
<td>22.01 (1.24)</td>
<td>19.57</td>
<td>23.67</td>
</tr>
<tr>
<td>Reference HR (b.min⁻¹)</td>
<td>60 (7.06)</td>
<td>48</td>
<td>69</td>
</tr>
</tbody>
</table>

Biomechanical responses were measured with the use of digital photographs and the 3D Static Strength Prediction Program™ (3DSSP). This software programme compares the posture captured by the photograph with the ability of the joints to withstand this posture, giving a percentage of the population who would be able to sustain the posture without developing injuries. Although the 3DSSP software programme is a static tool used to assess postures, it does provide an indication of the negative impacts of poor working postures, highlighting the joints that are worst affected. All working postures captured by digital photographs were analysed using this software programme.

The perceptual responses of workers were obtained with the use of a body discomfort map devised by Corlett and Bishop (1976), which was explained to the subjects prior to the commencing of data collection. As Carter and Banister (1994) point out, body discomfort is the first symptom of the development of a chronic WMSD, so by obtaining an indication of the discomfort one can adjust the task accordingly in order to prevent the onset of an injury in that particular part of the body.

To measure the effect of the task on gross motor ability, the Minnesota gross motor control test was conducted before and after work to see if any changes had occurred. The theory behind this being that the onset of fatigue impairs both physical and cognitive ability, thereby negatively impacting on gross motor ability. A decrease in gross motor control is indicative of an increased risk for errors and accidents. This test, which is illustrated in Figure 1, requires the subjects to turn over the cylindrical pieces on the testing board as quickly as possible.
Results and discussion

Physiological responses

The literature clearly states that for an 8-hour work shift working heart rates should not exceed 115 b.min\(^{-1}\), and according to Ayoub and Mital (1989) the optimal heart rate zone for a working day is between 90 – 110 b.min\(^{-1}\). Heart rates that exceed this target zone lead to the premature onset of physiological fatigue and a resultant decrease in both mental and physical capabilities.

On average, the mean working heart rates of the workers manually extracting timber was 105 b.min\(^{-1}\) (see Table 2). Although this is within the target zone, on the first day of testing the workers were clearing timber out of a burnt plantation which they said was not as taxing as a “normal” day. This was reflected in the heart rate data which was significantly lower on the first day when compared to the second day (\(p < 0.001\)). The mean heart rates of the workers assessed on the second day of testing were 117 b.min\(^{-1}\) with the maximum average being 125 b.min\(^{-1}\). Therefore, workers performing manual timber extraction on a “normal” day are likely to experience physiological fatigue, reduced performance ability and a higher risk of committing errors and being involved in accidents. Furthermore, a number of the subjects had heart rates in excess of 160 b.min\(^{-1}\) and up to 169 b.min\(^{-1}\), which is almost 90% of a 30 year old person’s maximum heart rate capability. This is exceptionally high for a manual task that is to be carried out for up to eight hours per day.

<table>
<thead>
<tr>
<th>Table 2: Average heart rates (HR) of workers over each testing day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
</tr>
<tr>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Lowest average HR</td>
</tr>
<tr>
<td>Highest average HR</td>
</tr>
</tbody>
</table>

\(\ast\) denotes significant difference between Day 1 and Day 2 (\(p < 0.001\))

Figure 2a illustrates the heart rate response for the individual with the maximum average working heart. It is evident that from the start of work this subject’s heart rate was above the recommended target zone of 90 – 110 b.min\(^{-1}\). The enforcement of regular rest breaks would result in a heart rate graph similar to that in Figure 2b where the mean heart of this subject, calculated hypothetically, was reduced from 125 b.min\(^{-1}\) to 107 b.min\(^{-1}\). The areas on the graph where the heart rate is below the target zone are where good cardiovascular recovery is possible.
Figure 2. Heart rate graph for the subject whose mean heart rate was 125 b.min\(^{-1}\) (a) and the hypothetical implementation of regular rest breaks (b).

Physiological response recommendations

- Regular rest breaks should be enforced to ensure that the cardiovascular system has sufficient time to recover. This will help to ensure that average working heart rates fall within the target zone, thereby reducing the cardiovascular load imposed on the workers and reducing the likelihood of premature fatigue.
- Workers must be encouraged to eat and drink during these rest breaks to ensure that energy stores are replenished and dehydration is avoided.
- Sufficient cool and fresh drinking water should be provided to the workers (four to five litres should be provided per person for an eight-hour shift).
Biomechanical responses

Various different techniques were used to move the logs to the roadside, depending on worker preferences and the gradient of the terrain. These techniques included carrying on the shoulder, rolling, lifting and pushing, and “throwing”. A flatter terrain, such as that on day one, forced the workers to carry the logs rather than roll them as they did on the second day when the terrain was substantially steeper (see Figure 3).

![Figure 3](image.png)

**Figure 3.** Flatter terrain on day one (a), and steeper terrain on day two (b).

In the following five figures, graphs from the 3DSSPP analysis have been included. These graphs indicate the percentage of the working population who would be capable of carrying out the task using the depicted postures without sustaining an injury. Based on theoretically accepted norms, the green part of the graph indicates an acceptable joint posture, the yellow indicates partial acceptability and the red is unacceptable.

