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Original Article

Role of work uniform in alleviating perceptual strain among construction workers

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Abstract: This study aims to examine the benefits of wearing a new construction work uniform in real-work settings. A field experiment with a randomized assignment of an intervention group to a newly designed uniform and a control group to a commercially available trade uniform was executed. A total of 568 sets of physical, physiological, perceptual, and microclimatological data were obtained. A linear mixed-effects model (LMM) was built to examine the cause-effect relationship between the Perceptual Strain Index (PeSI) and heat stressors including wet bulb globe temperature (WBGT), estimated workload (relative heart rate), exposure time, trade, workplace, and clothing type. An interaction effect between clothing and trade revealed that perceptual strain of workers across four trades was significantly alleviated by 1.6–6.3 units in the intervention group. Additionally, the results of a questionnaire survey on assessing the subjective sensations on the two uniforms indicated that wearing comfort was improved by 1.6–1.8 units when wearing the intervention type. This study not only provides convincing evidences on the benefits of wearing the newly designed work uniform in reducing perceptual strain but also heightens the value of the field experiment in heat stress intervention studies.

Key words: Perceptual strain index, Field experiment, Linear mixed-effects model, Intervention, Construction workers

Introduction

Heat stress is one of the major occupational hazards that can affect the safety, health and productivity of working people[1]. Construction workers are at a high risk of heat-related illnesses when they perform intensive work with prolonged exposure to a stressful environment[2]. The government, the construction industry, and researchers have taken the initiative to produce effective precautionary guidelines for safeguarding workers working in hot weather. The local government agencies have asserted that wearing appropriate summer work uniforms (e.g., thin and air permeable, loose-fitting, light-colored clothing) is one of the precautionary measures to protect workers from hostile weather[3, 4]. However, these "dos and don'ts" guidelines[1] conventionally take the recognized international standards as action-triggering benchmarks that lack reliability and validity in the specific regions[5]. They also lack precise criteria to assist in identifying the extent of effectiveness and practicality of these measures on helping workers combat heat stress. These guidelines thus seem to be formulated without convincing evidences based on real-life settings.

A significant body of literature has been dedicated to research on clothing thermal performance based on human wear trials in laboratory experiments and field studies. Numerous laboratory experiments can generate convincing evidences on the effectiveness of the well-designed clothing in attenuating heat strain under *perfect* conditions; however, these results must be treated cautiously

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when formulating guidelines for heat stress management[6] because of the varying environmental and physical conditions in the real world. Field studies are also indispensable to assess clothing performance in actual wear situations by measuring either physiological responses or subjective perceptions. These studies have been well documented in the fields of sportswear and insulative clothing but are rarely given enough attention on general work clothes. Thus, the role of summer work uniform in helping construction workers reduce heat strain remains ambiguous.

In addition to the effects of clothes, meteorological environment and physical activities are well known factors that influence the human thermal state. Environmental stress in the workplace weakens the body's ability to maintain thermoregulation[7]. Increasing ambient temperature and thermal radiation result in a higher heat load on the body, and a humid environment without air ventilation impairs heat exchange through evaporation. Heat production arising from muscular activity is one of the main components of exercise-heat stress[8]. The heat load gained from both thermal environment and physical activity may prevent adequate heat loss from the body, further resulting in exaggerated fatigue[9]. Prolonged exposure to direct sunlight also heightens the risk of heat-related illnesses when working in hot weather[10]. However, the interaction effects among these heat stressors are not well documented[5]. Interaction effects refer to the joint effects of the two or more causes on the consequences[11], which are widely discussed in social and health science research. They may help elaborate the complex correlations among various dimensions of heat stressors in relation to their influence on the responses to heat stress. Nevertheless, a scientific understanding of the responses to thermal stressors remains an intricate issue with little consensus on the multiple heat stressors and their interactions.

When it is invasive to directly measure physiological strain (e.g., body core temperature) at the workplaces, assessing perceptual strain may be an alternative approach for heat strain measurement because the rise in heat strain under hot conditions is also associated with elevated perceptual strain[12]. Thus, the Perceptual Strain Index is adopted for heat strain measurement in the current study. In terms of its non-invasive measurement of heat strain and unambiguous interpretation of the outputs, the perceptual strain index is expected to offer a practical solution for assessing heat strain under various heat exposures.

