In-Season Physiological and Biochemical Status of Reforestation Workers

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Tree-planting demands sustained high work-output and is associated with high injury rates but has not been characterized previously. Data were collected from 10 male planters after 19 ± 5 (T1) and 37 ± 5 days (T2) of planting. One severe infection and one knee strain injury were noted. Loads carried were 32% ± 5% body mass and heart rates were between 60% to 75% of maximum for 57% ± 26% of the planting shift. A loss of 1.7% ± 1.5% body mass occurred, although intake exceeded 5000 kcal/day. From 8% (T1) to 27% (T2) of postprandial blood glucose samples were found to be <3.3 mmol/L. Further evidence of the cumulative stress was seen in increased levels of resting cortisol (428 ± 163 to 741 ± 103 mmol/L), norepinephrine (2.09 ± 1.34 to 3.09 ± 1.05 mmol/L), and creatine kinase (184 ± 82 to 397 ± 174 U/L) at T2. The postactivity neutrophilia and lymphophilia (absolute count, CD4+ and CD8+) observed at T1 were blunted at T2. The implications of mild hypoglycemia, including possible effects on cognitive and motor function, warrant further study. (J Occup Environ Med. 2002;44:559–567)

Approximately 250 million trees are planted in the province of British Columbia each year,¹ all by manual labor. Tree-planters are paid per piece, working from 7 to 9 continuous hours with only a few minutes’ break for food or rest. Between 150 and 200 trees/hour are planted, and planters typically cover 16 km/day over difficult terrain. In the process of said planting, 20% of tree-planters will suffer a debilitating injury, resulting in a loss of 8500 workdays per year.² This injury rate is far in excess of the all-industry norm of 5/100 workers in British Columbia, and it exceeds even occupations such as deck and fence construction (12%) or pile driving (9%).² Furthermore, many tree-planters have planted for multiple seasons, and the long-term implications for degeneration of the musculoskeletal system cannot be ignored. Certainly, any program capable of reducing repetitive-use injuries in tree-planters would have economic, social, and long-term health benefits.

Only one previous physiological study of tree-planting has been reported.³ The strenuous nature of the work was shown to contribute to what the authors called a stress syndrome.³ This type of neuroendocrine condition has been shown to lead to immunosuppression, with a reduced ability of the immune system to effect tissue repairs after injury or to ward off infections when exposed to pathological organisms.⁴

It has long been known that physical activity results in increased uptake of glucose from the blood.⁵ In very long-duration events, liver gly-
cogen stores may become depleted and blood glucose levels may decrease, despite gluconeogenesis. Because of reliance on glucose as a fuel, hypoglycemia may impair the ability of the nervous system to conduct signals and, hence, contribute to injury susceptibility.

Research in the field of exercise physiology has identified effective ways of developing strength and fitness, of sustaining output during extended periods of high load, and of enhancing recovery. These techniques have not been applied previously to the workplace in a systematic manner. Thus, this project proposed to characterize the occupation of tree-planting by determining fitness, dietary intake, blood glucose, body composition, and markers of inflammation, immune, and neuroendocrine systems as affected by the work of tree-planting.

Methods

Subjects

Ten male planters volunteered to participate in the study. Informed consent was obtained, and the rights and privileges of the subjects were observed in accordance with the Declaration of Helsinki, World Medical Association, and the Greater Trail Community Health Council Ethics Committee.

Data Collection

Data were collected at two separate sessions. Time 1 (T1) was the approximate midpoint of the spring contract, after 19 ± 5 days of planting. Time 2 (T2) was the second to last day of the contract, after 37 ± 5 days of planting. In each case, subjects were at rest for baseline measures, collected at approximately 6:00 AM, immediately upon rising. Postexercise data were collected as soon as possible after completion of the day’s planting, at both T1 and T2. A progressive multistage run to predict maximal oxygen consumption (V̇O₂max) was performed on the day preceding testing at T1.

