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Perceived Thermal Response of Stone Quarry Workers in Hot Environment

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Introduction: Impact of heat on health of workers goes unrecognized by the virtue of the indispensable fact that every individual has varied perception and tolerance capacity. The present study determine the physiological signs with perceived subjective responses under the thermal stress.

Materials and Methods: The study was spread on open field stone quarry workers ($N = 934$) during the summer (May to June), post monsoon (September to October), and winter (December to January).

Results: In the summer months, dry bulb temperature range from 36.1 to 43.2°C and the distribution of Wet Bulb Globe temperature (WBGT) outdoor values were outlier-prone than normal distribution indicated heat vulnerability. The environmental effect on weighted average skin temperature (T_{sk}) local segmental T_{sk} and deep body temperature (T_{cr}) were greater than the effects that might be attributed to work severity. The tolerance time level in summer months (65 ± 13 min at WBGT 35 ± 2.3°C) was less than in other two season. About 85% of workers in summer, 68% in post monsoon and 79% in winter recorded working heart rate greater than 90 beats/min. Physiological and subjective responses to heat stress indicated that during summer month the workers complained of excessive sweating (93.5%), feeling of thirst/dry mouth (88.7%), elevated Core temperature (T_{cr}) (58.7%) and decreased working capacity (75.6%). The observation found that around 14% workers were vulnerable to heat stress and the workers had no knowledge to mitigate the heat related illnesses.

Discussion and Conclusions: The stone quarry work as compared to other outdoor workers have environmental adversaries which becomes confounding variables in the study of such occupations. There was significant difference ($p < 0.001$) as far as the physiological and thermoregulatory responses were concerned in three different months of investigation.

Keywords: stone quarry, heat wave, WBGT, tolerance time, perceived response

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INTRODUCTION

Heat waves are becoming increasingly severe and frequent, exacerbated by climate change threatening health and livelihood directly or indirectly (Dutta and Chorsiya, 2013; Azhar et al., 2014; Nag et al., 2014). Over a million workers are employed in quarrying and related activities in India (Saiyed and Tiwari, 2004). Types of rock extracted from quarries include cinder, chalk, china clay, clay, coal, coquina, construction aggregate (sand and gravel), globigerina limestone (Malta), granite, grit stone, gypsum, limestone, marble, phosphate rock, and sandstone. A number of sand stone quarries are located in different states of India, e.g., Rajasthan, Madhya Pradesh, Gujarat, Orissa, Karnataka, Tamil Nadu, and Andaman and Nicobar islands. Sand stone quarry is an open excavation from which the stone is obtained, by labor-intensive and strenuous methods. The workers use heavy hand tools for extracting process (layers of hard rocks) and perform many manual material handling tasks like breaking, drilling the hard rocks and lifting/carrying those for loading and unloading to transport to desired destination. The workers are exposed directly under the sun throughout their working day. Huge hammers or mechanical drilling are used to separate the stone blocks. Grecchi et al. (2009) have found that the traditional working methods cause musculoskeletal pain and discomfort among the stone quarry workers due to awkward postures and lifting of heavy weights. Epidemiological surveys on stone cutters and carvers found that the hand arm vibration induced white finger, sensor-neural, and musculoskeletal symptoms among the workers (Griffin et al., 2003; Makoto et al., 2005; TaMrin et al., 2012). Mathur (2005) reported that the average life span of stone quarry workers is ∼10 years less than their fellow villagers who never worked in quarries. In the western part of India summer temperatures in stone quarries often exceed 45°C, indicating the risks of heat-induced illnesses and disorders among workers, with the relative vulnerability of young and elderly workers.

Literature reviewed suggested enough evidence to demonstrate the increasing certainty that climate change significantly aggregates the probability of extreme weather conditions, most often in directions that lead to dangerous health consequences especially to people who carry out heavy physical labor as a part of their daily jobs like steel plant, power plant, forge plant, etc. (Krishnamurthy et al., 2017; Varghese et al., 2018). In developing countries like India these workers are generally migratory and work on daily wages. When the ambient temperature exceed that of body temperature (37°C), the body loose heat by evaporation or sweating by the mechanism of thermoregulation controlled by the hypothalamus section of the human brain But, humidity affects this thermodynamic stability by limiting sweat evaporation and heat loss, which creates health impacts and loss of work capacity among the exposed workers (Saghiv and Sagiv, 2020). A thermodynamic model of heat balance is applied, with due account of heat exchanges through the segmental and compartmental interfaces of the human body, microclimatic and outer environment (Nag et al., 2007).