There is a lack of scientific research on ascertaining the role of summer work clothes in real-life settings, as well as on identifying the interaction effects between/among heat stressors in construction. To bridge these research gaps, this study aimed to examine the effectiveness of summer work uniforms in reducing perceptual strain in conjunction with environmental and work-related factors and their interaction effects. The field experiment with a randomized design was executed to collect physical, physiological, meteorological, and perceptual parameters on sites. A linear mixed-effects model was then developed to examine the heat stressors (including work uniforms) and their interaction effects affecting perceptual strain of construction workers.

Subjects and Methods

Field experiment

Field experiments are necessary in the research on intervention strategies against heat stress on construction sites because the conditions in real-life settings vary from those in contrived laboratory experiments. Based on experimental methodology, a field experiment aims to enhance the external validity of laboratory test findings[13] and attempts to retain the cause-effect relationships in fieldwork[14]. In a field experiment, one or more independent variables are invariably manipulated (e.g., intervention and control conditions), and some contingent conditions (e.g., the changes of climatic condition and work intensity) cannot be held constant by the investigators[14]. It is acknowledged that filtering all potential influential factors in real-work settings is challenging[14]. As human response to heat stress is strongly influenced by heat acclimatization state[15], age[16], and work pace[17], these factors were scrutinized in the experiment in the present study. To determine whether an intervention (i.e., wearing the new work uniform) that can help construction workers combat heat strain, a randomized assignment of participants to an intervention group and a control group was implemented. A randomized experiment can establish the effect of an intervention more convincingly compared with alternative quasi-experimental evaluation methods with statistical controls[18]. With randomized assignment, the outcomes resulting from the controlled variables may be ensured to avoid systematically biasing factors[19]. Regarding the merits of the field experiment with a randomized assignment, we formed an intervention and a control group, with the former assigned to wear a newly designed work uniform (intervention type) and with the latter assigned to wear a trade uniform (control type) in a counter-balanced order.

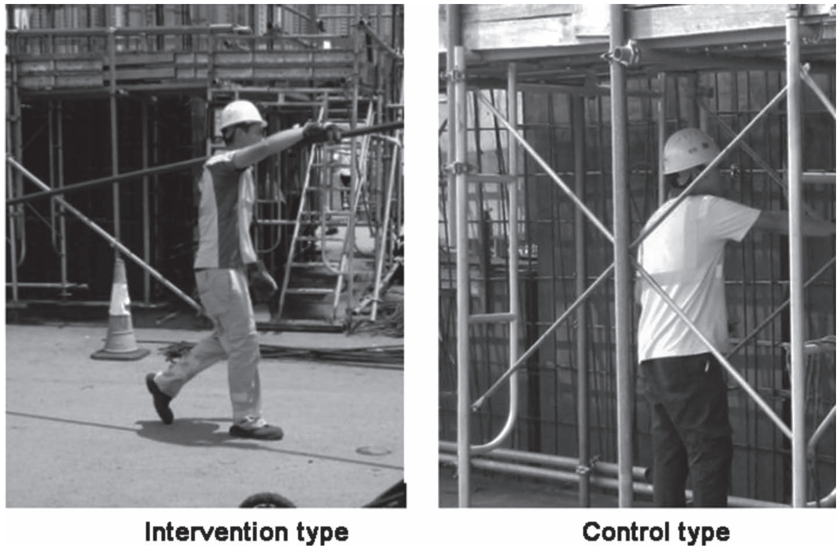

Fig. 1. Clothing type: intervention and control types.

Table 1. Basic description of the work uniforms

Type	Fiber content (main body)	Thickness (mm) (main body)	Mass (g)	Air resistance (KPa·s/m) (main body)[1]	Overall moisture management capacity (main body)[2]	UPF rating
Intervention–shirt	65% cotton, 35% polyester	0.62	175	0.06	0.80	45
Intervention–pants	100% cotton	0.48	368	1.96	0.86	50+
Control–shirt	100% polyester	0.83	260	0.14	0.51	45
Control–pants	60% cotton, 40% polyester	0.57	468	1.92	0.08	50+

Adapted from: Chan *et al.*[21]

Note: [1] A smaller value of air resistance indicates better air permeability of the fabric. Good air permeability promotes microclimate ventilation.

[2] The indices of overall moisture management capacity values can be graded and interpreted as: Grade 1: 0–0.2, poor; Grade 2: 0.2–0.4, fair; Grade 3: 0.4–0.6, good; Grade 4: 0.6–0.8, very good, and Grade 5: >0.8, excellent (Hu *et al.* 2005). Good overall moisture management capacity facilitates liquid sweat transfer from the inner side to the outer of fabric surface[23].