Body Composition

Body composition was estimated from the sum of skinfolds. Skinfold thickness was measured at 6 sites (chest, triceps, subscapular, suprailiac, abdominal, and anterior thigh) using a Harpenden Skinfold Caliper.

Dietary Analysis

Dietary analyses were performed from 3-day diet histories using Diet Analysis+, Canadian version 4.0 (Wadsworth/Thompson Learning, Scarborough, Ontario). Nutritive requirements were based on the Canadian Nutrient File.

Injury and Infection History

Subjects were questioned regarding the incidence and intensity of localized pain associated with chronic or acute trauma. They were also asked to report any occurrences of infection or illness such as fever, sore throat, congestion or cough, gastrointestinal symptoms such as vomiting or diarrhea, or wounds with delayed healing.

Blood Collection and Analysis

Blood samples were collected from an antecubital vein at rest and postplanting. Serum and plasma were frozen at −20°C until analysis, within 2 weeks. Quality control consisted of two to three levels of control sera included in every run. All samples from each data collection were run in a single assay.

Serum was analyzed for C-reactive protein using the latex method, and for α1-antiprotease by radial immunodiffusion (Dade Behring, Deerfield, IL). Creatine kinase was performed on the Vitros 950 Analyzer (Ortho Diagnostics, Raritan, NJ) and cortisols were analyzed on the TDX System (Abbott Laboratories, Mississauga, Ontario). Whole blood in 7.5% ethylenediaminetetraacetic acid tubes. Samples were kept refrigerated until the plasma was separated and frozen, within 10 minutes.

Capillary samples for glucose analysis were collected from fingertip or ear directly onto blood glucose sensor electrodes (Precision Q-ID Blood Glucose Monitoring System, MediSense, Inc, Bedford, MA). At T1, fasting samples were collected before breakfast, and subjects were also sampled every 90 to 120 minutes while working. At T2, samples were collected during the planting shift, before food consumption, and at 30, 60, and 90 minutes postprandial.

Heart Rates

Heart rates were measured every 5 minutes by telemetry for an entire planting shift (Excel Sport PC, Cardiosport, Healthcare Technology, New York, NY).
Handgrip and Coordination Tests

Handgrip strength was evaluated from three maximal trials, using the Jamar Handgrip Dynamometer (Jamar, Bolingbrook, IL) according to the standard protocol of Ashford et al. The coordination test was performed as follows: Subjects were seated, back unsupported, and with one hand, palm up, on or over the knee. After a countdown, the subject tried to clap this hand with the palm, then with the dorsum of the other hand, as fast as possible for 30 seconds. One repetition was scored when a clapping sound was made with both sides of the hand in succession. This protocol is used clinically to evaluate the specific neurological condition of dysdiadochokinesia. The procedure was videotaped, and counts were made in duplicate with the film playing at slow speed.

Statistical Analysis

Analyses were performed with variables grouped according to physiological function. All means are reported as ± 1 standard deviation. Major parameters were analyzed by regression analysis or by analysis of variance with subject and time as factors. Identification of significant differences was made using the Bonferroni t procedure. The level of significance was deemed to be P < 0.05.

Results

Table 1 presents the physical characteristics of the subjects. A significant correlation was found between initial fat mass and fat loss (r² = 0.88; P < 0.0001) but not between mass loss and cortisol levels. Bag weights averaged 32% of body weight (range, 21% to 39% body weight), with the heaviest bags being carried by those individuals with the highest average planting rates (r² = 0.79; P < 0.004).

Table 2 describes the planting conditions at the two sampling times.

Three-day diet history analysis indicated that the mean caloric intake was 5159 ± 1047 kcal/day, of which 14% ± 3% was protein, 50% ± 7% carbohydrate, and 35% ± 7% fat. This diet provided approximately 837 ± 20 kcal/day in excess of the predicted daily caloric requirement for maintenance of body weight in extremely active men.

Blood glucose values are presented in Fig. 1. When samples were collected at 90 to 120 minutes postprandial, 80% of the values were below fasting levels (T1). Blood glucose curves after food intake (T2) did show a increasing trend to 90 minutes; however, when individual values were considered, there was a greater incidence of low blood glucose levels at T2 than at T1 (Table 3).

