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Original Article

Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India: Implications for a Climate Change Future

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Abstract: Excessive workplace heat exposures create well-known risks of heat stroke, and it limits the workers' capacity to sustain physical activity. There is very limited evidence available on how these effects reduce work productivity, while the quantitative relationship between heat and work productivity is an essential basis for climate change impact assessments. We measured hourly heat exposure in rice fields in West Bengal and recorded perceived health problems via interviews of 124 rice harvesters. In a sub-group (n = 48) heart rate was recorded every minute in a standard work situation. Work productivity was recorded as hourly rice bundle collection output. The hourly heat levels (WBGT = Wet Bulb Globe Temperature) were 26–32°C (at air temperatures of 30–38°C), exceeding international standards. Most workers reported exhaustion and pain during work on hot days. Heart rate recovered quickly at low heat, but more slowly at high heat, indicating cardiovascular strain. The hourly number of rice bundles collected was significantly reduced at WBGT>26°C (approximately 5% per°C of increased WBGT). We conclude that high heat exposure in agriculture caused heat strain and reduced work productivity. This reduction will be exacerbated by climate change and may undermine the local economy.

Key words: Climate, Heat, Work, Heat strain, Cardiovascular effects, Productivity, Climate change

Introduction

Human physiological function and states of health are impaired by excessive environmental heat exposure; so too is work capacity and productivity[1, 2]. Under future conditions of climate change, especially with the anticipated increase in variability of short-term temperatures, exposure to extremes of heat will increase[3]. This poses a risk to heat-exposed workplaces worldwide − at higher, cooler, latitudes because temperatures are rising twice as fast there as the global average warming, and in tropical regions which already have very high seasonal heat exposures. Based on the current international standard from ISO for maximum recommended heat exposure during continuous work at high physical intensity[4], climate change will make such work more difficult for millions of people[5].

Rice paddy cultivation in India covers 44 million hectares[6], and the rural workers carry out manual harvesting in the hot sun during March to June, the hottest period of the year[7].

Occupational health risks and reductions of work pro-

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ductivity are linked to energy expenditure and workplace heat[1, 5]. There have been earlier studies of these relationships on mine workers in the 1960s in South Africa[8] and on cigarette manufacturing workers in the 1980s in India[9]. Experimental studies in climatic chambers have demonstrated the heat tolerance limits in different physical activity conditions[1, 10]. However, the heat impacts on working people in current routine work settings have not been reported.

Physiological acclimatization reduces health risks[8], and “behavioural acclimatization” by slowing down the workpace helps[11, 12], but this will only partly reduce the heat strain on the human body while working[8].

Hydration and nutrition are essential for maintaining high energy expenditure in agricultural work.[2, 11, 13] Increased heart rate indicates cardiac stress[14] both from physical work and heat exposure. Heat exhaustion, heat stroke, and even death, has been recently reported among agricultural workers in the USA[15]. Profuse sweating leading to daily dehydration may lead to chronic kidney disease[16].

Hourly productivity among workers in Thailand was reduced (10–60%) in construction and pottery industries (self-reporting)[17], depending on the level of heat exposure. Increase in the local temperature due to climate change may create impacts both on workers’ health and on economic conditions[18, 19]. Rice harvesting by hand in the hot climate of India causes a considerable cardiorespiratory and thermoregulatory strain[20, 21].

The impact of workplace heat exposure on behaviour, physiological function, cardiovascular health, risks of organ damage and diminished productivity has been a ‘blind spot’ in recent assessments of how future climate change will affect human well-being and health[22–25]. In September 2012, for the first time, the likely global and national labour productivity losses due to increasing workplace heat during climate change were assessed in terms of economic costs[26]. The results must be considered preliminary, but the very high estimated costs already in 2030 (globally 2.4 trillion US$ PPP) justify further research and analysis of this issue.

Quantitative evidence of the dual relationship of workplace heat exposure both to cardio-vascular strain and to hourly productivity of farm-workers in the field is lacking. This study provides the first formal assessment of these relations in rice harvesters in India − representative of a huge heat-exposed workforce in the developing world. The main objective of the study is to quantify the relationship between hourly heat exposure in workplaces and the hourly labor productivity and thus the work strain of these farm workers. The new evidence will be of key importance in making climate change impact assessments.