During the hot season, because of the strenuous physical activity and climatic condition the workers in stone quarry accumulate heat load and heat stress which effects their occupational health and work capacity. The health hazards get severe if the person is exposed higher temperature for a longer time. With increasing temperature in future it is likely that the health of vulnerable occupational groups like stone quarry workers are big challenge. Studies have found that the work environment higher than temperature 40°C causes human discomfort and high mortality (Steeneveld et al., 2011; Petitti et al., 2015; Bunker et al., 2016). Literature related to response of extreme climate exposure of workers in stone quarry is lacking. Since the combined load of strenuous physical work and exposure to extremely hot environment have negative impacts on human health and safety, the present study focused on generating epidemiological data on the heat-exposed stone quarry working population, with reference of biophysical perspective. Furthermore, these findings are needed to be substantiated by the subjective symptoms reported as perceived response under the thermal stress which underlies the utility of the present research work.

MATERIALS AND METHODS

Ethics

The written informed consent to participate in the study was taken as per the Indian Council of Medical Research (2000) ethical guidelines from the individuals (as all were above 18 years) for the publication of any potentially identifiable images or data included in this article.

A total of 934 men in the age range between 18 and 60 years were selected in the present crosssectional study of stone quarry workers from western part of India (**Figure 1**). Environmental and health risk surveillance were undertaken in stone quarry works, during the months of summer (May to June, $N = 521$), post monsoon (September to October, $N = 214$), and winter (December to January, $N = 199$) months. Workers underwent seasonal extremes of climate scenarios and experience hardships which may sometimes fall beyond their coping levels, resulting in heat injuries. Direct measurements of the thermometric parameter include ambient dry bulb temperature (T_a), wet bulb temperature (T_{wb}), dew point, wind velocity and globe temperature (T_g) were measured by Wet-Bulb Globe Temperature (WBGT) Monitor, Delta OHM (HD 32.1, Thermal Microclimate, Italy) and Relative Humidity/Temperature data by Lascar EL-USB-2-LCD, Sweden for several hours of observation period and continued for a number of days at each workplace. The environmental warmth was expressed in terms of WBGT index (Liljegren et al., 2008). The locations of stone quarry were same in the summer, post monsoon, and winter seasons during the investigations. However, same workers could not be followed up in different seasons since the workers were migratory and casual laborers worked on daily wages.

In order to ascertain susceptibility of workers to heat stress, a checklist enquiry was introduced for health risk surveillance, heat exposure- related morbidity of the work groups, including environmental warmth assessment, physical fatigue and perceived effort. The workers' subjective responses

