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Heat stress in forestry work

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Abstract

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An intrinsic characteristic of forestry work is that it is an outdoor activity, exposing its workers to the prevailing climate conditions. For a large majority of forest workers this implies being exposed to warm conditions while performing physically strenuous work. The overall aim of the thesis was to study effects of heat stress on the health and productivity of forest workers using manual working methods. Studies were made to evaluate the ISO heat stress measurement methods in forestry and the effects of dehydration on the health and productivity of forest workers in manual thinning. The studies were conducted in North East Zimbabwe in September-October 1996.

Three metabolic rate assessment methods of ISO 8996 were compared. Large variations between the assessments were found depending on the method chosen. Differences between the ISO heat stress indices in heat stress risk assessment were found as well as unacceptable variations in the assessment of allowable exposure times with ISO 7933. It seems therefore questionable that today's standard methods are able to guide manager of forest operations in reliable heat stress risk management.

The consumption of a fluid level assuring full hydration resulted in a significant lower percentage of heart rate reserve used, as well as a considerable reduction of time consumption when compared to consumption of a fluid level leading to mild dehydration. It was found that during harvesting, the responses of the forest workers on the fluid consumption levels were affected by their physical condition as well as their work manner and that changes in work manner had occurred between the fluid consumption levels for some workers. Moreover an accumulating effect of inadequate fluid consumption over days was found on the time consumption. As these results were obtained in mildly warm climate conditions, it is recommended to extend ILO's recommendation to drink at least 5 litres of water per work day during heavy forestry work also to temperate climate conditions.

Key words: ISO standards, physical workload, occupational health, labour productivity, dehydration, manual forestry work, working conditions.

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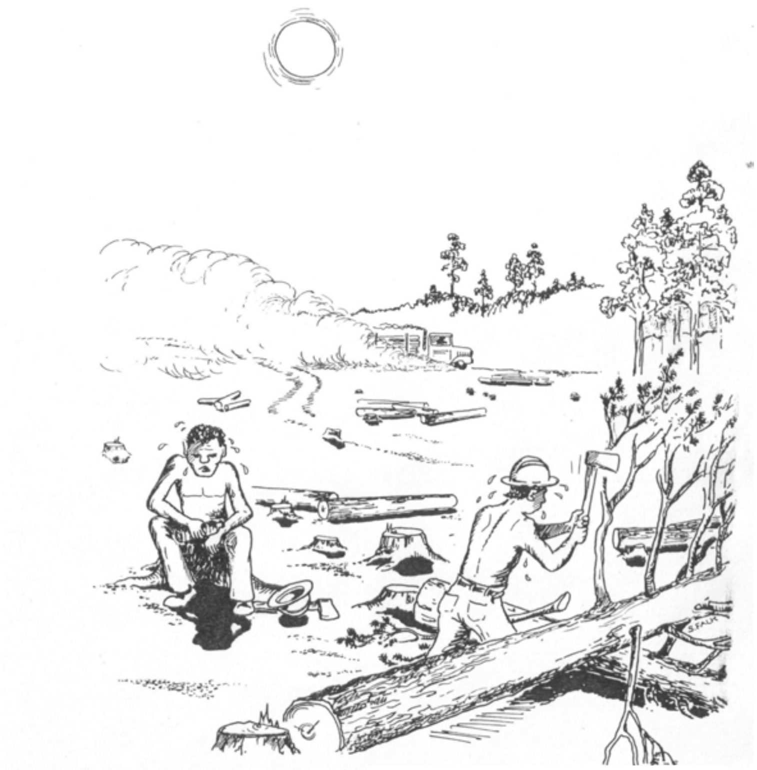

illustration: Sigge Falk

To Archer, Cossam, Elliot, Oscar and all their colleagues

Contents

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their roman numerals.

I. Staal Wästerlund, D. 1998. A review of heat stress research with application to forestry. Applied Ergonomics, 29(3):179-183.

