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Different Ergonomic Exposure Risk and Infrared Thermal Temperature on Low Back

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Abstract**—**Infrared Thermography (IRT) has been little documented in the objective measurement of ergonomic exposure. We aimed to examine the association between different ergonomic exposures and low back skin temperature measured by IRT. A total of 114 subjects among sedentary students, sports students and cleaning workers were selected as different ergonomic exposure levels. Low back skin temperature was measured by IRT before and post ergonomic exposure. Ergonomic exposure was assessed by Quick Exposure Check (QEC) and quantitative scores were calculated on the low back. Multiple regressions were constructed to examine the possible associations between ergonomic risk exposures and the skin temperature over the low back. Compared to the two student groups, clean workers had significantly higher ergonomic exposure scores on the low back. The low back temperature variations were different among the three groups. The temperature decreased significantly among students with ergonomic exposure ($P < 0.01$), while it increased among cleaning workers. With adjustment of confounding, the post-exposure temperature and the temperature changes after exposure showed a significantly negative association with ergonomic exposure scores. For maximum temperature, one increasing ergonomic score decreased -0.23 °C (95% CI -0.37, -0.10) of temperature after ergonomic exposure over the low back. There was a significant association between ergonomic exposures and infrared thermal temperature over low back. IRT could be used as an objective assessment of ergonomic exposure on the low back.

Keywords**—**Ergonomic exposure, infrared thermography, musculoskeletal disorders, skin temperature, low back.

I. Introduction

LOW back pain (LBP) is the most common musculoskeletal disorder, which gives a substantial psychological and economic burden to the patients and society, particularly among occupational populations [1]. Previous epidemiological studies reported that ergonomic risk factors including awkward back postures, hand force, physical effort, whole body vibration and job strain were associated with LBP [2], [3]. However, either the ergonomic risk factors or LBP were mostly assessed based on self-report or field observations. The physiological responses and other tangible changes in the lower back due to various ergonomic risk exposures or stresses have not yet been thoroughly investigated. For now, there has been still lack of high-quality and definitive diagnostic methods, leading researchers and practitioners to classify most LBP as nonspecific [4]. It is important to develop new techniques to measure the exposure to ergonomic risk factors, thus to understand possible pathophysiological mechanisms that may explain the cause of LBP [5].

The IRT has been a long history of applications in medicine since the first report of thermographic evaluation of pain by Albert et al. in 1964 [6]. Compared to other clinic examination methods like computed tomography, myelography, and magnetic resonance imaging, IRT has several obvious advantages of non-invasion, absolutely harmless, convenience and less cost. Besides, thermal images can be stored digitally and post-processed using software packages to obtain insight into various thermal patterns [7]. Meanwhile, IRT evaluates the functional phenomena particular the micro-blood flow in certain local area regulated by the autonomic nervous system, while CT or other radiological methods illustrate the morphological changes. For the sensitivity and validity, there were pro and con studies of IRT application in musculoskeletal disorders' assessment [8]-[11]. However, the special characteristic of IRT lies in its ability to offer a possibility for assessing the function of a certain organ or tissue, such as the vasomotor activity of the sympathetic nerve fibers, and to detect potential sympathetic dysfunction. Additionally, it can provide extra information about the status and disturbances of the sympathetic vasomotor tone, which cannot be obtained through other conventional methods [10].

In recent years, more and more studies have applied IRT in assessment of musculoskeletal disorders or ergonomic risk exposures [12]-[14]. Ramos et al. used IRT to examine the skin temperature on wrist and fingers during a typing work [15]. IRT was used to detected the physiological responses to repetitive movements, overloading and muscular hyperactivity that occur during musical performance [16]. Nevertheless, there were limited reports of high-quality studies using IRT to detect the potential health effects or to diagnose musculoskeletal disorders as a tool [17]. Moreover, few studies focused on the association between ergonomic quantitative exposures and the skin temperature changes using IRT on low back. There is a need to establish the possible association between skin temperature and ergonomic exposure/stress, not only for objectively diagnose musculoskeletal disorders, but also can be applied for assessing the effectiveness of ergonomic interventions and research. Therefore, in this study we aimed to use IRT to measure the low back skin temperature, and examine the association between the skin temperatures, temperature variations and different ergonomic risk exposures.