**Figure 4a** indicates a lifting technique used to “roll” the log. The log was lifted from the ground using this stooped posture, which given the weight of the average log, is suitable for less than 75% of the population in terms of the elbows, torso, hip, knee and ankle joints. In addition, this posture results in an unacceptable 10193N of compressional force being placed on the lower back (**Figure 4b**).
Figure 4. Stoop ping posture assumed while lifting logs (a), and the postural demands resulting from this posture (b).

The lengthwise “rolling” posture is illustrated in Figure 5a. As demonstrated in Figure 5b, this posture is unsuitable for the entire population and it results in 6803N of compression on the lower back. Furthermore, the foot position results in the balance being “unacceptable” thereby placing the workers at a high risk for slip, trip and fall accidents. This risk is exacerbated by the uneven terrain and the abundant existence of other logs and brush over and through which the workers are expected to work.

Figure 5. Posture assumed while “rolling” logs (a), and the postural demands resulting from this posture (b).
Figure 6a demonstrates a similar technique carried out by a different subject. In this example the strain placed on the shoulder joint is substantially lower, and 79% of the population would be capable of carrying out this task using this posture and not developing a shoulder injuring, compared to 0% using the posture depicted in Figure 5a. In addition the compression force on the low back decreased from 6803N to 5416N, which although still high it is an improvement. These improvements are considerable and are the result of the lower height at which the log was handled (i.e. the overhead factor was reduced substantially). The strain experienced by the elbow is however increased in Figure 6a. This is because the elbow joints were moderately more flexed thereby having to cushion more of the weight of the log, compared to when they were extended as in Figure 5a. Once again these workers have an unacceptable balance and are therefore at a high risk of slip, trip and fall accidents.

Another rolling technique is shown in Figure 7a, where once again the majority of joints would be at risk of developing injuries in most of the population (Figure 7b), and the compressional force on the spine is an unacceptable 14212N. The position of the feet places the individual at risk of slipping thus making balance “unacceptable”.

Figure 6. Posture assumed while carrying logs (a), and the postural demands resulting from this posture (b).
As mentioned previously, some of the workers actually carry logs on one shoulder, especially when the terrain is flat (see Figure 8a). As can be seen in Figure 8b, although the majority of the joints are at low-moderate risk (green – yellow), the shoulder and torso are of great risk of developing WMSDs (red). Perceptual responses, which are discussed in the following section, reflect the onset of chronic injuries in these joints. Because of the upright posture of this subject, yet the high load being carried, the force on the lower back is of moderate-to-high risk with the force being 5513N. The high load carried unilaterally forces the center of gravity to the side of the base of support thereby negatively impacting on the individual’s balance to an unacceptable degree.
Perceptual responses

The body discomfort results reflect the biomechanical responses to a large degree. As can be seen from Table 3, discomfort was experienced in most parts of the body. All of the subjects experienced shoulder discomfort, mostly at a relatively high intensity, and 50% of the subjects stated that they had tingling sensations in the rest of the arm and hand. As Sanders and Haug (1991) point out, these tingling sensations are a common symptom of a WMSD known as Thoracic Outlet Syndrome (TOS), which results from the impingement of the neurovascular bundle consisting of the brachial plexus, C8 and T1 nerve roots, and the subclavian artery and vein in the costoclavicular space, which lies between the clavicle and the first rib. This is a debilitating disorder resulting from factors such as the carrying of heavy loads hung from the shoulder or carried on the shoulder, as well as frequent overhead arm movements. Both these factors are illustrated in the biomechanical responses and these forestry workers could therefore be at high risk for the development of shoulder and neck problems.

Furthermore, the actual contact between the logs and the surface of the body, whether it is the shoulder or torso area, results in substantial discomfort. This is because there is no cushioning between these two hard surfaces to help absorb some of the pressure.

Table 3. Areas of the body and percentage of subjects who experienced body discomfort.

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Percentage of subjects experiencing discomfort</th>
<th>Intensity range (1 – 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulders</td>
<td>100 %</td>
<td>3 – 9</td>
</tr>
<tr>
<td>Lower back</td>
<td>50 %</td>
<td>3 – 8</td>
</tr>
<tr>
<td>Ankles</td>
<td>42 %</td>
<td>3 – 7</td>
</tr>
<tr>
<td>Upper arms</td>
<td>33 %</td>
<td>5 – 7</td>
</tr>
<tr>
<td>Torso</td>
<td>25 %</td>
<td>3 – 4</td>
</tr>
<tr>
<td>Knees</td>
<td>25 %</td>
<td>3</td>
</tr>
<tr>
<td>Thighs</td>
<td>17 %</td>
<td>7</td>
</tr>
<tr>
<td>Lower legs</td>
<td>17 %</td>
<td>3</td>
</tr>
</tbody>
</table>

The high compression forces ranging from 5416 – 14212 N placed on the spine are responsible for the discomfort in the lower back of the 50% of subjects. In addition to the high compression forces, a great deal of the tasks required lateral bending (see Figure 9a) of the spine and axial rotation (twisting of the spine) (see Figure 9b). These factors increase the demands placed on the lower back, and once again, this joint is at high risk for the development of a WMSD.
The high incidence of discomfort experienced in the ankles is reflective of the unacceptable balance as a result of the poor foot positions, which were discussed in the biomechanical responses. A lack of ankle support in the footwear of these workers could be a compounding factor.