Work uniform

Each work uniform is composed of a short-sleeved T-shirt and a pair of long pants (Fig. 1). The intervention type was designed by the research team with consideration of fabric thermal-moisture properties and clothing smart design (e.g., porous reflective strips, and meshed fabric on the side of the body)[20]. The control type was a traditional construction work uniform commonly used by workers. All the uniforms that fit the body size of the participants were provided. The basic features of these uniforms are shown in Table 1. The effectiveness of this intervention uniform on alleviating thermo-physiological and perceptual strain has been demonstrated in the laboratory experiment[21]. The earlier questionnaire surveys involving over 180 construction workers indicate that most of workers preferred to wear this uniform to keep them cool, dry, and comfortable without impeding work performance while performing daily work in summer[22].

Subjects

A total of 16 apparently healthy local construction workers were randomly selected for the field experiment between July and August 2014. Inclusive criteria included young male construction workers without history of diagnosed health problems, heat-related illness, and regular medication intake. All participants had acclimated to work in hot weather for about one month (from June to August in the summer season of Hong Kong). The number of participants engaged in rebar work, leveling, formwork, painting and plumbing works was 6, 2, 6, and 2, respectively. While painting and plumbing workers worked at outdoors or semi-outdoor areas under a shade, the other workers performed outdoor works throughout the entire wear trial. All participants performed their work at a ground floor or a platform. They participated in the field experiment on a voluntary basis and could withdraw at any time. Given a clear briefing on the experimental purposes and testing procedures, they were asked to write the consent form prior to the experiment. The study was fully approved by the Human Subjects Ethics Sub-committee of the authors' host institution.

Experimental procedures

Each subject participated in a one-day experiment, during which the intervention and control types were randomly assigned to the participants in a counterbalanced order in the morning and afternoon, respectively. Each experiment lasted from 8:00 am to 4:30 pm (excluding one hour break for lunch from 12:00 noon to 1:00 pm). Prior to the experiment in the morning, the participants were asked to wear the assigned work uniform and a heart rate belt with its monitor (Polar Wearlink®, United States). They were then requested to provide basic personal information, including name, age, and trade. Body mass (including the uniform) was measured by using a digital scale with 0.1 kg precision (Tanita, Japan). Height was measured to the nearest centimeter with a wall-mounted ruler. Afterward, the participants were asked to rest for 30 min in an air-conditioned room with the temperature maintained at approximately 22°C. They then performed their daily work at the working sites for 135 min of wear trial (e.g., from 9:00 am to 11:15 am in the morning, and from 13:30 pm to 15:45 pm in the afternoon). This exposure time was estimated based on a heat stress model developed by Yi and Chan[24]. During this period, the participants were allowed to drink water, take breaks, and self-pace their workload as they desired. This procedure aimed to lower the risks of dehydration and inordinate work pace in triggering excessive heat strain. Each subject might have different working periods depending on their work routines and consequently, the number of repeated measures for the targeted parameters might be unbalanced. They then recovered in the air-conditioned room for 30 minutes after work. During this recovery period, the participants were asked to complete a questionnaire that was administered to assess wearing comfort of the work uniforms. Upon the completion of these testing procedures in the morning, the participants were asked to have lunch and to rest in the air-conditioned room to ensure that they were fully cooled and dried (i.e., without heavy sweating) before participating in the afternoon test. Prior to the test in the afternoon, they were asked to change to another type of work uniform. The testing procedure in the afternoon was the same as that in the morning. No subjects quitted during the experiment.

Measurements and indices calculations

Empiric-based human and environmental monitoring was executed throughout the pre-work resting, working, and recovery periods. A heat stress monitor (QUESTemp°36, Australia) was located at ground floor near to the participant to measure the wet bulb globe temperature (WBGT) at every minute. Heart rate (HR) was recorded at one-minute interval. HR and WBGT were converted into five-minute averages for statistical analysis. The participants were requested to report on the rating of perceived exertion (RPE) and thermal sensation (TS) every 5 minute to determine the level of perceptual strain. These perceptual, physiological and meteorological parameters synchronously recorded at a sample frequency of 5 minute was regarded one set of data. The real time of each measurement was recorded and further calculated as the cumulative exposure time. Once the subject took a break, the measurement was suspended and the cumulative exposure time was recounted when the participant resumed work.