Changes in hemoglobin, hematocrit, and calculated plasma volume are presented in Table 4. No significant changes in any of the parameters were noted. All values were within the clinical normal range; however, when the individual results were examined, 26% of the values for hemoglobin were found to be at or below 142 ± 3 g/L (normal range, 140 to 174 g/L).

WBC and differential counts are also presented in Table 4. Total counts were significantly elevated above normal postexercise; however, a blunting of this response was noted at T2. Absolute neutrophil count was increased after exercise at both testing sessions, and both resting and postexercise values were suppressed at T2.
Counts were also elevated post-planting at T1 but not at T2, due to an elevated resting count at T2. This pattern was evident in CD4+/H11001, CD8+/H11001, and CD19+/H11001 absolute counts, whereas CD3-CD16+/CD56+/H11001 absolute cell counts were elevated at T2 rest only (Fig. 2).

Values obtained for serum chemistry and hormonal analysis are presented in Table 5. No significant changes were noted at any time for the indicators of systemic inflammation (C-reactive protein and α1-antitrypsin). However, resting levels of creatine kinase were significantly increased later in the season compared with the first sampling time and increased above resting levels after planting at both sampling times.

All cortisol levels were within the normal range at the first sampling session; however, seven of nine early-morning samples were greater than clinically normal at the second testing session. In addition, late-season resting norepinephrine values were significantly increased with 30% of planters, exceeding the normal range at T1 and increasing to 67% at T2.

No differences were noted for the measures of hand/wrist fatigue between pre-exercise and postexercise, or between early and late season (Table 6). Agility scores were found to be higher for the dominant hand.

The mean maximal heart rate recorded during the Leger test was found to be 198 ± 8 beats/min. The majority of planting time (56.7% ± 25.7%) was spent between 60% and 75% of maximal heart rates or 40% to 64% of V̇O₂max (Fig. 3). An additional 39.1% ± 27% was spent at sub-60% maximal heart rate (40% V̇O₂max), and the remainder, and by far the smallest proportion, of the day (2.2% ± 3.8%) was spent in the higher-intensity zone of 75% to 85% maximal heart rate (65% to 76% V̇O₂max). No heart rates in excess of 85% of maximal heart rate were recorded during a planting day.

**Discussion**

The objective of this project was to characterize the physical work of tree-planting using selected biochemical and physiological parameters. The most pronounced finding was that blood glucose levels remained at near hypoglycemic levels throughout the day (Fig. 1 and Table 3). From 21% (T1) to 45% (T2) of the blood glucose samples were found to be <4.0 mmol/L. The incidence of hypoglycemia was more pronounced at T2, when 27% of the values were ≤3.3 mmol/L. Recent investigations have demonstrated that although both attentiveness and motor response are impaired during hypoglycemia, motor response is more sensitive to hypoglycemia15 and slower to recover after restoration of blood glucose levels.16 Furthermore, complex skills such as driving have also been shown to be impaired at blood glucose levels in the range of 4.0 to 3.4 mmol/L.17 On the basis of this evidence, it seems likely that the potential for injury would be increased when blood glucose levels are low. Impairment of planters’ concentration and reflexes during foot placement on uneven terrain, or in the degree of force required to hold the shovel or open the planting hole, would all be likely to have negative impact. Unfortunately, the physiological measures of hand/wrist fatigue used in the current study were not sensitive enough to detect any impairment in motor function. This lack of detection was most likely due to a delay between the completion of planting and testing for hand strength and agility; future studies should examine the impact of hypoglycemia on motor function due to low blood glucose levels. Another potential implication is the role of low blood glucose levels in vehicular accidents, as planters may also be assigned driving duties at the end of the planting day. Motor vehicle accidents

![Fig. 1. Blood glucose levels during planting.](image-url)
ranked as the highest in terms of compensation costs by accident type in the 1994 to 1998 period.2