II. Staal Wästerlund, D. & Chaseling, J. 2001. Physiological and labour-productive effects of fluid consumption during forestry work. (Submitted manuscript).

III. Staal Wästerlund, D. 2001. Evaluation of methods for estimating the metabolic rate according to ISO 8996 in forestry work. (Submitted manuscript).

IV. Staal Wästerlund, D., Chaseling, J. & Burström, L. 2001. The effect of fluid consumption on the forest workers' performance strategy (Manuscript).

Introduction

Working conditions in the forestry sector

According to the ILO (1999) the forestry sector's labour force comprises of 1% of the world's total employment of which a large majority is working in developing countries. Annually they produce 1.5 milliard m^3 of industrial roundwood (FAO 2001). Being a predominantly rural based sector, it provides employment in areas where other employment alternatives often are rare (ILO 1999). In the industrialised countries, the number of forestry workers has decreased considerably due to mechanisation and the ILO (1999) predicts that this decrease will continue. In Sweden for example, the number of forestry workers decreased from 65800 in 1970 to 17600 in 1998 (Anon 1999). In the developing countries however, the ILO (1999) predicts that the number of forestry workers will increase in the near future due to a more intensive forest management and tree plantations.

The working conditions in forestry are widely different depending on the level of mechanisation. Where work is predominantly performed with machines, forestry work is a physically light indoor activity and its major occupational health problems can be related to static muscular work, a high mental work load and the psycho-social work environment (Gellerstedt 1993). The majority of forest workers are however still working outdoors with (motor-) manual working methods. According to Apud (1989), (motor-) manual forestry work is one of the heaviest occupations of all. This is confirmed by the standard of the International Organization for Standardization (ISO) 'Ergonomics – determination of the metabolic heat production' (ISO 8996) in which energy requirements for work activities of many sectors have been compiled, and where forestry activities can be found among the heaviest of work activities (ISO 1990).

In many countries, forestry work is still among the most accident prone industries (Axelsson 1997, Morat 2001), and especially in developing countries the working conditions can be described as poor, often lacking even the basic provisions such as proper housing and nutrition (ILO 1999). With an increasing pressure for a more sustainable forest management and the development of certification of forest management, voices have been raised to include the working conditions in the certification principles as sustainable forest management requires well-trained workers who are willing and capable to implement environmentally sound working practices. According to the motivation theory of Maslow (1954) persons who's basic needs are not fulfilled cannot be expected to be fully focussed on their performance quality, thus it is argued that "sustainable forest management … depends on the sustainable management of human resources" (Strehlke 1996). A suggestion for social criteria and indicators for sustainable forest management has been made by the ILO (Poschen 2000) for inclusion among others in the certification principles of the Forestry Stewardship Council (FSC). These criteria include among others occupational safety and health criteria.

A basic factor factor influencing the working conditions on any work place is the climate conditions. Health problems and productivity effects of cold working conditions in forestry have been documented *e.g.* by Lundgren (1946) and Axelsson *et al.* (1986). For a majority of forest workers however the climate conditions are predominantly warm throughout the year and its health and productivity effects on forest workers have so far been studied very little. Recommendations given to the sector are very broad such as ‘restrict heavy work to early mornings and late afternoons’, ‘organise work with adequate rest allowances’ and ‘supply sufficient water’ (Staudt 1993, ILO 1992).

Working when it is warm

The human body is an active system in responding to environmental inputs such as heat. According to Parsons (2000) the response depends upon a great number of factors which besides the environmental conditions depends on the person physical and psychological status as well as individual differences. The human thermal environment is determined by six basic parameters: the air temperature, the radiant temperature, the humidity, the air movement, the metabolic heat produced during work and the clothing worn by the person (Fanger 1970). The human physiological processes require a constant inner body temperature at 37 ºC, which implies that the body must balance the heat transferred into the body, the heat generated by the body and the heat dissipated to the environment. In conceptual form the heat balance can be expressed as (Parsons 1993):