II. Participants and Methods

A. Study Design and Participants

We applied a cross-sectional study design and examined the low back skin temperature before and post the ergonomic

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exposures. We cluster-sampled all students in one of classes at Putian University, who studied in a classroom by sedentary position for around 2 hours. After excluding 6 students who had recent LBP complaints, a total of 48 students were included as the sedentary group. Another student group was from 34 students who were recruited from another class and consented to participate in physical exercises. The exercises were sit-up, plank, back bend down and up, and/or squatting with weight of 10 kg. The students selected one or more style exercises to perform and lasted for about 10-minute. Each student performed twice with a quarter of interval for rest. This student group was called as sports students. Besides, we clustered sampled 32 cleaning workers at Putian University, who did a cleaning tasks for about 2 hours at campus. The cleaning tasks included mop/sweep floor, clean glasses, and collect rubbish. This present study was approved by Putian University ethic committee. Each participant signed the informed content.

B. QEC Scores

We applied QEC to assess participants' ergonomic quantitative exposures [18]. The QEC has been validated in the Chinese population and the intra- and inter-raters' reliability was also examined to be reliable [19], [20]. Three interviewers who had been trained with QEC completed the field observations and interviews during the investigations. Four body parts of participants with six anatomic sites were observed and assessed for the calculation of ergonomic exposure scores and exposure level based on the algorithm, including neck, shoulders/arms, back, and wrists/hands [18]. We calculated the back ergonomic exposure scores based on static position and/or movement of the back for the three groups. The stress, vibrations and work-pace score for cleaning workers were considered as well. Each participant was observed on the field and calculated the ergonomic exposure scores with QEC method. In this current study, we focused on the back QEC scores for statistical analyses.

C. Infrared Thermal Temperature Measurement

Guided by the 15-items consensus on the measurement of human skin temperature by Delphi study [21], we used the infrared thermal instrument (Model FORTRIC-325C) to calibrate the low back skin temperature with the calibration report of the production. Skin temperature was quantified using the IRT camera with a resolution of 320 × 240 pixels (FORTRIC model325-C, Shanghai, China) with noise-equivalent temperature difference (NETD) < 0.05 °C, and measurement precision/uncertainty of ± 2 °C or 2%. To make the stabilization of the electronic components, we turned on the camera at least 10 min before the measurement. All images were captured at a distance of 0.8 m from the region of low back (L3-S1), with a camera lens perpendicular to the low back area [21].

The baseline and post-exposure temperature over low back were measured respectively at a room temperature of 24-25 °C before and after the ergonomic loading among three groups. Then, thermographic images of the low back area were taken while standing normally. Infrared thermal temperatures were analyzed using the FORTRIC AnalyzIR thermography software. Maximum, minimum and average temperatures of the low back were the target metrics. The temperature variations (ΔT) were calculated by subtracting the temperature of the 'baseline' from that of the 'post' temperature for each metric among three group subjects.

D. Data Analyses

All analyses were based on parametric statistical methods; due that, the data distributions for the three groups were almost normal. Descriptive statistics including t test, chi-square test and ANOVA were used to compare the baseline characteristics among the three groups. Data analyses first focused on the comparisons of ergonomic exposure scores and the changes of skin temperature over low back among three groups. The changes of skin temperature over low back were compared by paired t test between 'pre' and 'post'. Then multivariable linear regression models were constructed to examine the association between thermal temperatures and ergonomic exposures over low back. Dependent variables were the baseline, post-exposure and the variations of maximum, minimum and average temperature over low back. The baseline temperature was considered as an adjustment when examining the associations between the post-exposure temperature, the variation and QEC scores. Repeated analyses were also performed with excluding cleaning workers to examine the potential effect of subject characteristic heterogeneity. All analyses were conducted using SPSS Statistical Software 21 for Windows (SPSS, Inc, Chicago, Ill, USA). P less than 0.05 was considered significant.

III. Results

Table I provides basic information of the subjects for three groups. The two student groups were similar in age, weight, height, BMI, smoking status and exercise habit, but significantly different from the cleaning workers, particularly in age, height and exercise habits. Cleaning workers had a significant higher QEC scores than that of the sedentary and sports students.