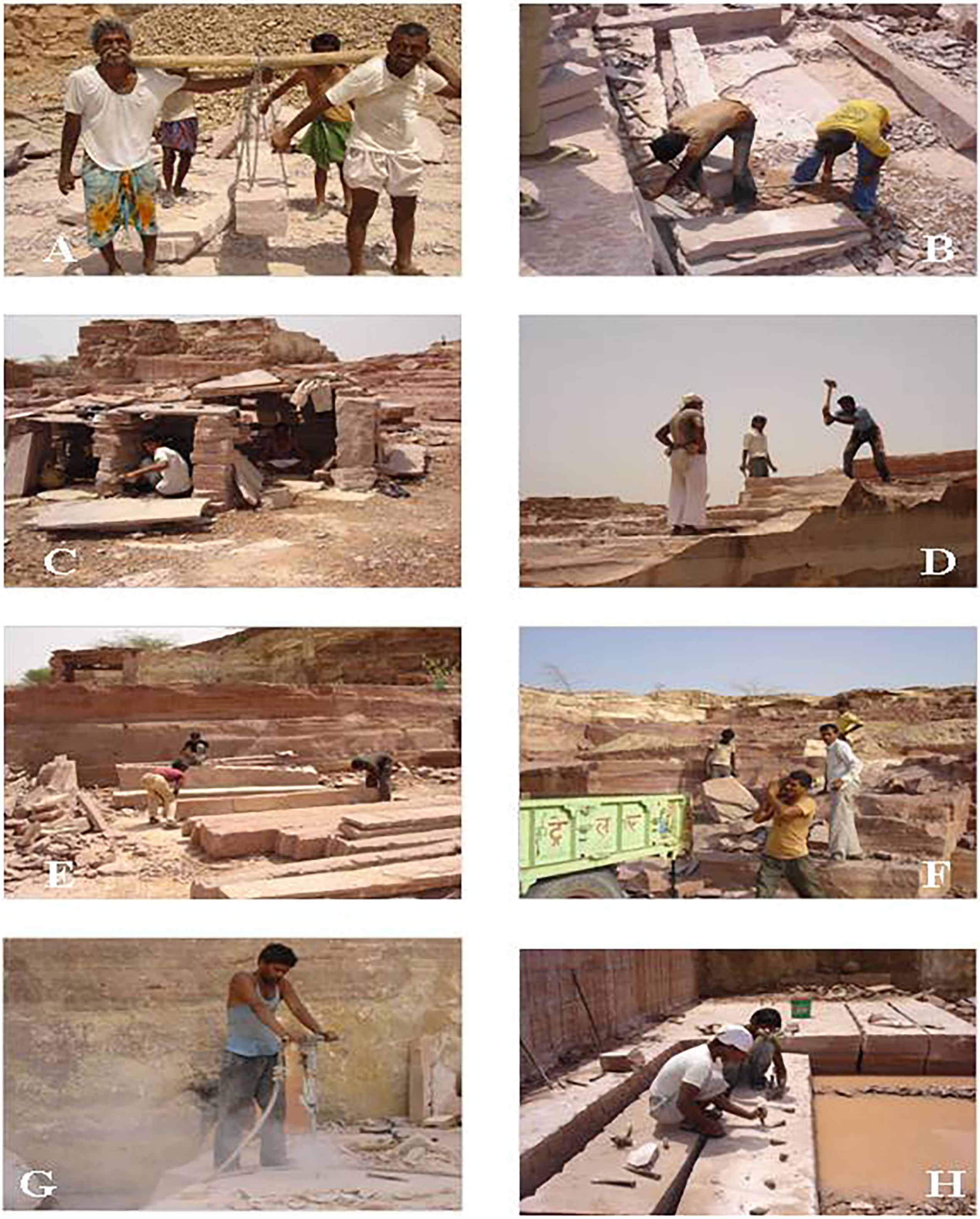

FIGURE 1 | Stone quarrying activities in the open cast mine: **(A)** carrying stone slab; **(B)** Removing slab for breaking; **(C)** self–made stone shelter in the mine; **(D)** Breaking stone with hammer; **(E)** Manually lifting slab for breaking; **(F)** Loading stone slab; **(G)** Drilling stone; **(H)** Separating stone slabs.

were recorded on a five-point Likert scale, and a score of 4 and 5 were taken as an indication of high strain response. Every worker was subjected to physiological variables measurement that included heart rate responses, blood pressure measurements, thermographic profile of the skin areas (T_{sk}) and deep body temperature (T_{cr}). The thermographic profile of the skin (T_{sk}) areas were recorded, using ThermoCAM, FLIR system (Sweden) from four exposed sites, i.e., head, hand, trunk, leg, and back trunk. The measurements were repeated thrice, i.e., pre-exposure and at an interval of about 2–3 h during work. Heart rate was measured by polar heart rate meter (S810^{TM} Polar Electro Oy, Finland); deep body temperature (T_{cr}) as oral temperature by thermometer and OMRON digital BP instrument was used to record the blood pressure during the work. The polar heart rate monitor and cuff of BP apparatus was tied to the chest and the arm of the worker respectively before the commencement of the work. The polar heart rate automatically record the heart rate and when BP need to monitor the OMRON BP apparatus was connected to the lead of the cuff and BP was measured in less than a minute for a single worker without interrupting their main work process. The data of Polar heart rate meter was later transferred to the computer. During the occupational exposures, the workers wore light clothing—wearing shorts, trouser or a lungi/dhuti (a loose fabric wrapped around join at ankle length) and a half-sleeve banian or t-shirt, with clothing insulation value approx. 0.6 clo (Summer clothing insulation unit).

The algorithm allowed computation of heat exchange parameters, including heat conductance, metabolic load, effective heat load, body heat storage, and the overall rate of change of body core temperatures. These dimensions led to the prediction of the limits of tolerance to work in hot environments. This algorithm is based on premise of biophysical approach propagated by Nag et al. (2007), utilizing the heat exchanges through different avenues across the segment (i.e., head, trunk, arm, hand, leg and feet) and body layers- blood, core (viscera plus skeleton), muscle, fat and skin (i.e., 6 segment × 5 layers = 30 compartments) (Nag et al., 2007). These are the following equations with thermodynamic model of heat balance of each segment (where storage δ H = 0) adopted from Nag et al. (2007).

$$\begin{aligned} \mathrm{Y}\Delta\mathrm{T}/\Delta\mathrm{t} = {} & (\mathrm{V}\rho\times\mathrm{S})_{\mathrm{Blood}}\times(\mathrm{T}_{\mathrm{Blood}}) + \Delta\mathrm{M} \\ & -[\{\mathrm{K}_{\mathrm{Blood-core}}(\mathrm{T}_{\mathrm{Blood}} - \mathrm{T}_{\mathrm{core}}) + \mathrm{K}_{\mathrm{Core-Muscle}} \\ & (\mathrm{T}_{\mathrm{Core}} - \mathrm{T}_{\mathrm{Muscle}}) + \mathrm{K}_{\mathrm{Muscle-Fat}}(\mathrm{T}_{\mathrm{Muscle}} - \mathrm{T}_{\mathrm{Fat}}) \\ & + \mathrm{K}_{\mathrm{Fat-Skin}}(\mathrm{T}_{\mathrm{Fat}} - \mathrm{T}_{\mathrm{Skin}}) + \mathrm{H(i)}(\mathrm{T}_{\mathrm{Skin}} - \mathrm{T}_{\mathrm{Environment}})\} \\ & \times\mathrm{SA} + (\mathrm{C}_{\mathrm{Res}} + \mathrm{E}_{\mathrm{Res}} + \mathrm{E}_{\mathrm{Skin}})] \end{aligned}$$

Where Y, product of compartmental mass and specific heat, $\Delta T/\Delta t$, change in temperature with time, V, volume (liter), ρ, density (kg/L), S, Specific heat of blood (W h/kg °C), ΔM, (total-basal metabolic energy, W.h), K, conductance of body compartments (W/m^2.°C), T, resultant body temperature (°C), H(i), combined heat transfer coefficients of segments (W/m^2.°C), SA, surface area (m^2), C_{Res} and $E_{Res,}$ resoiratory heat loss through convention and evaporation (W.h), E_{skin}, evaporation heat loss for skin (W.h).