$$M - W = E + R + C + K + S$$

The metabolic rate (M) of the body provides energy to perform mechanical work (W). As the efficiency of human muscles is less than 25% (Axelson 1974), a major part of the energy released is transferred into heat (M-W). Therefore the production of body heat is large when performing physically strenuous work such as forestry work. Heat can be transferred to the environment by evaporation (E), radiation (R), convection (C) and conduction (K). If the heat transfer to the environment is less than the heat produced, excess heat is stored (S). When the body becomes ‘too hot’, mechanisms for losing heat are started and controlled by the anterior hypothalamus. The excess heat is transported to the skin where blood vessels dilate to increase heat loss, the heart rate raises to transport heat to the skin and to cope with the decreasing stroke volume and the body starts to sweat. In a warm environment the evaporation of sweat is the most important way to exchange heat with the environment. The clothing provides a thermal resistance between the body and the environment, which is depending on its material and the type of cloths worn but also on the work posture and fitting of the cloths. In addition to physiological responses, there is an important behavioural response (Parsons 1993). If the responses cannot maintain the heat balance and heat is stored by the body, the human can eventually suffer from heat illness and death (Parsons 1993).

Measuring and evaluating the thermal environment

The number of indices to assess the thermal environment is numerous. Kampmann and Piekarski (2000) divide the methods for evaluating the thermal environment into four groups: a) subjective evaluation by test subjects, b) compilation of the climatic parameters in a single parameter (*e.g.* the Wet-Bulb-Globe-Temperature (WBGT) index), c) combining climatic parameters which give the same physiological effect, and d) calculation of the heat balance to model the required sweat rate (SW_{req}) and the predicted sweat rate under the prevailing conditions. A basic problem for the evaluation of the thermal environments is that the reactions can differ considerably between persons (Havenith *et al.* 1995), which made it difficult to find strain indicators that can protect all from uncompensable heat stress risk. The ISO has chosen the WBGT-index and the required sweat rate (SW_{req}) as standard methods for evaluating the thermal environment (ISO 1989a,b). Both indices aim at indicating for uncompensable heat stress risk when the inner body temperature rises above 38 °C (Parsons 1993). The WBGT-index provides guidance in determining risk for uncompensable heat stress by reference values for different levels of metabolic rates while the SW_{req} provides allowable exposure times based on a comparison of the model's required and predicted sweat rate. Smolander *et al.* (1991) evaluated both indices on the same set of data. They found that a) the WBGT-index might slightly underestimate risk in warm humid climates while the SW_{req} might slightly overestimate in that climate situation, b) that neither standards took sufficiently into account the sweating capacity of physically trained men, and c) that the allowable exposure times of SW_{req} could be questioned due to the large inter-individual variability in the physiological responses. Other researcher have found similar results (Kampmann & Piekarski 2000, Kampmann *et al.* 1992, Graveling *et al.* 1988) and the SW_{req} is at present under review (Malchaire *et al.* 2000, Malchaire *et al.* 2001). The WBGT-index indicated risk for uncompensable heat stress in forest operations in east Kalimantan, Indonesia (Gandaseca *et al.* 1997), in Japan (Yoshimura 1998) and in South Eastern USA (Smith *et al.* 1985). SW_{req} has however so far not been used in forestry.

The heat stress indices require an assessment of the metabolic heat production for which the ISO has compiled six methods in the ISO standard 8996 'Ergonomics – determination of the metabolic heat production' (1990). Besides the method for direct measurement of the oxygen consumption during work, the standard consists of methods which estimate the metabolic rate. Direct measurements is however considered impossible in field experiments as it would directly interfere with the work (Parsons & Hamley 1989, Horwat *et al.* 1988). The accuracy of the estimation methods has so far only been evaluated in a few studies (Giedraityte *et al.* 2001, Horwat *et al.* 1988).