The relative heart rate (RHR) (Eq. (1)) was used to estimate the relative physical workload related to muscular activities[25].

$$RHR = \frac{HR_w - HR_r}{HR_{max} - HR_r} \times 100 \quad (1)$$

where RHR refers to the heart rate increases compared to rest expressed as a percentage of the rest to maximal heart rate range, HR_w was HR measured during work, HR_r was the minimal HR during rest, and HR_{max} = 220-Age[26].

The perceptual strain index (PeSI) was developed by Tikuisis *et al.*[27]. It has been commonly used to evaluate the human perceptual strain in both laboratory and field settings, in which the PeSI can well reflect physiological strain[28, 29].

$$PeSI = 5 \times \frac{RPE_i}{10} + 5 \times \frac{TS_i - 1}{6} \quad (2)$$

where RPE_i and TS_i are the simultaneous perceived exertion and thermal sensation respectively during working period. RPE was assessed by the using the Borg's CR-10 scale with anchors ranging from 0 "Nothing at all" to 10 "Extremely strong"[30]. TS was measured by a seven-point scale modified based on Ballantyne *et al.*'s[31] study, namely, 1 – very cool, 2 – cool, 3 – slightly cool, 4 – neutral, 5 – slightly hot, 6 – hot, and 7 – very hot. These scales in

Chinese languages were provided during the experiment.

Seven items of subjective attributes were listed as bipolar descriptors on a 7-point Likert scale in the questionnaire. The meanings of scale 1 to 7 of each attribute were represented as from hot to cool, from clammy to dry, from airtight to breathable, from thick and heavy to thin and light, from work performance interfered to non work performance interfered, and from uncomfortable to comfortable. A Chinese version of the questionnaire was provided for construction workers. Three textile experts of the research team were asked to verify the translations of each language.

Data analysis

A total of 568 sets of physical, physiological, perceptual, and microclimatological data were collected. Descriptive data were presented as mean value and standard deviation (SD) or standard error (SE) to quantitatively describe the main features of the collected data in the field. The differences in physical, physiological, and microclimatological data between the intervention and control conditions were examined by analysis of variance (ANOVA), while the differences in perceptual responses were tested by Mann–Whitney U test. The difference of each subjective rating between the two uniforms was tested using the Wilcoxon signed-rank test based on 16 pairs of questionnaires.

In the field experiments with a repeated measurements design, multiple observations carried out on the same participant generally result in the correlated errors. Consequently, multiple responses from the same participant cannot be regarded as independent from each other. This assumption is explicitly violated in traditional regression analyses (e.g., linear regression analysis and generalized linear models). With repeated measurements of each participant, an autocorrelation between repeated observations on individuals through time may exist and must be considered when estimating the relationship between factors and responses[32]. Therefore, traditional regression methods are no longer appropriate for a repeated measurements design. Additionally, the interaction effects among heat stressors on heat strain are usually neglected by the early studies, thereby leading to probably questionable estimations and interferences.

As the level of heat strain can vary greatly across individuals based on their physique along with different environmental and physical conditions, these variance components should be considered in the evaluation of cause-effect relationships. The mixed-effects model enables the estimation of the variance components of exposure levels that are adjusted for individual factors in order to improve the assessment of hazardous exposure[32]. Repeated measures models incorporate specialized variance-covariance structures to account for serial correlations[33, 34]. The time interval between repeated observations can vary across repetitions. The mixed-effects models are robust to deal with unequally spaced data collection points, which do not require equal variances at each time point or equal covariance between all pairs of time points and are capable of accounting for correlations among repeated measurements[35]. The unique advantage of the mixed-effects model is the inclusion of both fixed and random effects[36]. Fixed effects provide estimates of the average responses in a group, whereas random effects (e.g., participant effects) account for the natural heterogeneity in the responses of different participants and allow the estimation of responses for each participant[32]. Therefore, mixed-effects models with repeated measures provide a satisfactory estimate of the true (unbiased) effect of an intervention against hazardous exposure.

Given the nature of the experimental design and the complexity of the cause-effect relationship between perceptual strain and heat stressors, a linear mixed-effects model (LMM) with repeated measures was used in the present study to ascertain the role of work uniforms in combating perceptual strain in real-life settings. This model was employed to identify the determinants of a number of heat stressors on perceptual strain among construction workers. In this study, work trade (coding: 1=rebar work, 2=leveling, 3=form work, 4=painting and plumping), workplace (coding: 1=outdoor, 2=semi-outdoor), clothing type (coding: 1=intervention type, 2=control type), exposure time, WBGT, RHR, and their interactions were regarded as fixed effects, whereas the participants served as the random effects. In the whole-day experiment, repeated measurements for each subject were coded as sequential numbers, which might vary because of different work routines; consequently, the intervals between adjacent repeated measurements for each subject might not be the same when the measurements were suspended by breaks.