STATISTICAL ANALYSIS

Data analysis was performed using SPSS statistical software, version 16.0. Descriptive statistics was applied to understand the charactersitics of temperature profile and physiological variables of the workers. One way ANOVA was used to study the differences of these variables among three different seasons. Percent prevalence was calculated for perceived sign and symptoms responses of the workers. The level of significance was set at $p < 0.05$.

RESULT

The open-field day-time ambient conditions are presented in **Table 1**. The percentile distribution, skewness, and kurtosis values of WBGT estimated during the three seasons of investigation reflected the variations in environmental warmth. During summer (May to June), the distribution of WBGT outdoor values was more outlier-prone than the normal distribution. The positive kurtosis indicated a relatively peaked distribution. The WBGT values spread out more to the right from the proximity of the mean (35 ± 2.3°C) and thereby indicating a component of heat vulnerability of the sample population concerned. The environmental data were found to be statistically different in three seasons (summer, post monsoon, and winter) of the investigation. The workers had mean body weight 53.8 ± 9 kg and body surface area 1.6 ± 0.1 sqm.

Beside variation in the environmental conditions, the magnitude of physiological responses of the stone workers attributed to the combined stress of environmental exposure and the intensity of the work performed, with the potential to health consequences. A comparison of local T_{sk} and weighted average T_{sk} of workers in summer, post monsoon and winter are in **Table 2**, indicating their T_{sk} responses differed significantly. During the summer and post-monsoon months, the 5th−95th percentile values of T_{sk} of varied from 30.1 to 40°C and 32.7 to 37.3°C, respectively. Whereas, in the winter months, the 5th−95th percentile values of T_{sk} of local areas ranged from 24.6 to 34.7°C. The profile of segmental T_{sk} indicated the relative space for adjustment against the extent of the core temperature buildup of the workers. **Table 2** also includes the weighted average T_{sk} of the whole body, which was obtained from the surface area and sensitivity weighting of local area T_{sk}. The weighted T_{sk} during summer and post monsoon remained at 35.3 ± 1.3°C and 35.0 ± 1.0°C, respectively, whereas the value during winter was 31.6 ± 1.4°C. One-way ANOVA shows that the T_{sk} of the local areas significantly differed during the three investigating seasons. The trunk, upper arm, hand, thigh, and foot temperatures in summer and post monsoon were relatively more than a winter month.

Different physiological responses, given in **Table 3**, indicates significant differences ($p < 0.001$) in bodily strains of the stone quarry workers in three seasons of investigation. The average heart rate response of the workers during work in summer and winter seasons were 108 ± 14.6 and 109 ± 21.2 beats/min, respectively, whereas the heart rates were relatively less (99 ± 14.6 beats/min) in the month of post monsoon. The increase in heart

TABLE 1 | Environmental conditions at workplaces.

Variable	Statistics	Summer ($N = 521$)	Post monsoon ($N = 214$)	Winter ($N = 199$)
Dry bulb temperature (^{0}C)	Mean ± SD	40.0 ± 2.4	35.2 ± 2.2	26.6 ± 5.3
	5th Percentile	36.1	33.1	20.0
	95th Percentile	43.2	38.9	34.5
	Skewness	0.3	0.6	0.2
	Kurtosis	0.5	−0.9	−1.6
	F Value		1,265.8 ($p < 0.001$)	
Outdoor WBGT (^{0}C)	Mean ± SD	35.5 ± 2.3	32.2 ± 1.8	23.1 ± 2.0
	5th Percentile	31.8	28.1	20.0
	95th Percentile	39.4	35.4	26.8
	Skewness	0.7	−0.4	0.1
	Kurtosis	0.6	0.2	−0.7
	F Value		2,382.0 ($p < 0.001$)	

TABLE 2 | Local skin temperature profile of workers at workplaces.