Subjects and Methods

Study design

This study compares exposure and outcome variables in the same individuals at different times. The physiological parameters and the hourly work output were analyzed in relation to changes in workplace heat levels. The study was carried out during 50 d in April to June 2011, coinciding with the harvesting period before the monsoon arrived. All aspects of the study were carried out according to the Ethical standards of the departmental research committee of Kalyani University.

Study population

The subjects were 124 male agricultural workers in the age range 18–45 yr with a minimum work experience of two years. They represented typical rice harvesters in West Bengal. The heights and weights were similar in all ten-year age groups (average height 160–165 cm, and weight 60–65 kg).

As the age range of the subjects was wider so a subset of 48 workers in the same age group of 25–34 yr were randomly chosen as the study group for the physiology and productivity parts of the study.

Environmental parameters

Air temperature (Ta, dry bulb temperature) was measured hourly during five work hours each day with a Digital Multi-Stem Thermometer with external sensing probe (Model No. ST-9269, India) shielded from the sun and close to the workers on the farm fields. Wet Bulb Globe Temperature (WBGT)[1]1 was measured at a fixed site in the field using a globe thermometer (for Tg), a natural wet bulb thermometer (for Tnwb) and a dry bulb thermometer (shaded from the sun producing Ta). The WBGT was then calculated with the standard calculation formula[1].

$$WBGT = 0.7\ Tnwb + 0.1\ Ta + 0.2\ Tg.$$

During harvesting, productivity and climate variables were recorded three times: in the beginning of work (06.00; first hour), in the middle hour (09.30) and in the last period of work (12.30; fifth hour).

Based on simultaneous temperature and WBGT estimates at the farm fields an empirircal relationship was established and used to calculate the WBGT levels for each of the hours in the work productivity part of the study. An analysis of associations between WBGT levels and work productivity makes it possible to compare the results with occupational standards and other studies.

In relation to climate change it is important to consider how the local climate has been changing in recent decades. Detailed data are available from the nearby weather station at Kolkata Dum-Dum airport and stored at the US NOAA global climate database (National Oceanographic and Atmospheric Administration). Using software (Hothaps-Soft) that calculates daily values for the routinely collected temperatures and humidity since 1980 (Otto et al., unpublished) the trends of WBGT were estimated.

Health complaints and heat concerns

A questionnaire including details of workload, job demand, work output, food habits, hydration habits, health problems, etc. was used in interviews at the end of a day's work (the Hothaps questionnaire) [27]. Pilot trials were made on a different group of rice harvesters. As the majority of the subjects (n=124) were illiterate, the questionnaires were completed by an interviewer in their local language (Bengali).

Cardiovascular strain

Physiological data were collected during "experimental" hours at three different temperature ranges from the subgroup of 48 subjects in the age range 25–34 yr. These subjects were asked to perform their work of harvesting using a sickle for a time period of 30 min. No restriction was imposed on the speed of cutting, so the subjects cut according to their capacity and at a speed that was comfortable for them. Working heart rate was recorded every minute during this work period and the recovery heart rate was recorded for up to 15 min after the cessation of work. In a real work situation, after harvesting for 30–45 min, the harvesters take a rest of 5–10 min and then resume work. Heart rate was measured every minute using a wearable heart rate monitor (Polar Accurex Plus, Polar electro Oy, S810i, Finland).

In the analysis of results we compared average heart rate trends expressed as the following physiological variables:

Resting Heart Rate (HRr): The subjects were allowed to rest for a period of 30 min. Following the rest period; the heart rate monitor was worn and recorded for 5 min. The minimum value per minute obtained during this period was considered as the resting value.

Peak Heart Rate (HRp): The maximum heart rate recorded during the test.

Average Working Heart Rate (HRw): Estimated from the value of the 4th to 30th min of work[28].

Sum of recovery heart beats (SRHB): A measure of work strain, which was calculated by summing the heart rate values during the recovery period of 10 min[14].