Counter-regulatory hormone responses are elicited when blood glucose levels decreased to approximately 4.0 mmol/L.15 The expected correlation between cortisol levels and blood glucose levels was observed in the current study (r = 0.56; P < 0.007; Tables 3 and 5). The means by which cortisol acts to increase blood glucose levels include blocking the ability of WBC to take up glucose and increasing the breakdown of proteins for the production of glucose in the liver. Both of these actions would have consequences to planters over course of a season. The reduced supply of fuel to WBC suggests that the action of the immune system in repairing injuries and fighting infections could be impaired; in fact, the immunosuppressive effect of cortisol has been well-documented.18 In the current study, a blunting of the leukocytosis normally seen after exercise4 was observed at T2, along with increased cortisol levels (Tables 4 and 5). Examination of the WBC differential count and lymphocyte subsets suggests that the postexercise leukocytosis at T1 was primarily due to increased numbers of circulating neutrophils, whereas the elevated resting levels at T2 were primarily due to increased numbers of lymphocytes (Fig. 4).

Muscle wasting in response to increased cortisol levels is also well documented.19 In the current study, planters lost an average of 1.7% ± 1.5% of body mass over 14 days. Skinfold measurements indicated that approximately 75% of this loss was due to loss of fat mass, with the remainder of the loss due to loss of lean muscle mass (Table 1). The low blood glucose levels and loss of body mass suggest that the dietary intake was insufficient to meet the energy requirements of planting. However, 3-day diet histories indicated that the mean caloric intake of the planters was 5159 ± 1047 kcal/day, well in excess of the recommended intake for extremely active occupations, including lumberjacks, construction workers, heavy manual digging, and rickshaw pullers.20 Further analysis of the planters’ diet revealed that the macronutrient distribution was 14% ± 3% protein, 50% ± 7% carbohydrate, and 35% ± 7% fat. Sports science has clearly demonstrated the benefits of increased carbohydrate intake (60% to 70% of the total caloric intake) on both the duration of and intensity sustained during endurance performance (reviewed in Hawley et al21). These effects are particularly pronounced when carbohydrates are supplemented during exercise (reviewed in Hargreaves 22). Furthermore, recovery from prolonged exercise has been shown to be significantly improved by the provision of high glycemic-index intake in the postexercise period.23,24 Future work should examine the effect of increasing the total carbohydrate intake in the form of carbohydrate supplements during and immediately postplanting.

### TABLE 4

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Hemoglobin (g/L)</td>
<td>153 ± 6</td>
<td>148 ± 9</td>
</tr>
<tr>
<td>Hematocrit (L/L)</td>
<td>0.45 ± 0.03</td>
<td>0.43 ± 0.02</td>
</tr>
<tr>
<td>Plasma volume (%)</td>
<td>4 ± 5</td>
<td>3 ± 3</td>
</tr>
<tr>
<td>WBC count (10⁹/L)</td>
<td>6.3 ± 1.4</td>
<td>9.8 ± 1.4*</td>
</tr>
<tr>
<td>Lymphocytes (10⁹/L)</td>
<td>1.8 ± 0.4</td>
<td>2.3 ± 0.4*</td>
</tr>
<tr>
<td>Neutrophils (10⁹/L)</td>
<td>3.9 ± 1.5</td>
<td>6.7 ± 1.4*</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD. WBC, white blood cell. T1, time 1; T2, time 2. * Significantly higher than resting values, P < 0.007. ** Significantly lower than T1, P < 0.03. *** Significantly higher than T1, P < 0.02.
Serum creatine kinase (CK) levels have been shown to increase in association with inflammation and disruption of muscle tissue.\textsuperscript{25,26} After planting at $T_1$, CK levels doubled; by $T_2$, CK levels remained elevated at rest (Table 5). These CK values were higher than those reported by Banister et al\textsuperscript{3} for tree-planters but comparable with those seen in athletes during regular training.\textsuperscript{27} Conformation of the moderate level of CK response is provided by the lack of change in the acute-phase proteins C-reactive protein and $\alpha_1$-antitrypsin (Table 5), which have been shown to increase in response to infection, trauma, or severe exercise.\textsuperscript{28,29} Other indicators of systemic stress are levels of the catecholamine hormones epinephrine and norepinephrine. Exercise, low blood sugar, injury, and stress have all been shown to stimulate the release of catecholamines from the adrenal medulla. Increased plasma levels of norepinephrine may also reflect spillover from increased sympathetic nervous system activation.\textsuperscript{30} Clearance of these hormones from the plasma after an acute event is extremely rapid; baseline levels are normally restored within minutes.\textsuperscript{30} Previously, Banister et al\textsuperscript{3} had identified a “burn out” syndrome, identified by elevated catecholamine levels and attributed to the continued cardiorespiratory, thermal, and metabolic stresses endured by planters. Although the absolute values obtained by Banister et al\textsuperscript{3} were higher than those found in the present study, the trends were the same. A significant increase in resting norepinephrine levels occurred from $T_1$ to $T_2$, whereas epinephrine levels remained more stable (Table 5). These data confirm the trend toward increased stress at $T_2$ observed in cortisol, blood glucose, WBC, and CK levels.