Segmental T_{sk}	Statistics	Summer ($N = 521$)	Post monsoon ($N = 214$)	Winter ($N = 199$)
Head (^{0}C)	Mean ± SD	35.8 ± 1.2	34.8 ± 1.0	30.7 ± 2.4
	5th Percentile	33.0	33.2	26.8
	95th Percentile	37.4	36.7	34.6
	Skewness	−0.1	1.1	−0.1
	Kurtosis	−0.4	0.1	−0.8
	F Value		264.4 ($p < 0.001$)	
Trunk (^{0}C)	Mean ± SD	35.1 ± 1.6	34.9 ± 1.2	32.1 ± 1.8
	5th Percentile	32.6	33.0	28.8
	95th Percentile	37.5	36.8	34.7
	Skewness	−0.2	1.2	−0.4
	Kurtosis	0.2	0.1	−0.1
	F Value		282.8 ($p < 0.001$)	
Upper arm (^{0}C)	Mean ± SD	35.1 ± 2.1	35.2 ± 1.2	29.3 ± 2.1
	5th Percentile	31.2	33.1	25.3
	95th Percentile	38.2	37.0	32.6
	Skewness	−0.5	1.2	−0.4
	Kurtosis	−0.1	0.1	0.2
	F Value		672.5 ($p < 0.001$)	
Hand (^{0}C)	Mean ± SD	35.6 ± 1.3	35.0 ± 1.2	32.3 ± 1.6
	5th Percentile	33.6	33.1	29.4
	95th Percentile	38.0	36.7	34.7
	Skewness	0.2	−0.3	−0.3
	Kurtosis	0.3	0.2	−0.3
	F Value		424.6 ($p < 0.001$)	
Thigh (^{0}C)	Mean ± SD	35.6 ± 1.9	35.2 ± 1.3	31.7 ± 1.5
	5th Percentile	32.7	33.0	29.1
	95th Percentile	38.9	37.2	34.0
	Skewness	0.3	−0.1	−0.3
	Kurtosis	0.3	−0.4	0.8
	F Value		388.3 ($p < 0.001$)	
Foot (^{0}C)	Mean ± SD	35.2 ± 3.0	35.2 ± 1.4	28.9 ± 2.4
	5th Percentile	30.1	32.7	24.6
	95th Percentile	40.0	37.3	32.9
	Skewness	−0.1	−0.3	−0.1
	Kurtosis	0.1	−0.3	−0.1
	F Value		448.5 ($p < 0.001$)	
Weighted T_{sk} (^{0}C)	Mean ± SD	35.3 ± 1.3	35.0 ± 1.0	31.6 ± 1.4
	5th Percentile	33.0	33.3	29.2
	95th Percentile	37.4	36.6	33.8
	Skewness	−0.1	0.0	−0.3
	Kurtosis	−0.4	−0.3	−0.3
	F Value		264.4 ($p < 0.001$)	

rate in winter is due to decrease in environmental warmth and increase in physical load. The environmental load and heart rate responses differed significantly in summer and post-monsoon months of investigation [$F_{(2,931)} = 31.3$, $p < 0.001$]. About 85% of the workers in summer, 68% in post monsoon, and 79% in winter have working heart rates greater than 90 beats/min. The heart rate response and the prediction of oxygen uptakes at the range of 0.76–1.96 l/min for the workers, indicate that the severity of stone quarry work might be categorized as heavy to extremely heavy in summer and heavy to moderately heavy in post monsoon and winter. The systolic blood pressure in the month of winter was marginally higher (139 ± 15 mmHg) as compared to summer months (133 ± 17.1 mmHg). Also there was no significant difference in diastolic blood pressure during three seasons.

The average level of T_{cr} of the stone quarry workers during work in the months of summer, post monsoon and winter illustrates the dynamic equilibrium of heat transfer supposedly maintained between the body core and periphery, in regulating the buildup of body temperature. As given in **Table 3**, the 95th percentile value of T_{cr} in summer months reached 40.1°C. It was noted that nearly 10% of the workers, the T_{cr} level during their work in summer months crossed the critical limit value of heat tolerance (39°C) and these workers were at unsafe zone of exposure. This remains a challenge to recognize those vulnerable workers who might be at risk of heat disorders. None of the workers during post monsoon and winter crossed the heat tolerance criteria.

The workers had similar demographic and physical characteristics and they were engaged in equivalent nature of work. The physiological demand of work for the workers in the month of May to June was ∼14% higher, as compared to the strains during post monsoon and winter. The weighted T_{sk} and T_{cr} of the workers are grouped according to the WBGT range (**Figure 2**). There was a consistent increasing trend of T_{sk} and T_{cr}, however the gradient tend to decrease when the WBGT exceeded 32.9°C. This hallmarks the critical zone where the probably the thermoregulation mechanism of the body switched on to maintain the body haemostasis and further control build up of temperature at core so, that the workers body could adapt to the thermal environment. The cascades of event occurs to offload the produced heat is by increasing the cutaneous blood flow that bring the hot blood closer to the external environment

TABLE 3 | Physiological responses of workers during stone quarrying work.