Net and Relative Cardiac Cost: Net cardiac cost (NCC) and relative cardiac cost (RCC) were considered as two derived indices of cardiac strain[29]:

NCC = Sum of working heart beats − (resting heart beat/min) × period of work (min).

$RCC = (NCC/ [(HR_p - HR_r) \times \text{working period}]) \times 100.$

Work productivity measurements

Harvesting starts in the morning (05.00–05.30 h) and continues until 12.00–12.30 h. A new area was selected each day and all harvesters working there were counted as a group (10–18 per group). The subset of 48 volunteers made groups according to size of the field and their work output per hour was recorded by tally counters who calculated the number of rice bundles laid down by each group. During the study period the workers were not told about the planned analysis, which most likely ensured that the workers cut the crops according to their usual capacity. Their work was "self-paced" and differences in hourly work output can be related to the workers' perceived comfort with the environmental conditions. A total of 28 group results were recorded at different hours and environmental heat levels.

The study was undertaken for 5 work hours each day and the hourly number of bundles was divided by the number of workers in each group to calculate the average hourly productivity per worker. The 5 h work excludes the rest breaks for Tiffin (lunch or light meal) but small breaks (3–6 min), taken between work tasks, were included as part of the normal work time management. The results were tabulated according to the hourly average calculated WBGT, which varied between different days and hours of the day.

Statistical analysis

Mean and standard deviation (SD) of the environmental and physiological parameters were calculated. Then Students *t*-test was used to test for any significant differences between the measured parameters at different times and heat exposures.

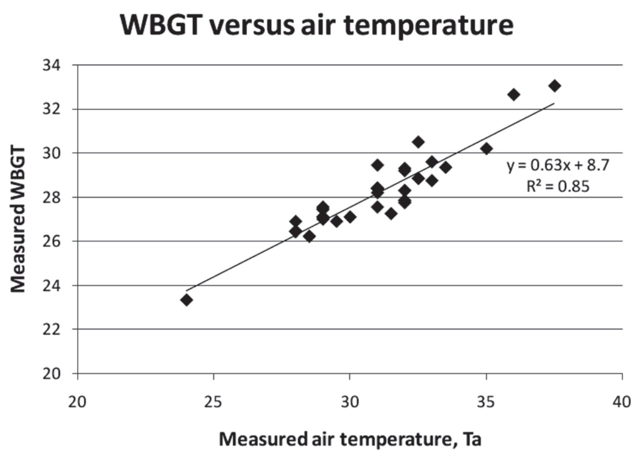

Fig. 1. Comparison of estimated WBGT and Ta at different time points.

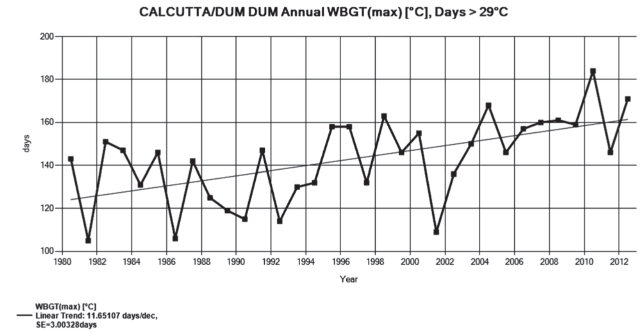

Fig. 2. Time trend 1980 − 2010 of number of days with WBGTmax at 29°C or higher at Kolkata airport weather station (12 days more each decade).

Table 1. Health complaints and heat concerns presented at the questionnaire interviews with the rice harvesters (N=124)

Health complaint	Number of harvesters affected	% affected
Pain in different body parts	89	72
Digestive problems	81	65
Cardiovascular problems	15	12
Other problems (eyes, ears, respiratory)	31	25
Heat concerns	**Number reported**	**% reported**
Aware of heat stress symptoms	69	56
Discomfort during hottest days	46	37
Exhaustion during hottest days	62	50
Work productivity lost when hot	50	40
Forced to work during hot days due to poverty	73	59

N.B.: The percentages do not add up to 100% due to multiple responses.