The shoulder joints and lower back exhibited the worst discomfort in terms of both the percentage of subjects experiencing the discomfort and the intensity of discomfort. WMSD in these joints can be exceptionally debilitating and every effort should be made to prevent these from occurring. As Carter and Banister (1994) stated, musculoskeletal discomfort is often simply resolved by rest. However, the underlying cause of the discomfort must be investigated to prevent the progression to a disabling musculoskeletal disorder.

All responses to this task indicate excessive strain being placed on the entire body.

Biomechanical and perceptual response recommendations

- As recommended for physiological responses, rest breaks are important to allow the musculoskeletal system time to recover. This will help provide relief from physical body discomfort and it will also help reduce the risk of developing a WMSD.
- Workers should be educated about the ill-effects of poor working postures and WMSDs, and they should be sensitized to the sensation of body discomfort, which is often ignored or simply “worked-through”. When workers start to experience physical discomfort they should be encouraged to modify their working postures or techniques so that the body part in which discomfort is being experienced can be rested and the load be placed on another body part to allow for recovery of the musculoskeletal structures.
- Task diversity and job rotation are two important ways in helping overcome the strenuous
nature of physically demanding work. If workers can be rotated between different jobs where the task demands vary, the likelihood of chronic fatigue and the development of WMSDs is considerably reduced. Ideally manual timber extraction workers should be rotated into a task where the postural demand is substantially reduced.

- Poor postures that were observed and should be minimised include:
  - Excessive stooping (see Figure 4a and 7a)
  - Twisting of the spine, particularly while stooping
  - Overhead use of the arms (see Figure 5a and 8)

- The use of a mechanical claw (Figure 10), such as those used by stackers, should be considered. This will prevent the workers from having to stoop to such an extent.

![Figure 10. Example of a mechanical claw.](image)

- The negative impact of overhead use of the arms can be reduced by lowering the height at which the log is handled. The benefits of a small change in this height are evident when comparing Figure 5b and 6b.

- The loads being carried on the shoulder (see Figure 8a) were up to approximately 100 kg. **THIS SHOULD NOT BE ALLOWED.** Workers should not carry three logs on a shoulder and heavier logs that need to be carried in this way (see Figure 9a) should be done by two people. Consideration should be given to the maximum acceptable weight to be lifted and carried by one person.

- It should be ensured that the footwear of these forestry workers provides sufficient ankle support. This will help to reduce the strain placed on the ankle joints, as well as the resultant discomfort currently experienced in this joint.

- The workers should be consulted as to other possible interventions. Some of the workers have clearly been quite innovative and they have started using foam padding to help reduce the contact pressure between the log and the body surface. This is demonstrated in Figure 11. Based on this idea, the use of some form of padded protective vest could be considered.
Another possible intervention that could be considered is the use of a “sling” type device which could be used to assist with the carrying of logs. This device could fasten around the waist to transfer the bulk of the load to the hips and lower extremity rather than the whole load being carried on the shoulders and upper extremity.

**Gross motor ability**

With the high physiological and biomechanical demand, the subjects were likely to experience cardiovascular and musculoskeletal fatigue, which is said to negatively impact on gross motor control. However, it is evident in **Table 4** that the subjects’ results did not differ significantly pre- and post-work, with the time taken to complete the pre-work test being 90.06s and that taken to complete the post-work test being 86.47s. The minimum and maximum values reflect the shortest and longest times taken to complete the task both pre- and post-work. Although it is proposed that the post-work improvements occurred as a result of a “learning effect”, it is encouraging to note that no significant decrease in motor ability took place. In future studies it is suggested that the subjects be allowed to practice the test a few times before the pre-work test, so that the test is already “learnt” before both pre- and post-work tests take place.

**Table 4.** Gross motor control results (time taken to turn over the 60 blocks).

<table>
<thead>
<tr>
<th></th>
<th>Pre-work test (s)</th>
<th>Post-work test (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>90.01 (10.8)</td>
<td>86.47 (11.4)</td>
</tr>
<tr>
<td>Min</td>
<td>71.0</td>
<td>69.9</td>
</tr>
<tr>
<td>Max</td>
<td>106.7</td>
<td>104.8</td>
</tr>
</tbody>
</table>

**Conclusions**

As demonstrated by the high working heart rates resulting from the high work intensity, as well as large forces placed on various joints of the body caused by the heavy loads that are maneuvered and the
poor postures adopted while maneuvering the logs, the manual extraction of timber places high physiological and biomechanical demands on the workers. This manifests itself in the early onset of fatigue as well as high levels of body discomfort, which are early “warning signs” for the development of work-related musculoskeletal disorders. Several recommendations have been made which will assist in reducing the physically demanding nature of this work, and helping the workers to better cope with the demands under which they are placed.

References