Variable	Statistics	Summer ($N = 521$)	Post monsoon ($N = 214$)	Winter ($N = 199$)
Heart rate (beats/min)	Mean ± SD	108 ± 14.6	99 ± 14.6	109 ± 21.2
	5th Percentile	88	80	80
	95th Percentile	135	120	152
	Skewness	0.6	0.9	0.8
	Kurtosis	−0.1	2.4	0.5
	F Value		31.3 ($p < 0.001$)	
Systolic BP (mmHg)	Mean ± SD	133 ± 17.1	128 ± 13.4	139 ± 15.0
	5th Percentile	106	109	115
	95th Percentile	158	153	163
	Skewness	0.3	0.6	0.1
	Kurtosis	1.0	0.4	1.3
	F Value		21.9 ($p < 0.001$)	
Diastolic BP (mmHg)	Mean ± SD	78±12.7	79 ± 12.8	77 ± 10.7
	5th Percentile	60	60	60
	95th Percentile	98	101	94
	Skewness	1.7	0.6	−0.6
	Kurtosis	14.7	2.0	1.5
	F Value		1.5 (NS)	
T_{cr} (^{0}C)	Mean ± SD	37.3 ± 1.1	36.7 ± 0.4	36.8 ± 0.5
	5th Percentile	36.2	36.1	36.1
	95th Percentile	40.1	37.3	37.8
	Skewness	1.8	0.0	0.7
	Kurtosis	3.1	−0.7	0.3
	F Value		42.6 ($p < 0.001$)	
Sweat loss (gm/min)	Mean ± SD	15.6 ± 1.7	13.7 ± 1.5	6.5 ± 1.8
	5th Percentile	13.0	9.7	3.9
	95th Percentile	18.4	15.8	9.8
	Skewness	0.8	−1.1	0.4
	Kurtosis	1.2	1.4	−0.7
	F Value		2,099 ($p < 0.001$)	
Predicted tolerance time (min)	Mean ± SD	65 ± 12.7	83 ± 17.4	199 ± 42.7
	5th Percentile	46	62	131
	95th Percentile	88	132	266
	Skewness	−0.1	1.7	0.0
	Kurtosis	0.4	2.8	−0.7
	F Value		2,429.2 ($p < 0.001$)	

and loose the heat by radiation, convection, and evaporation of sweat into latent heat.

The segmental heat exchanges and the rate of body temperature build up were estimated and arrived at a time duration that corresponded to the limit of tolerance of 39°C and referred to as heat tolerance time (**Table 3**). During the summer season, the tolerance time was significantly less, in comparison to other two seasons. In post-monsoon season, the tolerance time was arrived at 83 ± 17 min at WBGT 32.2 ± 1.8°C; i.e., 18 min drop in tolerance time for 3.3°C increase in WBGT. For the winter season, the heat tolerance time was estimated as 199 ± 43 min at WBGT 23.1 ± 2.0°C. About 134 min drop in tolerance time for ∼12°C increase in WBGT in summer season.

The questionnaire surveyed the checkpoint that looked into the signs and symptoms of heat-related illnesses, as given in **Table 4** (Nag et al., 2013; Hanna and Tait, 2015). Corresponding to observations of physiological and subjective responses to heat stress, the workers were vulnerable to heat illnesses. Over 21.3% of the stone quarry workers complained of decreased urine output situation during the summer exposure, in comparison to only 7% workers in post monsoon and 17.6% in winter. Nearly 93.5% of the workers complained of excessive sweating and 88.7% feeling of excessive thirst/dry mouth and ∼58.7% workers reported elevated T_{cr} during the summer months. About 3/4th of the workers complained of decreased working capacity.

Perceived effort/exertion of an individual scored using Borg's scale corresponded closely to the severity of the tasks performed. The perceived effort levels remained in the range of 14–17 and for this level of subjective response, the heart rate variations might correspond to 140–170 beats/min. However, the 95th percentile values of heart rates for the workers in the months of summer, post monsoon and winter were 135, 120, and 152 beats/min, respectively. The subjective response to overall physical fatigue score remained at a high level, i.e., close to 9–10 in 13 point scale, however, the relative fatigue to different levels of environmental warmth could not be reflected. The self-reporting of perceived effort, physical fatigue, and any other heat-related symptoms by the illiterate workers have limitations and therefore, appropriate indoctrination of the workers and consistent recording by the field investigators was essential in establishing relationships between the symptoms and heat exposures.

Our study shows a need of break or rest rooms of the workers that may effective in reducing the thermal load of participants. Further, studies on stone quarry work may be advantageous in estimating the exact nature of thermal load experienced by workers and its discernible effects. Nevertheless, it will help in understanding India's burden of heat stress illness, both occupational and otherwise.