A three-step process was employed to generate the most appropriate LMM with the criterion of *most parsimonious with the best fit to the data*, as adopted from Henderson *et al.*[37] and Bertulat *et al.*[38]. The main effects included in the candidate model with the same random effects were determined first. The main-effects model was built in a manual backward stepwise manner by removing parameters resulting in $p > 0.05$ until all remaining parameters showed a significant effect. Meanwhile, Spearman's correlation for

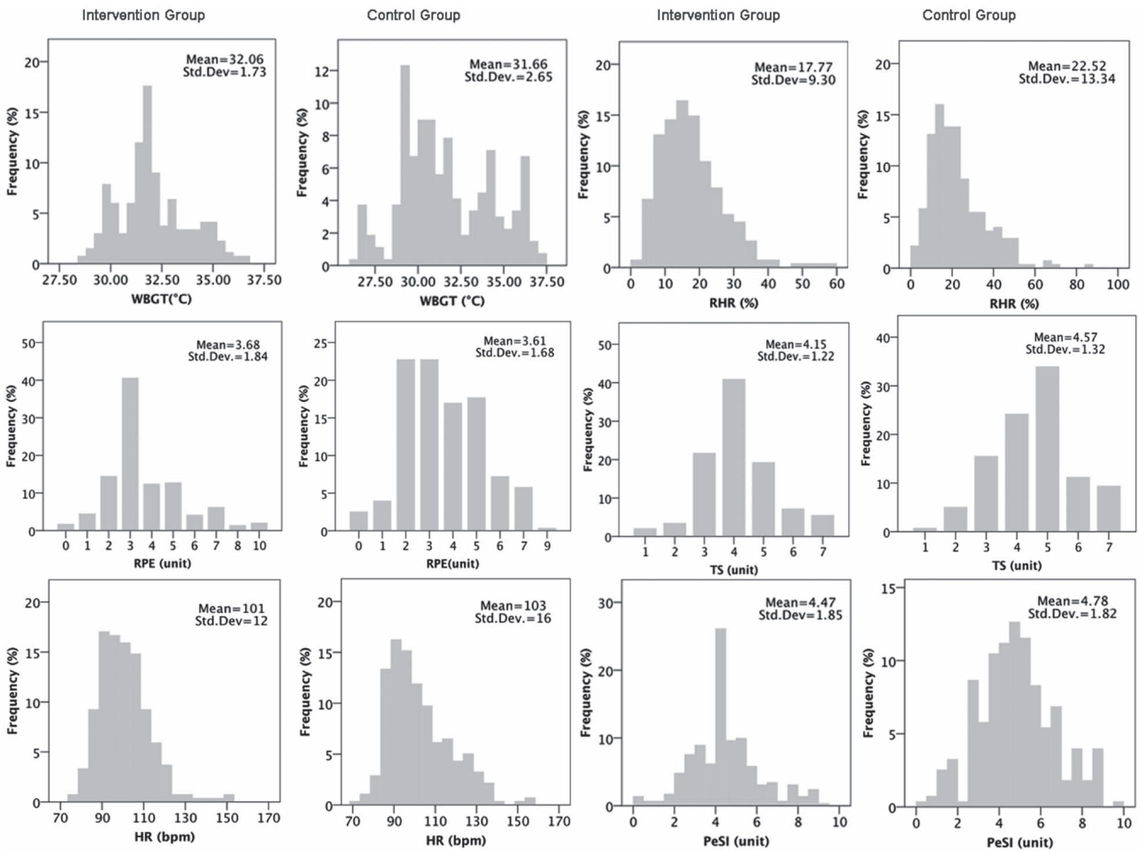

Fig. 2. Histograms displaying frequency distributions of meteorological, physiological, and perceptual parameters under the intervention (N=291) and control conditions (N=277).