Dehydration

Sweating decreases the blood volume which leads to a lower capacity of heat transport from the inner body to the body surface as well as to a lower oxygen transport from the lungs to the muscles (Hamilton *et al.* 1991). Dehydration therefore increases the risk for uncompensable heat stress and decreases the productivity (Sawka 1992). Voluntary replacement of the lost fluids tends to be too little (Clapp *et al.* 1999, Spioch & Nowara 1980, Wong *et al.* 1998). Its effect on the physical performance has been extensively studied in connection to sports medicine (*e.g.* Barr *et al.* 1991, Fallowfield *et al.* 1996, Hamilton *et al.* 1991, Saltin 1964) or for military purposes (Buskirk *et al.* 1958, Mudambo *et al.* 1997, Montain et al. 1999). In the occupational setting, however, the need for sufficient drinking seems not to be seen as a management issue. Dehydration in forestry work was documented by Wigaeus Hjelm & Frisk (1985) in Vietnam, Trites *et al.* (1993) in Canada and by Bates *et al.* (2001) in New Zealand.

Aim of the thesis

The overall aim of the thesis was to study effects of heat stress on the health and productivity of forest workers using manual working methods.

The following questions have been addressed:

a) what lessons can be learned from heat stress research for the management of heat stress in forest operations and what gaps in knowledge exist in adopting heat stress management into forest operations;
b) are today’s measurement and evaluation methods able to guide foresters in a proper management of heat stress risk;
c) is there an effect of dehydration on the health and productivity of forest workers;
d) what behavioural response do forest workers have to dehydration and may their performance strategies change due to the effect of different fluid levels.

Material and methods

A literature search was made in international data bases and reviewed on their application to forestry in Paper I. The literature was limited to the English, Swedish and German language. From the research areas for which urgent needs for studies with application to forestry were identified, two were chosen for experimental studies. These were the effects of dehydration and an evaluation of the heat stress risk determination methods in forestry with special reference to the metabolic heat determination methods in ISO 8996.

The experimental studies were conducted during regular harvesting operations in forest plantations in North East Zimbabwe in September-October 1996 and concerned regular work tasks performed by contract labourers. Four male forest workers with at least 2 years of experience on manual thinning work took part in the study presented in Papers II and IV. They performed thinning of a 13 years old *Pinus patula* stand with hand tools. The forest workers were each to produce a 2.4 m^3 stack of pulpwood along the road each day. All trees were felled with axe and hand saw, debranched with axe, cross cutted with hand saw into logs and subsequently carried to the road side. When logs for the stack were assembled at the roadside, they were debarked with a debarking spud. For the study presented in Paper III, three experienced forest workers performed each one activity. One worker produced firewood of *Eucalypthus grandis* (gum tree) logs with an axe, one worker carried *Pinus elliotti* pulpwood logs from the forest stand to the road side and one worker debarked and stacked *Pinus elliotti* pulpwood logs along the road side.

In the study of Paper II and IV, the forest workers commenced at 7 o'clock in the morning and continued without prescribed breaks until the stack was completed at approximately noon in natural changing climate conditions. The temperature varied between 7.8 and 29 ºC WBGT, which was below the average temperature for the season. In the study of Paper III the forest workers were studied for observation periods of one hour at the time between 10 and 14 hrs and the temperatures varied from 17.2 to 24.1 °C WBGT. The air temperature, globe temperature, wet bulb temperature and wet-bulb-globe temperature (WBGT) were measured with a Brüel & Kjær WBGT heat stress monitor type 1219 in both studies while the air velocity was measured at random occasions during each observation period in the study of Paper III.

Two fluid consumption levels were chosen for comparison in the study of Paper II and IV. During the eight consecutive working days that each forest worker was studied, they consumed either 0.17 l or 0.6 l of water each half hour. The low fluid consumption level was chosen to reach a mildly dehydrated condition without risk for heat illness and the high fluid consumption level to assure a fully hydrated condition. The water levels were assigned at random to the working days for each forest worker. Due to study limitations, two forest workers were studied during day 1 to 8 and two during day 9 to 16. The maximum oxygen uptake capacity (VO_2max) was determined before and after work each day with the steptest (Apud 1989) and the weight change was monitored each hour. As measure for exertion the percentage of heart rate reserve was used (Rodahl 1989).