The infrared thermal temperatures and their changes over low back for different groups are illustrated in Table II. The two student groups exhibited significantly decreased maximum, minimum and average temperature over low back after two-hour sedentary and one-hour physical warm-up. For cleaning workers, the maximum, minimum and average temperature increased after 2-hour cleaning tasks, but did not reach statistical significance. Except the maximum temperature before the exposure, the low back temperatures of both pre and post the ergonomic exposures were significantly different among three groups.

Table III showed the factors that predicted the post-exposure temperature over low back. Ergonomic exposure measured with QEC scores was significantly associated with decreased temperature of low back for the post-exposure. One score increased for ergonomic exposure may decreased more than 0.2 °C after ergonomic exposure, for maximum temperature -0.23 (95% CI -0.37, -0.10), for minimum temperature -0.21 (95% CI -0.40, -0.02), and for average temperature -0.26 (95% CI -0.42,

-0.11). Age and baseline temperature were positively associated with post-exposure temperature over low back. The fitness of linear regression model in term of R square for the maximum, minimum, and average temperature was 0.679, 0.680 and 0.699, respectively. The baseline temperatures over low back had not any significant associations with QEC scores (data not displayed).

TABLE I
BASIC CHARACTERISTICS OF SUBJECTS AMONG SEDENTARY STUDENTS, SPORTS STUDENTS AND CLEANING WORKERS

	Sedentary students	Sports students	Cleaning workers	P
N	48	34	32	
Male sex, n (%)	16 (33.3)	16 (47.1)	12 (37.5)	0.912
Age, Mean (SD), yrs	22.8 (0.8)	22.2 (0.6)	51.9 (4.0)	<0.000
Weight, kg	61.1 (14.5)	67.1 (13.4)	57.5 (6.9)	0.107
Height, Mean (SD),cm	168.1 (8.2)	171.1 (8.2)	156.2 (3.1)	<0.000
BMI	21.5 (4.0)	22.8(3.4)	23.6 (3.2)	0.168
Smoking, n (%)	6 (12.5)	4 (11.8)	6 (18.8)	0.755
Exercise habit, n (%)				0.010
Seldom <1 time/week	8 (16.7)	6 (17.6)	18 (56.3)	
Sometimes, 1-4 times/week	30 (62.5)	20 (58.8)	10 (31.2)	
Often, ≥ 5 times/week	10 (20.8)	8 (23.5)	4 (12.5)	
QEC scores, Mean (SD)	21.0 (1.8)	24.8 (2.8)	32.6 (1.9)	<0.000

SD: Standard Deviation, BMI: Body Mass Index.

TABLE II
INFRARED THERMAL TEMPERATURE AND THEIR CHANGES OVER LOW BACK AMONG DIFFERENT ERGONOMIC LOADING GROUPS

Temperature, mean (SD)		Sedentary students	Sports students	Cleaning workers	P&
Maximum	T0	35.41 (0.92)	34.57 (0.62)	34.89 (1.39)	0.064
	T1	34.71 (1.24)	32.80 (1.09)	35.32 (1.16)	<0.000
ΔT_{Max}*		-0.71 (1.05)	-1.77 (0.86)	0.43 (1.24)	<0.000
$P^{\$}$		0.006	0.000	0.081	
Minimum	T0	33.39 (1.36)	31.35 (0.88)	31.78 (1.66)	0.001
	T1	32.43 (1.59)	29.35 (1.46)	32.09 (1.52)	<0.000
ΔT_{Min}*		-0.96 (1.39)	-2.01 (0.74)	0.31 (1.34)	<0.000
$P^{\$}$		0.001	0.000	0.141	
Average(ROI)	T0	34.51 (0.96)	33.12(0.84)	33.53(1.48)	0.004
	T1	33.64 (1.40)	31.15 (1.28)	33.85 (1.25)	<0.000
$\Delta T_{Average}$ *		-0.87 (1.18)	-1.96 (0.76)	0.32 (1.32)	<0.000
$P^{\$}$		0.001	0.000	0.130	

*$\Delta T = T_1 - T_0$, T_0: Baseline temperature, T1: post-exposure temperature; SD: Standard Deviation, ROI: Region of Interest; & ANOVA among three groups; $ Paired-t test.