nominal variables and Pearson's correlation for continuous variables were tested for collinearity. If the magnitude of correlation between two independent variables was significantly higher than 0.7, only the one resulting in a univariate model with the smaller p value was inclusive in the main-effects model. In the second step, the interactions to include in the candidate model set were determined. On the basis of the number of potential interactions among fixed effects, each potential two- or three-way interaction was added to the model that included the main effects derived from the first step. All possible two-way interactions, and all three-way interactions that included *clothing*, were included in this analysis. This procedure assisted to investigate how clothing type affects perceptual strain. A full factorial model was not included in the current study because of the colinearities and complex relations between or among the variables[39]. For the models that included three-way interactions, all their component two-way interactions were considered because it was necessary to interpret linear models corrected by the lower-order interactions[37, 40]. The main effects-only model was compared with the more complex model using the corrected Akaike's information criterion (AICc) for small sample size[41, 42]. Only the interactions resulting in smaller AICc than the main effects-only model were included in the candidate model set. The final step was to fit all the candidate models with all possible combinations of main effects and the interactions selected in the preceding steps and then selected the most appropriate model using AICc. A first-order autoregressive covariance structure was assumed for the covariance structure of the repeated measures in the sequential numbers[37]. Scale identity was assumed for the covariance structure of the random effects in order to consider the independence of the observations between participants[43]. Restricted maximum likelihood was used for parameter estimation. The analysis methods were all performed by SPSS 20.0, and statistical significance was set at $p<0.05$ for all statistical analyses.

Results

Overview of data collected on sites

The demographic characteristics of these participants were as follows (mean and SD): age 21.7 (1.9) yrs, height 173.7 (5.1) cm, body weight 65.0 (11.8) kg, and body mass

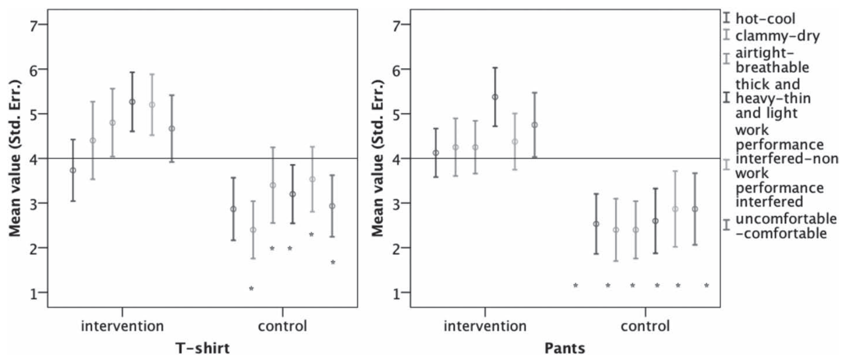

Fig. 3. Ratings of subjective sensations on the two uniforms (significant difference marked as * on the graphs) (N=16).

index 21.5 (3.5) kg/m^2.

Figure 2 displays the frequency of meteorological, physiological, and perceptual parameters collected under the intervention and control conditions. A wide spectrum of empirical data was captured on sites. The participants in the intervention group were exposed to significantly higher environmental stress (32.06±1.73°C for Intervention vs. 31.66±2.65°C for Control, $p<0.05$) but had a lower workload than those in the control one (17.77±9.30% for Intervention vs. 22.52±13.34% for Control, $p<0.001$). They had similar HR and RPE in course of the experiment between the two groups. HR ranged from 76 to 151 bpm with a mean value of 101 bpm under the intervention condition, while it varied from 71 bpm to 180 bpm with a mean value of 103 bpm under the control one. RPE under the intervention and control groups varied from 0 to 10 (mean±SD=3.68±1.84) and 0 to 9 (mean±SD=3.61±1.68), respectively. Ratings of TS (4.15±1.22 for Intervention vs. 4.57±1.32 for Control, $p<0.001$) and PeSI (4.47±1.85 for Intervention vs. 4.78±1.82 for Control, $p<0.05$) of the participants in the intervention group were significantly lower than those in the control one.

Differences in ratings of subjective sensation between the two uniforms were found (Fig. 3). In general, the intervention type was rated significantly better than the control type on most of subjective attributes ($p<0.05$). Meanwhile, the average ratings of the intervention type on most of attributes were above four, which indicates a satisfactory level based on the 7-point Likert scale. Wearing comfort was improved by 1.6 (SD=2.3) and 1.8 (SD=2.0) units when wearing the intervention shirt and pants, respectively, compared with wearing the control ones.