In the study of Paper III, three methods of the ISO 8996 standard for estimating the metabolic rate were compared. These methods were the classification of the metabolic rate for kinds of activities (method A), estimation of the metabolic rate for body posture, type of work and body motion related to work speed (method B), and the estimation of metabolic rate using the heart rate (method C). With method A, work is classified in one of five metabolic rate classes with a tabulated value according to examples of activities given for each level. With method B the metabolic rate is calculated by adding the metabolic rate for body posture, the type of work and the work speed related to distance or height to the basal metabolic rate. As no relation between heart rate and oxygen consumption was determined the estimation according to method C was made using the formula $M = 4 * \overline{HR} - 255$ where M is the metabolic rate (W/m^2) and $\overline{HR}$ is the mean heart rate (beats/min) (ISO 1990). Three newly trained observers (two women and one man) assessed the metabolic rate of an activity simultaneously each using a different method for one observation period and changed methods for the next observation period until each observer had used all three methods. The activities was studied twice according to this procedure.

Time studies were made for all activities in the studies of Papers II, III and IV. For the study in Paper II and IV, a continuous time study with snap-back timing was made for defined work elements, using a centi-minute watch. During harvesting, the time for the work elements per tree was recorded and during debarking the time for the work elements per log. For the study in Paper III the observers used the same time study technique to determine a time-weighted average metabolic rate for method A and B. Heart rate was recorded in all studies with a Polar Sport Tester PE 3000 and body mass changes were measured with a Philips HP 5324 scale.

Generalised Linear Models were used in the studies of Paper II, III and IV to test the variables for significant differences. In Paper II, the variables were tested against the error term defined by the interactions of the individuals with the fluid consumption levels. To include the accumulative effects of fluid consumption over days in the analysis, the data were analysed as a multi-period crossover experiment with unbalanced within block replication (Bodero & Reason 1986). In Paper III the data were analysed as a latin square experiment while means were compared using the Tukey HSD test. To explore the developments over time, the harvesting operation during the dehydration study was divided into five consecutive volume classes (00-20%, …. , 81-100%) and the work elements and mean heart rates per tree were distributed over the volume classes in their respective order and contribution to the volume produced. All analysis were carried out using SAS statistical software (SAS Institute Inc., 1999).

Results and discussion

Management of uncompensable heat stress risk

With the results of Paper I and III, it seems questionable that with the present ISO heat stress determination methods a reliable heat stress management can be obtained in forestry operations. Vogt et al. (1983) found that compensation through self-pacing was unreliable, which implies that risk for heat stress is to be incorporated in the work organisation. Either this can be achieved by scheduling work at times there is no heat stress risk or by adjusting the metabolic rate with sufficient rest time or job rotation. The WBGT measurements by Gandaseca *et al.* (1997), Yoshimura (1998) and Smith *et al.* (1985) showed that the first option may be limited. To adjust the metabolic rate of the work, it is impertinent to have reliable determination methods. The estimated metabolic rates in Paper III showed variations of up to 36% for the same observation period caused by the estimation methods used and the observers (figure 1). In addition it was found that the estimations were significantly different between the methods and that the variation between the methods were inconsistent for the activities, which may indicate that the accuracy of the methods may be dependable on the work activity that is studied. Giedraityte et al. (2001) found variations of 7 to 38% depending on the method and the activity studied.