Predictive factors for the variations of infrared thermal temperature over low back are demonstrated in Table IV. With adjustments of other potential confounding factors, QEC score was significantly associated with decreased thermal temperature variations over low back. The increased QEC score was significantly related with decreased maximum temperature change of -0.23 ℃ (95% CI -0.37, -0.09), minimum temperature change of -0.20 ℃ (95% CI -0.39, -0.01) and average temperature change of -0.26 ℃ (95% CI -0.41, -0.10). Additionally, age was positively associated with the temperature changes, while the baseline temperature showed negative association with the temperature changes over low back. For BMI, significant inverse association was seen for maximum temperature changes (B = -0.08, 95% CI -0.18, -0.01). The fitness of linear regression model in term of R square for the changes of maximum, minimum, and average temperature was 0.575, 0.405 and 0.527, respectively. Excluding cleaning workers for repeat analyses reproduced the similar results that QEC was negatively associated with the change of low back temperature (data not shown).

TABLE III
PREDICTIVE FACTORS OF POST-EXPOSURE TEMPERATURE OVER LOW BACK
(N = 114)

Predictive factors	B	95% CI	P
T_{Max}			
Sex, male	-0.67	-1.47, 0.13	0.099
BMI	-0.07	-0.17, 0.03	0.173
Age	0.09	0.05, 0.13	0.000
Baseline T_{max}	0.62	0.28, 0.96	0.001
QEC scores	-0.23	-0.37, -0.10	0.002
T_{Min}			
Sex, male	-0.37	-1.43, 0.69	0.480
BMI, Kg/m2	-0.06	-0.20, 0.08	0.416
Age, yrs	0.09	0.04, 0.14	0.001
Baseline Tmin	0.79	0.45, 1.13	0.000
QEC scores	-0.21	-0.40, -0.02	0.031
TAverage			
Sex, male	-0.58	-1.46, 0.31	0.197
BMI	-0.07	-0.19, 0.05	0.230
Age	0.10	0.06, 0.14	0.000
Baseline Taverage	0.70	0.35, 1.04	0.000
QEC scores	-0.26	-0.42, -0.11	0.002

TABLE IV
PREDICTIVE FACTORS OF INFRARED THERMAL TEMPERATURE VARIATIONS OVER LOW BACK (N = 114)

Predictive factors	B	95% CI	P
ΔTMax			
Sex, male	-0.64	-1.45, 0.16	0.115
BMI	-0.08	-0.18, -0.01	0.043
Age	0.09	0.06, 0.13	0.000
Baseline Tmax	-0.40	-0.74, -0.06	0.023
QEC scores	-0.23	-0.37, -0.09	0.002
ΔTMin			
Sex, male	-0.33	-1.40, 0.73	0.526
BMI, Kg/m2	-0.07	-0.21, 0.05	0.179
Age, yrs	0.09	0.04, 0.14	0.001
Baseline Tmin	-0.21	-0.55, 0.13	0.101
QEC scores	-0.20	-0.39, -0.01	0.039
ΔTAverage			
Sex, male	-0.54	-1.43, 0.35	0.224
BMI	-0.08	-0.19, 0.03	0.085
Age	0.10	0.06, 0.15	0.000
Baseline Taverage	-0.32	-0.67, -0.02	0.042
QEC scores	-0.26	-0.41, -0.10	0.002

IV. DISCUSSION

In this present study, we investigated ergonomic quantitative exposure with QEC, measured the skin temperature over low back with IRT, and examined the association between the ergonomic exposure and the skin temperature. We found that skin temperature over low back changed significantly with different ergonomic risk exposures. The higher ergonomic exposure scores were significantly associated with the lower temperature over low back. Meanwhile, the ergonomic exposure scores were inversely related to the temperature variations in terms of maximum, minimum and average temperature.