No correlation was observed in the current study between blood glucose levels and epinephrine levels; however, this finding may have been due to the timing of collection of catecholamine samples (early morning) relative to the blood glucose samples (throughout the workday). Increased levels of hemoglobin have been shown to directly increase endurance performance, as demonstrated by increased time to fatigue, increased power at submaximal levels, and increased $V\dot{O}_2$ max (reviewed in Gledhill\textsuperscript{31}). Although athletic populations are sometimes found to have lowered hemoglobin levels because of expansion of plasma volume, restoration of hemoglobin levels may result in enhanced performance. In the presence of adequate iron stores, training can result in hemoglobin levels in the range of 160 to 170 g/L, especially when combined with mild altitude exposure (1000 to 2500 m).\textsuperscript{32–34} In the current study, mean hemoglobin levels were found to be in the normal range (Table 4); however, when examined on an in-

### Table 5

<table>
<thead>
<tr>
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<th>Pre</th>
<th>Post</th>
<th>Pre</th>
<th>Post</th>
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<tbody>
<tr>
<td>CK (U/L)</td>
<td>$184 \pm 82$</td>
<td>$409 \pm 131^{b*}$</td>
<td>$265 \pm 101^{b}$</td>
<td>$397 \pm 174^{b*}$</td>
</tr>
<tr>
<td>$\alpha_1$-antitrypsin (g/L)</td>
<td>$1.3 \pm 0.2$</td>
<td>$1.3 \pm 0.2$</td>
<td>$1.3 \pm 0.3$</td>
<td>$1.3 \pm 0.3$</td>
</tr>
<tr>
<td>C-reactive protein (mg/L)</td>
<td>$&lt;6.0$</td>
<td>$&lt;6.0$</td>
<td>$8.6 \pm 6.0$</td>
<td>$9.5 \pm 6.7$</td>
</tr>
<tr>
<td>Cortisol (nmol/L)</td>
<td>$428 \pm 163$</td>
<td>$300 \pm 147$</td>
<td>$741 \pm 199^{b,**}$</td>
<td>$300 \pm 101$</td>
</tr>
<tr>
<td>Epinephrine (nmol/L)</td>
<td>$0.15 \pm 0.15$</td>
<td>$0.17 \pm 0.10$</td>
<td>$0.17 \pm 0.10$</td>
<td>$0.17 \pm 0.10$</td>
</tr>
<tr>
<td>Norepinephrine (nmol/L)</td>
<td>$2.09 \pm 1.34$</td>
<td>$3.09 \pm 1.05^{b,*}$</td>
<td>$3.09 \pm 1.05^{b,*}$</td>
<td>$3.09 \pm 1.05^{b,*}$</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Data presented as mean $\pm$ SD. CK, creatine kinase; $T_1$, time 1; $T_2$, time 2.