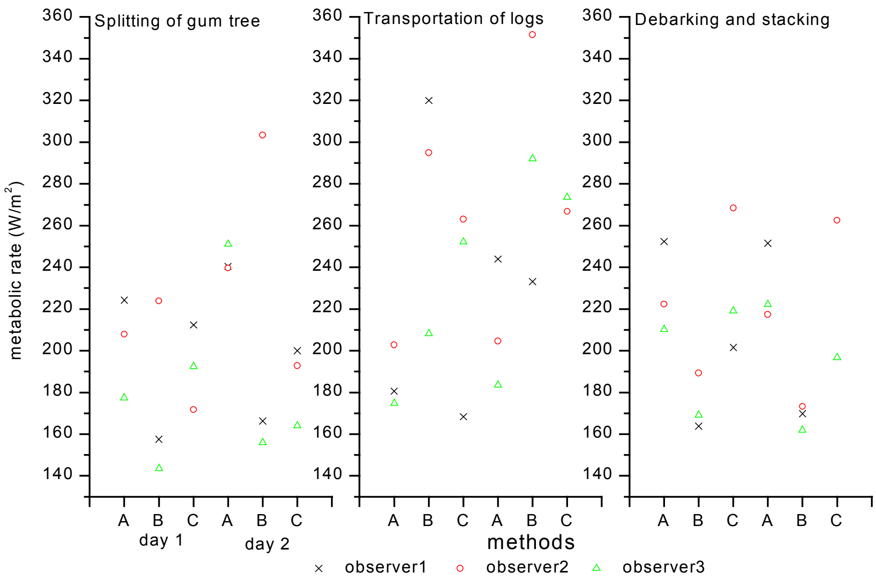

Figure 1. The estimated metabolic rates according to method A (classification according to kind of activities), method B (estimation according to task components) and method C (heart rate) for each observer.

The WBGT- index is an exploratory method that distinguishes between only five metabolic rate classes with reference values. For further analysis and interpretation such as adjusting work-rest schedules or job rotation schedules, the ISO (1989a,b) refers to the SW_{req}. The allowable exposure times estimated by the SW_{req} method on the other hand showed in Paper I to be very sensitive to small changes as a variation in metabolic rate of 10% lead to differences in allowable exposure times of 176%. In Paper III the variation in metabolic rate estimations caused differences in allowable exposure times of up to 265 minutes for the same activity.

While SW_{req} incorporates the thermal insulation of the clothing in its assessment model, the WBGT-index presupposes that the clothing has a thermal insulation of 0.6 clo. This is comparable to a clothing ensemble of underpants, shirt, light-weight trousers, socks and shoes (ISO 1989b). In the study in Paper III, forestry workers used heavier cloths as well as a safety helmet, which resulted in a very different assessment of the risk by the two heat stress indices of the climate conditions at hand. A draft British standard is at present under review on how to interprete the heat stress standards for workers using personal protective equipment (Hanson 1999). This draft standard includes among others correction values for the WBGT-reference values depending on the clothing used as well as suggestions for adjustments in the heat balance model of the SW_{req} if water vapour impermeable clothing is worn. There is however a considerable lack of data on the clothing insulative values of protective equipment such as safety helmets, boots and gloves (Hanson 1999).

A reduction of the heat stress reference values to adjust for protective clothing will affect work-rest schedules and will therefore have considerable economic consequences (Crockford 1999). Yet it will not alleviate the experienced discomfort while working, which is at present the main reason for not using the protective equipment (Väyrynen 1983). Another option suggested in Paper I is a better balancing of the protective quality and comfort depending on the conditions where the protective equipment is used. In Paper I it was concluded that the protective quality of the clothing is at present prioritised over comfort. Yet studies considering the heat stress effect on the comfort of the protective equipment have not looked at the safety aspects of the suggested alternatives.

Health and productivity effects of dehydration

The dehydration study presented in Paper II showed a significant lower usage of the percentage of heart rate reserve as well as a significant time reduction for the high fluid consumption level compared to the low (table 1). This is in line with the findings of *e.g.* Barr *et al.* (1991), Fallowfield *et al.* (1996), Walsh *et al.* (1994), Hamilton *et al.* (1991) and Gonzaléz Alonso (1998).