Results

Heat exposures

The three components of WBGT were measured at three time points of each study day at a fixed point in the farm area. The WBGT averages of early mornings to noon values per week of the seven week study period were 27–29°C and specific days were 23–33°C.

The hourly worker heat exposures in the physiology and productivity parts of the study were only measured as dry bulb temperature (Ta). In order to estimate WBGTs based on Ta values the variables were compared with the actual WBGT measurements. There is good correlation (Fig. 1) between Ta and the WBGT (r^2=0.85; n=24). The linear regression equation was WBGT = 0.63 × Ta + 8.7°C. WBGT is lower than Ta (Fig. 1), which is what one would expect as relative humidity lower than 100% lowers WBGT. The highest WBGT level at 33°C represents extreme workplace heat exposure (Parsons 2003)[1].

The number of days each year that WBGT at midday (WBGTmax) reaches ≥ 29°C at Kolkata airport has increased from approximately 120 days in 1980 to 160 days per year in 2011 (Fig. 2). There is considerable annual variation, but the trend is obvious.

Health complaints and heat concerns

Health complaints included pain (prevalence = 72%) (Table 1), which may be due to awkward working postures, the strain of long hours of repetitive work and related heat exhaustion. Digestive problems (65%) (Table 1) may be caused by insufficient water supply and sanitation. Further investigations of the health of this working population are planned, including underlying causes, prevention and treatment possibilities.

Heat concerns during work included heat exhaustion, discomfort and productivity losses during the hottest days

Table 2. Cardiac strain and energy expenditure of the male rice harvesters (N=48) working for 30 min at different environmental temperatures

Parameters	28–30°C	31–33.5°C	35–36°C
Peak heart rates (HRp) (beats/min)	119 ± 10.5	122 ± 9.5*	132 ± 11.5**
Sum of Recovery Heart Beats (SRHB)	493 ± 24.2	872 ± 21.3**	1,260 ±16.9**
Net cardiac cost (Beats)	951 ± 80.4	971 ± 202	1,095 ± 111**
Relative cardiac cost (%)	74 ± 3.3	78 ± 4.2*	81 ± 5.7*

Mean values ± SD; *$p<0.05$; **$p<0.001$.

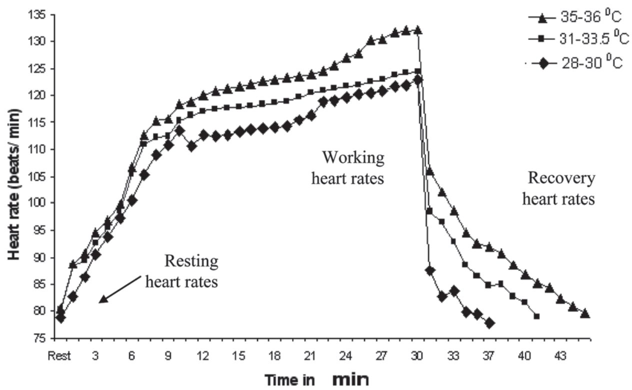

Fig. 3. Heart rates of the rice harvesters (N=48) in different environmental temperature ranges, before, during and after a 30 min work period.

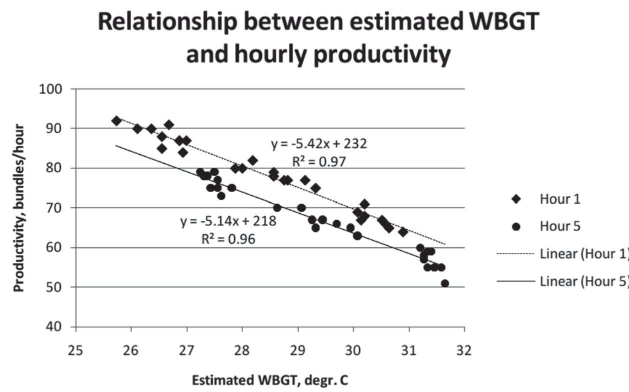

Fig. 4. Bundles of rice harvested per hour (productivity) at different environmental heat levels, WBGT (Each point is a group average of 10–18 workers; hour 1 is first work hour of the day, and hour 5 is the 5th work hour).