\textsuperscript{b} Exceeds the normal clinical range.

\textsuperscript{*} Significantly greater than preexercise, $P < 0.05$.

\textsuperscript{**} Significantly greater than $T_1$, $P < 0.001$.

### Table 6

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip strength (kg)</td>
<td>$51.4 \pm 6.7$</td>
<td>$52.1 \pm 8.4$</td>
<td>$47.2 \pm 5.9$</td>
<td>$49.3 \pm 6.3$</td>
</tr>
<tr>
<td>Right hand</td>
<td>$50 \pm 5.3$</td>
<td>$53.7 \pm 7.3$</td>
<td>$46.9 \pm 5.1$</td>
<td>$49.4 \pm 5.4$</td>
</tr>
<tr>
<td>Left hand</td>
<td>$58 \pm 10^{*}$</td>
<td>$57 \pm 7^{*}$</td>
<td>$63 \pm 8^{*}$</td>
<td>$65 \pm 9^{*}$</td>
</tr>
<tr>
<td>Agility test (no. of slaps)</td>
<td>$52 \pm 8$</td>
<td>$55 \pm 7$</td>
<td>$58 \pm 7$</td>
<td>$55 \pm 8$</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Data presented as mean $\pm$ SD. $T_1$, time 1; $T_2$, time 2.

\textsuperscript{*} Significantly greater than the nondominant hand, $P < 0.02$. 
individual basis, 26% of the values decreased below 142 g/L. It is unlikely that the lower hemoglobin levels were due to plasma volume expansion, as calculated plasma volume changes over the course of the study were stable at $-3\% \pm 3\%$.

Given that planters typically work in conditions of moderate altitude exposure (Table 2), they may have suboptimal hemoglobin levels, and future investigations should consider examining preseason ferritin levels to ensure an adequate supply of iron. Presumably, in parallel to the enhanced endurance performance observed in athletics, the increase in oxygen transport capacity would result in lower relative workloads during planting.

The tree-planters’ mean $\dot{V}O_2 max$ was found to be $47.3 \pm 6.0 \text{ mL/kg per min}$ (Table 1), lower than the values for trained men. The rela-

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**Fig. 3.** Mean heart rates recorded every 5 minutes during a typical planting day.

**Fig. 4.** Changes in relative neutrophil and lymphocyte counts (percentage total WBC), with a day of tree-planting early and late season. Asterisks indicate significantly different from resting $P < 0.02$; pound signs indicate significantly different from early season $P < 0.03$. 

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tive workload experienced by the planters can be extrapolated from the daily heart rates during planting (Fig. 3). Nearly 60% of the planting day was spent between 60% and 70% of maximal heart rate or 40% to 64% of VO₂max. Interestingly, the two planters with the highest fitness levels (approximately 54 mL/kg per min) were also the only two who spent time above 150 beats/min and had the highest planting rates (over 2400 trees vs the group mean of 1558 ± 561 trees planted). Furthermore, studies have shown that lower fitness levels are associated with an increase in injury in firefighters, infantry soldiers, and office workers. An area for future investigations then, would be to institute a preseason training program to increase VO₂max and determine the influence of improved fitness on planting efficiency and injury rates.

Conclusions

The work of tree-planting was found to be rigorous: 2 of 10 planters sustained an infection or injury. Physiological effects were observed in that planters were found to be borderline hypoglycemic throughout the planting day. Evidence for increasing levels of stress over the planting season was seen in the increased CK, cortisol, and norepinephrine levels; immunological data; and loss of body mass with increased number of days of planting. Future work should examine the potential for enhanced performance and injury reduction with the use of preseason physical preparation, carbohydrate supplementation, or both.

Acknowledgments

This research was made possible by a grant from Weyerhaeuser Canada, British Columbia Timberlands Division. The author also specifically thanks André Arnold, Chris Akehurst, Norm Druck, Dan Livingston, Sherry Wilson, and all of the tree-planters for their help.

References

31. Gledhill N. The influence of altered blood volume and oxygen transport ca-