DISCUSSION

The stone quarry work as compared to other outdoor thermal environment occupation like steel plant, steel plant, power plant, and forge plant where it is difficult to control the environmental adversaries which becomes confounding variables in the study of such occupations. According to Indian Meteorology Department (IMD), a category of heat wave includes places where the normal maximum temperature is more than 40°C. Researchers had found that for the last 25 years the average global temperature rose by 0.6°C (De et al., 2005; IPCC, 2007). The conditions of the heat wave prevailed in the regions where the study was undertaken during the summer (May to June), as the 95th percentile value of dry bulb temperature was 43.2°C. The

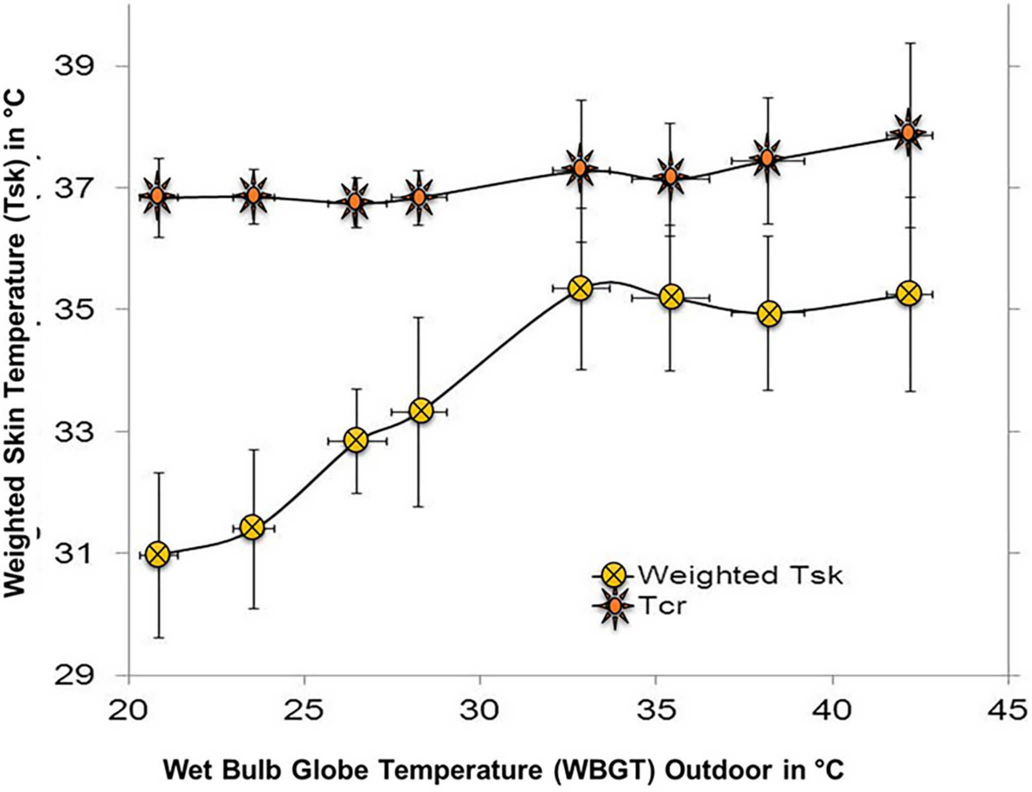

FIGURE 2 | Weighted average T_{sk} and T_{cr} at different environmental warmths.

environmental load in the month of winter was substantially less in comparison to conditions during the season summer and post monsoon.

The cardiovascular and thermoregulatory responses of the stone quarry workers differed significantly in the month of summer, post monsoon, and winter. The responses were the resultant of combined effect of environmental warmth and work strenuousness that ranged from heavy to extremely heavy in the month of summer, post monsoon and heavy to moderately heavy in the month of winter. The study observed a small increase in systolic blood pressure during the winter months. The trend of the results corroborates to the findings of Kristal-Boneh et al. (1995) that the average Systolic BP at work was higher in winter than in summer. The activation of the sympathetic nervous system and secretion of catecholamine might be increased in cooler environment, resulting in increase in blood pressure through an increased heart rate and peripheral vascular resistance (Alperovitch et al., 2009).

The relative effects of environmental stress on the physiological responses that would be expected beyond the level attributed to physical work, however, need to be ascertained. Data indicated that the environmental effects on local segmental T_{sk} and weighted average T_{sk} of workers were greater than the effects that might be attributed to work severity (Nag et al., 2013). The profile of segmental T_{sk} indicated deviation from the thermo-neutral reference, provoking distinctive peripheral response for feedback and regulation in building up of body temperature. For the range of environmental warmth from 25 to 43°C WBGT (ISO Standard 7243, 1989), the workers had an increasing trend of T_{sk} and T_{cr}, however the gradient tended to narrow down when the WBGT exceeded 32.9°C and the gradient was found to be < 3°C (Nag et al., 1997, 2013). The stone quarry works are performed directly under sun and the physiological demand of work in the month of summer was ∼14% higher, as compared to the demands in the months of post monsoon and winter.

However, the biophysical analysis of heat exchanges between the body core and skin surface yield the rate of body core temperature build up and accordingly, the tolerance time of heat exposure was arrived at, corresponding to the of T_{cr} 39°C (Hanna and Tait, 2015). Above 39°C of T_{cr}, serious heat stroke and neurological effects may occur to a worker (Parsons, 2003).