(Table 1). The latter effect is obvious to them, as their daily pay is related to the number of rice bundles they cut and assemble. Older workers (above 30 yr of age) tended to report more of these concerns.

Cardiovascular strain

The heart rate increased to the peak value observed for the combination of work and environment during the first 10 min of work and then the curve somewhat plateaus off, but is still increasing slowly and at some point reaches to its peak as self paced workloads slightly vary (Fig. 3). After cessation of work the heart rate recovery is fast in case of low temperature i.e. 28–30°C, and comparatively slower in the higher temperature ranges.

The peak heart rate (HRp) is significantly higher in the air temperature (Ta) ranges of 31–33.5°C ($p<0.05$) and 35−36°C ($p<0.001$) than at 28–30°C (Table 2). The percentage of resting heart rate (%RHR) also increases with temperature, as do the sum of recovery heart beats and the cardiac cost variables (Table 2).

Work productivity measurements

The 28 group tests of productivity included hourly work output (numbers of rice bundles) for each group between early morning and noon. Air temperature (Ta) was measured during the 1st and 5th work hours, and using the relationship between Ta and WBGT reported earlier (Fig. 1) the equivalent WBGT levels were calculated. The relationship between hourly WBGT and work productivity for the 1st work hour of each day and the 5th work hour (Fig. 4) show close correlations ($r^2 = 0.96$ and 0.97). The difference in work output between the 1st and the 5th work hours is partly related to the higher heat levels in the 5th hour, but there is also a constant difference of approximately 5 rice bundles per hour, which indicates that the workers are more tired after four hours of work. The increasing cardiac strain during the hotter work hours (Fig. 3) is a sign linked to heat exhaustion as well. Data on heat levels and work productivity during the 3rd hour of work is also available and the results show a similar trend between the 1st and 5th hours.

As WBGT increases, the number of rice bundles harvested decreased (Fig. 4). According to the fitted line equations, the numbers of rice bundles at a WBGT of 27°C were 86 and 79 for the 1st and 5th hours, respectively. At a higher WBGT (31°C), the corresponding numbers are 65 and 59 bundles. Approximately 5% of the work output at

26°C in the first hour (90 bundles) is lost for each degree C of WBGT increase.

Discussion

This study highlights the health and work productivity related problems experienced by people who have to carry out physical work when exposed to high levels of heat. In Murshidabad, West Bengal, 70% of men are involved in agricultural work. Most of them come from poor socio-economic backgrounds and do not own the land they work on. Between March and June they perform harvesting and post harvesting activities in the wheat and the rice paddy fields for 120−140 Indian Rupees (=2.4 US$) per day. Generally, the men are the only member of a family (minimum of 4–6 members) earning an income.

The work is heavy labour and very stressful as they are unable to take sufficient rest between or during their work days. Many of them use no protective measures such as hats, umbrellas or raincoats in summer and the rainy seasons. The weekly average WBGT at 29°C and hourly WBGT as high as 33°C (Fig. 1), mean that even moderate physical labour becomes a heat hazard for health if sufficient hourly rest periods to cool down are not provided[1, 4, 30]. The trend towards higher numbers of such hot days (Fig. 2) creates climate related threats to the health and livelihood of these harvesters and their families. The projected increased heat levels in the future[3] will add to these threats as climate change progresses.

According to Pradhan et al. (2008)[31], the significant increase in the SRHB with the increase in temperature (Table 2) caused increase in the heat strain of the workers after working in the heat. The net and relative cardiac costs are significantly higher in the hot environments, 31–33.5°C and 35–36°C, than at 28–29°C (Table 2) and can be considered to be high[32, 33]. The work productivity per hour gradually decreases with the increase in heat exposure (Fig. 4) as well as with the order of the working hour (i.e. workers produce less as their working time progresses). Work intensity must be slowed down to reduce internal body heat production, cardiac strain, and heat exhaustion[1]. This "self-pacing" for health protection reduces hourly work productivity[5]. The quantification of this reduction as a function of WBGT is an important input into climate change impact assessments, but very little quantitative evidence is available. Our study is the first recent analysis of this issue.