Skin temperature was influenced not only by ambient environmental conditions like room temperature, humidity and wind rate, but also demographic characteristics such as age, sex, BMI and smoking status [22]. It was advised that the comparisons or changes/variations of skin temperature (ΔT) on same subjects measured by IRT should be applied to eliminate the potential interference factors mentioned above. In this study, we not only examined the association between ergonomic exposures and skin temperature, but also focused on the temperature changes between baseline and post ergonomic exposure, using ΔT as dependent variable to examine its association with ergonomic risk exposure. The skin temperature over low back either maximum, minimum or average was significantly different among three different ergonomic exposures. The two student groups demonstrated declined temperatures while cleaning workers showed elevated temperature after the ergonomic exposures. Further multiple and the reproductivity analyses consistently indicated that ergonomic exposure scores were significantly inversely associated with the low back temperature and its variations while other potential factors were adjusted for.

Thermography has been useful as an objective auxiliary method to detect the skin temperatures and their variations on certain areas of the body [17]. Muscle contraction and local blood flow over low back reduced, thus the skin temperature over the low back decreased consequently [23]. These physiological responses could be applied to explain our results that the low back temperature reduced significantly after the exercises among the sports students. Further analyses using multiple methods consistently indicated that higher ergonomic exposure scores were associated with lower temperature over low back. The results were in line with other previous studies. Herrick and colleagues used thermoghraphy to diagnose Raynaud's phenomenon manifested by a reduced temperature or ischemia of a finger [24]. As reported by Lasanen et al., less ergonomic loading with upright working posture, which supposed to be assessed as lower QEC scores, reduced the spatial variation in upper back temperature [12]. Another finding that higher QEC scores were associated with less variations of temperature over low back was similar with the previous reports by Herberts et al. [25], Bertmaring et al. [26] and Govindu et al. [27]. Their statements were that the lower temperature slopes/variations may present a higher risk of injury due to reduced blood flow, supporting that reduced blood flow may be the primary injury mechanism for body injuries during high risk of ergonomic exposures.

The possible biomechanism explanation is that long-term exposure to ergonomic risk reduced the area blood flow and even press the neural fiber which might cause pain and chronic injury. For cleaning workers, there was an observed increase in low back temperature with post-exposure, although it was not statistically significant. This could be attributed to the fact that some cleaning workers reported lower back pain (LBP), which might involve inflammation in the lower back, leading to a rise in temperature following ergonomic exposures. The student subjects had not any musculoskeletal disorders, which were quite different from cleaning workers who reported LBP in daily work among some of them. The similar results excluding the cleaning workers further supported our findings. It was a pity that we had not enough samples with specific LBP data to further analyze the association between low back symptoms and temperature among those cleaning workers currently. Our results provided further evidence that thermography may be a useful ergonomic exposure assessment tool. This study also indicated that infrared temperature could be reflected sensitively by task loading changes, demonstrating its potential use for risk assessment over low back. Specifically, changes in observed blood flow patterns during task performance were likely to conform to known physiological responses to injury [26].

Age was found to be related with the higher temperature over low back in this study, which was in line with the study by Kenny and Journeary [28]. BMI was found to be related with lower temperature and variations over low back, which was consistent with the report by Chudecka et al. [29]. Higher BMI indicated more subcutaneous fat. This fact can be explained by considering that subcutaneous fat works as a thermal insulator, which reflected on the less temperature variations over low back [30].

This study provided evidence that IRT may be useful and reliable in assessment of ergonomic exposures. Seldom study focused on the quantity of ergonomic exposure and skin temperature. As far as we know, this is the first study reported the association between QEC scores and the skin temperature measure by IRT over low back, though the limitation of cross-sectional design existed. Besides, the consideration of potential confounding factors, repeated analyses, and consistent results supported our findings. Of course, there were several weaknesses in this current study. First, we only measured the baseline and post-exposure temperature over low back, did not follow the further temperature changes with times, which might be useful in exploring the profound and delayed physiological responses with ergonomic loading. Sample sizes was small and could not perform the stratified analyses by three groups, by symptomatic and asymptomatic subjects particularly among clean workers. Despite that skin temperature is influenced by demographic characteristics such as age, sex, BMI and smoking status, the temperature changes/variations were used as dependent variable, thus the confounding effect by those factors mentioned above might be minimized, and the results seemed not produced by chance.

V. Conclusion

In conclusion, there was a significant association between ergonomic exposures and infrared thermal temperature over low back. IRT can be used as an objective measurement for assessment of ergonomic loading. Future research orientation might focus on ergonomic long-term effect on body temperature and intervention effect evaluation by IRT.

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