As observed, there was considerable difference in the tolerance time of stone quarry work in three different seasons, due to the differences in the environmental variables and workload. The tolerance time level in summer months (65 ± 13 min at WBGT 35 ± 2.3°C) was less than other two seasons (post monsoon and

TABLE 4 | Workers' subjective response to signs and symptoms of heat strains.

	Summer (*N* = 521)	Post monsoon (*N* = 214)	Winter (*N* = 199)
	% of workers expressed heat strain		
Heavy sweating	93.5	91.1	69.8
Elevated heart rate	76.0	59.8	61.3
Weakness or fatigue	75.2	78.5	62.3
Dizziness/nausea	40.5	31.8	41.2
Headache	51.1	43.5	44.2
Confused and irritated	44.5	20.1	19.1
Skin tanning	55.1	9.8	23.6
Excessive thirst/dry mouth	88.7	82.7	55.3
Decreased urine output	21.3	7.0	17.6
Loss of appetite	47.0	26.6	36.7
Blurred vision	44.5	37.4	25.1
Hot or dry skin (no sweating)	21.9	7.0	18.1
Red face	51.2	36.9	20.1
Chill feeling/shivers	45.5	31.8	23.6
Mental disorientation	43.8	15.4	27.6
Elevated body temperature	58.7	17.8	52.3
Seizure	13.4	0.0	6.5
Slurred speech	7.7	0.5	4.0
Abdominal spasms	35.9	32.7	31.2
Muscle pain/cramp (arms/legs)	48.2	57.9	64.3
Fainting/feel collapse	13.6	4.7	28.6
Pink or red bumps	35.3	25.2	10.1
Itching skin	39.2	24.3	14.1
Irritation or prickly sensation	29.6	31.8	13.1
Loss of work capacity	75.6	62.1	57.3

winter). From the cross-sectional data on stone quarry workers, it was estimated that there was ∼14% loss of tolerance time per degree increase of WBGT, from 33 to 35°C WBGT. The loss of tolerance time might also indicate loss of productivity due to heat exposure, which Kjellstrom (2016) referred to as High Occupational Temperature Health and Productivity Suppression (Hothaps) effect, for loss of working ability or working capacity. The relative workload was higher during winter season. It is likely that the workers might be adopting self-adjustment strategy in the pace of work distributing the work and workload as per the varying environmental exposures. The make-shift shelters where the workers take rest during the hottest hours. It was observed that the environmental effects on workers appeared to be greater than the effects of work severity, therefore consistent field investigators was essential in establishing relationships between the symptoms and heat exposures.

In repeated occupational exposures high heat load and strenuous physical activity, human's defense mechanism undergoes progressive changes for internal thermal stability (acclimatization), depending upon on physiological adaptive capacity (Morioka et al., 2006). Data amply suggest that the workers during the summer months were at unsafe zone of exposure and 14% of the workers were vulnerable to heat illnesses. Also, the workers lack awareness and measures to mitigate risks. This kind of data from a larger sample size is greatly important in the assessment of the health, safety and productivity impacts of climatic changes with seasonal variation, and therefore, might be useful to develop prevention programmes of the population at risk to heat waves.

STRENGTHS AND LIMITATIONS

The location of this cross-sectional study of stone quarry workers was the same in summer, post monsson and winter months but, the specific workers and worker tasks differed between the survey times. However, regardless of the possible difference in three seasons the survey participants and their ativities, perceived heat-related symptoms and environmental measurments of heat stress has supported our overall finding that heat stress is an important risk factor for worker health. Also of note is that this study may be conservative in its findings as responses related to heat disorders among stone quarry workers may be higher than those figures observed in the study due to a healthy worker bias (i.e., those most affected by the heat were absent or had stopped doing this type of work). Another possible explanation may be attributed to the fear of being reprimanded by the management for discussing issues that may portray them negatively.

A key strength of this study is that we surmised that the high exposure coupled with strenuous physical load are the major contributing factors. Further, there is lack of Indian heat exposure guidelines for determining ceiling limits of environmental exposure for tropical heat exposure of the population. Our study supports the establishment of separate tropical or India specific heat exposure guidelines and interventions that could simultaneously be worker protective but realistic in this climate.

CONCLUSION

The study bears considerable practical importance to assess the magnitude of thermal stress among stone quarry workers in the working environment and the worker's physiological reaction to it, and therefore to ensure optimal conditions for health and productivity. The study has a limitation of focusing only on three seasons, however, the basic premise was that the cardiovascular and thermoregulatory parameters are critical to manifest ones thermal environmental perceptive responses in a occupational situation. The habitual occupational involvement makes the workers naturally acclimatized to hot environment, however, even the habitual workers during peak summer months are at potential risk of developing heat-related illness. The comprehensive analysis of the physiological and thermoregulatory responses of workers to heat stress and strain would eventually ascertain the relative vulnerability of the stone quarry workers for their exposure to extreme hot environment.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors if required, without undue reservation. But, in that case the identity or the personal information of the participants will not be shared.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Indian Council of Medical Research. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.