The few studies that have quantified work productivity in relation to heat exposure in field work situations did not document the cardiac strain to the same extent as our study[8, 9]. Our quantitative estimates of the work productivity loss at different WBGT values (Fig. 4) for a common type of agricultural work can be used to estimate the future productivity loss in this type of work, as climate change increases the number of days with very high heat exposures in many parts of the world. It should be pointed out also that among the variety of health effects that will be related to climate change[34], many of the effects not due to direct heat exposure will also be of particular importance for working people[35]. Comparison has been done with the productivity (Fig. 4) and effort/cardiovascular strain (Table 2) by dividing the net cardiac costs (beats) in each temperature class by productivity (bundles/hour). Results show that each bundle would require 11 beats per bundles/hour at 28–30°C, 13 beats per bundles/hour at 31–35°C and 17 beats per bundle/hour at 35–36° C. Of course, these numbers may vary in different settings and should be studied further. However, these estimates show that the effort or strain for a specific production output is higher in heat. Following from that, heat has two effects: it lowers the productivity and makes the products more "expensive" when evaluated by human strain.

The workload and heat impacts can be minimized by using protective broad-brimmed hats against direct solar exposure and by carrying out work in cooler hours at night, using head lamps. However, poor farm workers are not likely to have the resources to acquire such protection. Proper hydration is also essential, as a worker may sweat 1 litre per hour[1]. Access to clean drinking water during work in the fields is needed, but is not always available in locations with generally poor surface water quality. Daily nutrition also influences exhaustion risk. These harvesters eat water-soaked cooked rice, onion and sour curd as their daily lunch, but this is not sufficiently nutritious. Lack of nutrition can also affect work productivity over longer time frames than the acute effect of excessive heat exposure.

Conclusions

High workplace heat exposures on poor agricultural workers create cardiovascular strain and lowered work productivity. The heat index (WBGT) levels above 26°C are known to affect human work capacity, but very few quantitative studies of workers in their usual daily work have been carried out. Higher heat levels are common during the hottest months in India and other tropical and subtropical countries, and the demonstrated productivity loss is likely to be a common threat to workers and the local economy. An increase of heat exposure (WBGT) of 1°C may cause a reduction of work productivity of approximately 5%. The results of this study can be used to calculate work productivity losses in exposed occupations as climate change progresses. If actions to reduce workplace heat stress are not implemented, the economic outputs of exposed working populations will be reduced and global efforts to reduce poverty will be undermined.