Linear mixed-effects model

Table 2 depicts the most appropriate linear mixed-effects model, based on the model selection procedure, included WBGT, RHR, exposure time, the interaction between clothing and trade/place, and the interaction between workplace and the WBGT. The statistical form of this model is given by Eq. (3). The parameter estimates of this model are shown in Table 3.

$$PeSI_{ij}=\beta_0+\beta_1\times WBGT+\beta_2\times RHR+\beta_3\times T+\beta_4\times clo\times trade +\beta_5\times clo\times place+\beta_6\times place\times WBGT+\mu_i+\varepsilon_{ij} \quad (3)$$

where $PeSI_{ij}$ is the perceptual strain level for the ith participant in the jth measure, β_n (n=1,2,…6) is the coefficients of fixed effects, WBGT is wet bulb globe temperature, RHR is relative heart rate, T is exposure time, clo is type of work uniform, place is the workplace, μ_i is the random effect for participant i, ε_{ij} is the random unexplained error.

The final model was found to produce statistically insignificant random effects, indicating that the responses to perceptual strain were therefore consistent across all participants. The effects of temperature, workload, exposure time, clothing type, trade, and workplace on perceptual strain were given by a linear combination of the main effects and interaction effects. Temperature, workload, exposure time had significantly positive effects on perceptual strain, thus indicating that perceptual strain increased along with temperature, workload, and exposure time. For instance, a temperature increase of 1°C yielded a growth of 0.5 unit in perceptual strain, and a workload increase of 10% of relative heart rate and an extended exposure time of 10 min aggravated perceptual strain by 0.4 and 0.2 unit, respectively. As regard to the highly significant interaction between clothing type and trade, participants from each trade wearing the intervention uniform had a significant benefit on alleviating perceptual strain. For example, perceptual strain was significantly reduced by 5.8, 6.3,

Table 2. Results of linear mixed-effects model (LMM) selection: main-effects model and the top five factorial models selected using Hurvich and Tsai's Criterion (AICc)

Independent variable	main-effects model	model 1	model 2	model 3	model 4	model 5	RI
WBGT	√	√	√	√	√	√	1
RHR	√	√	√	√	√	√	1
T	√	√	√	√	√	√	1
Clo	√						0
Trade	√						0
Place	√						0
Clo × Trade		√	√	√	√	√	1
Clo × Place		√	√	√	√	√	1
Clo × WBGT × Trade						√	0.08
Trade × WBGT				√	√		0.34
Place × WBGT		√			√		0.51
AICc	1,337.39	**1,312.67**	1,313.70	1,313.91	1,314.61	1,315.71	—
ΔAICc	—	0	1.02	1.24	1.94	3.04	—
ω(AICc)	—	0.37	0.22	0.20	0.14	0.08	—

Abbreviation: WBGT – wet bulb globe temperature, RHR – relative heart rate, T – exposure time, Clo – type of work uniform, Place – workplace, ω – the Akaike weight, RI – relative importance of independent parameter.

Calculations: $\Delta AICc_i = AICc_i\text{-}minAICc$, $\omega(AICc_i) = \frac{\exp\left(-\frac{1}{2}\times\Delta AICc_i\right)}{\Sigma\exp\left(-\frac{1}{2}\times\Delta AICc_i\right)}$, where i is the ith model.

Table 3. Coefficient and standard error of the linear mixed-effects model

Parameter		standard error	p
Fixed effects	**coefficient**		
Intercept	−10.63	6.49	0.102
WBGT	0.51	0.21	**0.015**
RHR	0.04	0.01	**<0.001**
T	0.02	0.00	**<0.001**
Intervention × Rebar work	−5.76	1.11	**<0.001**
Intervention × Leveling	−6.33	1.24	**<0.001**
Intervention × Form work	−6.11	1.11	**<0.001**
Intervention × Painting and plumbing work	−1.63	0.56	**0.004**
Control × Rebar work	6.92	6.56	0.293
Control × Leveling	8.42	6.60	0.203
Control × Form work	8.23	6.58	0.211
Intervention × Outdoor	13.40	7.01	0.056
WBGT × Outdoor	−0.33	0.21	0.126
Random effects	**variance**		
Participant	0.62	0.35	0.073
Residual	0.71	0.04	**<0.001**

6.1, and 1.6 units when rebar, leveling, form, painting and plumbing workers wearing the intervention type, respectively. This finding suggested that this uniform seemed to be beneficial in alleviating perceptual strain across the four trades. No significant interactions between the other parameters were observed.

Discussion

As shown in Fig. 3, wearing the intervention uniform kept construction workers drier and more comfortable with less interference in work performance than wearing the control one. The practical value in reducing unpleasant perceptual strain and improving wearing comfort by wearing appropriate work uniform is to promote the well-being of occupational workers. Wearing the intervention uniform with pleasant subjective sensations may encourage people not to take off these clothes in the heat[44]. In this regard, the usage of the intervention uniform can provide a comfortable microclimate environment for construction workers. As it can be expected, the well-being of construction workers would be improved when they are willing to wear the newly designed uniform while working in hot weather.