Table 1. The heart rate reserve (%) and time consumption (min) during the entire working day, the harvesting and the debarking period for the low and high fluid consumption levels.

	entire working day		harvesting		debarking	
	low fluid	high fluid	low fluid	high fluid	low fluid	high fluid
heart rate reserve (%)	39.9	36.5	48.2	47.9	35.6	31.9
time consumption (min)	234.1	209.0	91.7	103.8	117.8	130.3

Large individual differences between the test persons' physiological responses were found however, in particular for the harvesting period, while there was no significant differences found between the test persons' response in time consumption. The time reductions obtained during harvesting and debarking were of similar proportion, although harvesting was conducted during the cooler period of the working day as compared to debarking. Also harvesting was always performed in the shade while debarking was performed along the roadside mainly in the sun. As the assignment of the test persons was to produce a certain volume and the forest stand consisted of trees of different sizes, there was scope for the forest workers to change the compilation of the pulpwood stack by changing the choice of tree size. Since the heart rate and the time consumption per volume is affected by the tree size (Sundberg 1960, Sundberg 1941, Kilander 1961) a possible change in choice in tree size would also affect the heart rate response and time consumption of the forest workers. In Paper IV it was found that the difference in heart rate reserve as well as the time consumption response between the two fluid consumption levels could be attributed to a change of tree size for one test person. There was also a trend found for this test person for an increased use of directional felling towards to road to limit the time for carrying during the high fluid consumption level. As psychological studies have shown that decision making processes are influenced by the physical work load, stress and heat (Paas and Adam 1991, Nygren, 1997, Ramsey 1995) it may be possible that the difference in fluid consumption levels affected the decision making process of this test person. The differences in heart rate response and time consumption found for the other test persons could not be attributed to changes made in the performance strategy, yet the performance of one test person during the high fluid consumption level seemed to be affected negatively by uncomfortable abdominal bloathing (McConell *et al.* 1999, Robinson *et al.* 1995). The responses found for the harvesting task were therefore a combined effect of the physiological changes provided by the fluid consumption levels as well as behavioural changes.

In Paper II, a significant accumulative effect of inadequate fluid consumption was found although the test persons were provided with 0.5 litres of water at the start of each new study day. It seems that this amount was either insufficient or that the absorption was impeded by the work. Since there are no other studies done on the effects of repetitive dehydration on consecutive working days, there may be long-term effects of dehydration on the performance that need to be studied further. Yet, the accumulative effect not only underlines the importance of sufficient fluid intake during work, it also shows a need for extension activities to the workers for fluid intake after work. Wong *et al.* (1998) found that only 53% of the fluid intake was retained by the body after a 4 hour recovery period following exercise.

All current guidelines for sufficient fluid consumption concern warm or hot environments. The ILO (1992) recommended the consumption of at least 5 litres of water during the work day for heavy forestry work in a hot environment.

Montain et al (1999) suggest a consumption of approximately 0.7 litres per hour for continuous hard work for soldiers wearing hot weather battle dress uniform in 25.5 - 28 °C WBGT. Paterson (1997) found that the sweat rate of chain saw operators in New Zealand exceeded 3 litres per day when the temperature exceeded 17 °C WBGT. The upper limit for fluid replacement during exercise is according to Sawka (1992) 1.0-1.5 litres/hour for an average adult. In the present dehydration study, the least squares mean body mass loss for the low fluid consumption level was as large as the least squares body mass gain for the high fluid consumption level. Although this measured body mass change is not the accurate sweat rate since it was measured fully clothed, it indicates that a sufficient fluid consumption level for the prevailing climate conditions may have been around 0.7 litres per hour. As these results were obtained in temperate climate conditions, the results therefore indicate that ILO's recommendation should be extended to include temperate climate conditions as well.

Study limitations and future needs for research

The results of paper II, III and IV are based on a limited number of test persons. As a large variation in the data material was expected due to differences within the forest stand, the climate conditions between study days as well as inter-individual differences in response to heat exposure. Therefore a choice was made to repeatedly study a limited the number of test persons rather than more test persons with less replications within the time limit made available by the host company for this study. Further studies on more test persons and other activities are required for more general conclusions. The methods used for the determination of physiological variables such as the steptest or the percentage of heart rate reserve with a estimated maximum heart rate in Paper II or the body surface area in Paper III, may lead to considerable errors when used on individual persons (Apud 1989). As the studies were structures as randomized block designs with individuals as blocks, such errors were eliminated from the fluid consumption effects in papers II and IV or the method effects of paper III in the statistical analysis.