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References

1) Parsons K (2003) Human thermal environments. The effects of hot, moderate and cold temperatures on human health, comfort and performance, 2nd Ed., Taylor & Francis, London.
2) Bridger RS (2003) Introduction to ergonomics, 2nd Ed., Taylor & Francis, London.
3) Jendritzky G, Tinz B (2009) The thermal environment of the human being on the global scale. Global Health Action; Special Vol: 10–21.
4) ISO (1989) Hot environments −Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature). ISO Standard 7243. International Standards Organization, Geneva.
5) Kjellstrom T, Holmer I, Lemke B (2009) Workplace heat stress, health and productivity −an increase change for low and middle income countries during climate change, Global Health Action.
6) TNAU (2011) Agricultural crop scenario for India. Tamil Nadu Agricultural University. http://agritech.tnau.ac.in/agriculture/agri_cropscenario_india.pdf. Accessed July 15, 2012.
7) Kumar KR, Sahai AK, Kumar KK, *et al*. (2006) High-resolution climate change scenarios for India for the 21st century. Curr Sci **90**, 334–45.
8) Wyndham CH (1969) Adaptation to heat and cold. Environ Res **2**, 442–69.
9) Nag A, Nag P (1992) Heat stress of women doing manipulative work. Am Ind Hyg Assoc J **53**, 751–6.
10) Zhao J, Zhu N, Lu S (2009) Productivity model in hot and humid environment based on heat tolerance time analysis. Build Environ **44**, 2202–7.
11) Davies CT, Brotherhood JR, Collins KJ, Doré C, Imms F, Musgrove J, Weiner JS, Amin MA, Ismail HM, El Karim M, Omer AH, Sukkar MY (1976) Energy expenditure and physiological performance of Sudanese cane cutters. Br J Ind Med **33**, 181–6.
12) Bates GP, Schneider J (2008) Hydration status and physiological workload of UAE construction workers: a prospective longitudinal observational study. J Occup Med Toxicol **3**, 21–31.
13) Takagi K, Masuda T, Kida N (1970) A report on the food intake of farmers in single and double crop districts before the introductive of power cultivators. J Sc Labour **46**, 593–625.
14) Dey NC, Samanta A, Saha R (2007) Assessment of cardiac strain amongst underground coal carriers −A case study in India. Int J Ind Ergon **37**, 489–95.
15) MMWR (2008) Center for Disease Control and Prevention (CDC). Heat-related deaths among crop workers −United States, 1992–2006. Morbidity & Mortality Weekly Report, June 20, **57**, 649–53.
16) García-Trabanino R, Dominguez J, Jansa J, Oliver A (2005) Proteinuria and chronic kidney disease on the coast of El Salvador. Nefrologia **25**, 31–8 (in Spanish).
17) Langkulsen U, Vichit-Vadakan N, Tapatagaporn S (2010) Health impact of climate change on occupational health & productivity in Thailand. Global Health Action.
18) Kjellstrom T (2000) Climate change, heat exposure and labour productivity. Epidemiology **11**, S144.
19) Kjellstrom T (2009) Climate change, direct heat exposure, health and well-being in low and middle income countries. Global Health Action **2**, 1–4.
20) Nag PK, Goswami A, Ashteker SP, Pradhan CK (1988) Ergonomics in sickle operation. Appl Ergon **19**, 233–9.
21) Nag PK, Nag A, Ashtekar SP (2007) Thermal limits of men in moderate to heavy work in tropical farming. Ind Health **45**, 107–17.
22) Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, Friel S, Groce N, Johnson A, Kett M, Lee M, Levy C, Maslin M, McCoy D, McGuire B, Montgomery H, Napier D, Pagel C, Patel J, de Oliveira JA, Redclift N, Rees H, Rogger D, Scott J, Stephenson J, Twigg J, Wolff J, Patterson C (2009) (Lancet-University College London Institute for Global Health Commission). Managing the health effects of climate change. Lancet **373**, 1693–733.
23) World Bank (2009) Climate change and development. World Development Report 2010. World Bank, Washington DC.
24) World Bank (2012) Turn down the heat. World Bank, Washingotn DC.
25) WHO and WMO (2012) Climate change atlas. World Health Organization and World Meteorological Organization, Geneva.
26) DARA (2012) Climate Vulnerability Monitor 2012. DARA,

Madrid. website: daraint.org.
27) Kjellstrom T, Gabrysch S, Lemke B, Dear K (2009) The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Global Health Action.
28) Nag PK, Sen RN, Ray US (1979) Cardiorespiratory performance of porters carrying loads on a treadmill. Ergonomics **22**, 897–907.
29) Costa G, Berti F, Betta A (1989) Physiological cost of apple firming activities. Ergonomics **20**, 281–6.
30) ACGIH (2009) TLVs for chemical substances and physical agents & Biological exposure indicators. American Conference of Government Industrial Hygienists, Cincinatti.
31) Pradhan CK, Thakur S, Mukherjee AK, Roychowdhury A (2008) Energy expenditure of cycle rickshaw pullers in different places in India. Ergonomics **51**, 1407–17.
32) Palenciano L, Gonzalez V, Santullano LA, Montoliu MA (1996) Cardiac frequency in miners recorded during four to five work shifts. Eur J Appl Physiol Occup Physiol **73**, 369–75.
33) Chamoux A, Borel AM, Catilina P (1985) Pour la standard d' unfrequence cardiaque de repos. Arch Mal Prof **46**, 241–50.
34) McMichael A, Campbell-Lendrum D, Ebi K, Githeko A, Scheraga J, Woodward A (2003) Climate change and human health: risks and responses. World Health Organization, Geneva.
35) Bennet C, McMichael T (2010) Non-heat related impacts of climate change on working populations. Global Health Action.