For a holistic assessment on the influence of multifactorial heat stressors on perceptual strain, this study using a linear mixed-effects model further revealed that WBGT, workload, exposure time, and interaction effect between trade and clothing had significant impacts on perceptual strain. Echoed to the previous studies[24, 45], the findings of this study also indicate that the increasing ambient temperature, workload, and exposure time had significant effects on the aggravation of heat strain among construction workers. Given that the interaction effect between clothing type and work trade was found in this study, perceptual strain of construction workers across four trades was significantly reduced by approximately 1.6 to 6.3 units when they wore the new uniform. Particularly, the rebar, leveling, and form workers who perform outdoor works all the time received more benefits from wearing this uniform than the painting and plumbing workers. The practical value of the attenuation of perceptual strain lies in the fact that wearing the intervention type may contribute to a higher tolerance level in the heat[46] than wearing the control one. The declined perceived thermal strain may allow individuals to increase their voluntary workload and to combat fatigue, and eventually to extend physical performance under heat exposures[46]. The results underline that wearing the new uniform is effective and practical in reducing perceived heat strain for working in hot weather.

Based on the results of the linear mixed-effects model, it is concurred with the well-established guidelines and research findings[1, 3, 17] such as, (a) rescheduling work-rest pattern and/or providing shelter to avoid prolonged exposure to direct sunlight, (b) adjusting work rate by self-pacing, and (c) taking plenty of water to avoid dehydration. The specification of the newly designed work uniform may be used as a good practice and an industry standard regarding wearing *appropriate* summer work uniforms.

The study presents two major contributions. First, a field experiment with randomized assignment was executed to evaluate the effectiveness of a newly designed work uniform in alleviating heat strain in real-work settings. As an extension and expansion of a standard laboratory experiment, a randomized field experiment that accounts for the nature of a real-life setting[47] can alternatively provide a clear picture of the functions of work uniform. In light of the merits of the randomized experiments, the findings of the present study may be of practical value in providing evidence-based guidelines for safeguarding construction workers exposed to hot weather. Second, the results generated from the mixed-effects model with repeated measurements indicate that the perceptual strain level of construction workers across four trades was significantly attenuated when they wore the new uniform. The interaction effect provides a fresh perspective in ascertaining the role of summer work uniform in a field setting.

It is recognized that many boundary conditions such as health condition, medicine, nutrition[48], dehydration level[49], aerobic fitness[50], alcohol and smoking habits[51], sleep quality[52], motivation[53], thermal preferences and other inter-individual variables[46] that would influence the responses and individual perception of heat stress are not described exactly in the present study. A short questionnaire survey or careful physiological measurements on these facets can be administered in future studies. Workers in different age groups and trades may also differ in thermal sensitivity in hot working environment. The same research methodology could be extended to wider age groups and trades with an enlarged sample size to verify the current findings. Additionally, the unavoidable placebo effect yielded by the non-blind test in the field experiment may be an inherent limitation, particularly given that the measurement instruments are subjective measurements. That is, construction workers might have perceived an improvement when wearing a fresh uniform compared with the existing one. Such a self-healing property[54] may influence participants' and experimenter's beliefs and expectations, and eventually resulting in information bias[55, 56]. Even though blinding and the placebo effect may not be the core elements of the randomized control experiment[57], their possible effects on the research outcomes should not be ignored. The double-blind test is thus recommended to avoid the potential placebo effect, in which the intervention and control groups are not informed to the participants and the conductors who seeing the participants. Furthermore, it is recognized that the experimental protocol of the current study should be improved. That is, the two trials in separated two days and each test session has a complete work shift should be performed. This will help avoid the confounding effects of the human circadian rhythm on the physiological responses in the two trials.

Conclusions

The current study answers a practical question about the benefits of wearing a newly designed work uniform in under real-work settings. First, wearing the intervention uniform exhibits a practical value in improving workers' comfort level and possibly promoting the well-being of site personnel working in hot and humid weather conditions. More importantly, an interaction effect between clothing and trade reveals that perceptual strain of workers across four trades was significantly alleviated while wearing the intervention type. This study fosters a fresh and scientific approach to the management of heat stress risk in construction, which contributes to the enhancement of the research methodologies and practical problem solving.

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