The temperature conditions during the studies were below average for the season, which limited the dehydration effect of the low fluid consumption and may have caused uncomfortable bloathing during the high fluid consumption level. Yet there was a significant difference in favour of the high fluid consumption. There is a lack of studies on dehydration under temperate conditions as heat loss through sweating is supposed to be alleviated by heat loss through convection, radiation and conduction, implicitly assuming a behavioural response to use light clothing. In the present studies all test persons wore a sturdy cotton boiler suit, shoes and a safety helmet provided by the company, which limited the area that is in direct contact with the environment. Some wore t-shirts under this garment and one even a pare of trousers. Also the conditions during the field studies resembled temperatures found in the summer in countries with a temperate climate. Since these climate conditions are seasonal, there may be need for studies on the awareness of sufficient fluid consumption during the warm seasons in countries with temperate climate conditions.

In the dehydration study, the body mass loss was attributed only to dehydration ignoring the body mass loss for the energy expenditure. Also the fluid provided in the dehydration study consisted only of water. Since the dehydration level was only mild, no risk for acute heat cramps was anticipated (Barr *et al.* 1991). In general however there is a concern for the nutritional condition of forest workers in developing countries (ILO 1991) which could imply an insufficient replacement of energy sources as well as lost salts. Mueller-Darss and Staudt (1974) argued that the performance of forest workers in Suriname was rather impeded by the nutritional status of the workers than the climate conditions. Apud and Valdes (1995) found that Chilean workers producing approximately 25 percent more than the average worker, also had a significantly higher food intake. Research on the combined effect of fluid and food may give examples of large productivity improvements with simple means.

According to Apud (1989) the major source of variation in the determination of the VO_2max with the steptest is caused by variation the stepping rate. Although help was provided for the test persons during the dehydration study to keep the stepping rate by a metronome, differences between days may have occurred. The variation found for the VO_2max measured each morning before work may also be a result of activities performed the day before in the worker's free time, which was beyond the control of the study. The test persons were weighted fully dressed with unevaporated sweat still attached to their skin or soaked in their cloths, which may have affected the measurements of the body mass change. The time studies during the dehydration study were made by two experienced work study persons. However no control was made if there was any systematic difference between the work study persons in their time measurements. For the determination of metabolic rates in Paper III, the observers were newly trained on the methods being used. They were however very familiar with the activities that were observed.

Conclusions and recommendations

Parsons (1993) claimed in his book on the human thermal environments concerning the risk for uncompensable heat stress, that 'there seems …. to be a tendency to forget the requirements for working practices, despite the satisfactory knowledge, lessons seem to have to be re-learnt'. The studies described in this thesis showed that with today's ISO standard methods it is questionable that proper requirements for the forestry working practices can be made. The metabolic rate assessment methods showed to give significant different assessments, and the variation between the assessments caused an unacceptable variation in the recommended allowable exposure times provided the required sweat rate standard (ISO 7933). It is recommended to evaluate the metabolic rate assessment methods further with regards to their weaknesses and strengths which could guide practitioners of the standard in his/her choice of method to use. As a revision of ISO 7933 is expected in the near future, further evaluations are recommended.

The dehydration study showed that sufficient fluid consumption will not only decrease the risk for heat stress, it will also limit the loss of productivity. As the study was conducted under temperate conditions, it is recommended to extend ILO's recommendation for the consumption of at least 5 litres of fluid per day during heavy forestry work, also to temperate conditions. The effects of fluid consumption could for the harvesting task be attributed to physiological and behavioural changes. The effect of dehydration on work behaviour needs to be studies further. Moreover an accumulative effect of inadequate fluid consumption was found on the productivity which underlines the need for extension on sufficient fluid consumption under and also after work.

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