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ARTICLE

Using trunk posture to monitor heat strain at work

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ABSTRACT

This study aimed to determine if trunk posture during walking is related to increases in rectal temperature (T_{re}). 24 males treadmill walked in one of four conditions (1): 30 min at 3.0 mph and 0% grade, 20 °C and 50% relative humidity (RH), wearing healthcare worker (HCW) PPE; (2): 30 min at 3.0 mph and 0% grade, 27.5 °C and 60% RH, HCW PPE; (3): 30 min at 3.0 mph and 0% grade, 32.5 °C and 70% RH, HCW PPE; and (4): 40 min at 40% VO_2max, 30 °C and 70% RH, wearing firefighter PPE. Trunk posture (Zephyr BioHarness 3) and T_{re} were measured continuously. T_{re} was positively related to trunk posture, controlling for covariates ($B = 3.49$, $p < .001$). BMI and age moderated this relationship ($T_{re} \times$age, $B = 0.76$, $p < .001$; T_{re}*BMI, $B = -1.85$, $p < .001$). Trunk posture measurement may be useful in monitoring fall potential and magnitude of heat stress of workers in hot environments.

Practitioner Summary: Occupational hyperthermia increases worker risk for heat illness and injury but is difficult to monitor in the field. This investigation shows that trunk posture is independently and positively related to core temperature. Non-invasive measurement or visual inspection of trunk posture could provide novel insight on individual heat strain level.

Abbreviations: PPE: Personal protective equipment; T_{re}: Rectal temperature; H1: Hypothesis 1; H2: Hypothesis 2; H3: Hypothesis 3; RH: Relative humidity; HR: Heart rate; GEE: Generalized estimating equations

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KEYWORDS
Trunk posture; trunk flexion; hyperthermia; personal protective equipment; core temperature

Introduction

Many occupations, such as firefighting and emergency healthcare response, require the use of personal protective equipment (PPE) during exposure to hot and humid environments. The addition of PPE limits the body's ability to properly regulate homeostatic rectal temperature (T_{re}), therefore causing physiological heat strain and an increased risk for heat stress-related injuries (de Almeida et al. 2012; Havenith, den Hartog, and Martini 2011) as well as slips, trips, and falls (Kong et al. 2010; Kong, Suyama, and Hostler 2013; Chang et al. 2016). In addition, PPE can increase the workload of occupational activities, increasing heat production, and decrease balance due to added weight of the entire ensemble (White and Hostler 2017; Hu and Qu 2016). It is imperative that during these times of high heat stress, precautions are taken to keep workers healthy and safe.

It has been previously shown that high T_{re} ($T_{re} > 38$ °C) induces central fatigue (González-Alonso et al. 1999), which alters brain frontal lobe cortical activity (Nielsen et al. 2001) and, consequently, negatively affects muscular force generation (Thomas et al. 2006; Nielsen et al. 2001; Cheung 2008). Increased and earlier onset of muscular fatigue from hyperthermia may result in alterations in the biomechanics of walking and gait stability (Park et al. 2011) as well as increased postural sway from lumbar extensor fatigue (Davidson, Madigan, and Nussbaum 2004). Also, it has been shown that walking in the heat may increase gait variability (Kong et al. 2010). Such changes in gait likely contribute to an increased incidence of fall-related injuries which comprised of 21.0% of firefighter injuries in 2015 (Haynes and Molis 2017). While the effect of hyperthermia on gait characteristics has been explored previously, the effect of heat stress on trunk posture, specifically trunk flexion during walking, has not been investigated. Given the current literature that shows impairment of biomechanics and muscular

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force production with hyperthermia, we hypothesized that, during hyperthermia, muscle fatigue of the torso would result in adaptive trunk flexion. Furthermore, it has been previously shown that increased trunk flexion characterizes the early stages of a fall (Do, Breniere, and Brenguier 1982) and may influence lower extremity gait patterns (Saha, Gard, and Fatone 2008) and alter energy expenditure (Nankaku et al. 2007). Additionally, it has been demonstrated that firefighting activities, without heat stress, reduce spinal stability and increase spinal flexion (Gregory et al. 2008). Therefore, confirmation of the association between the severity of hyperthermia and increased trunk flexion during walking may provide information that would allow the ability to predict workers who are at increased risk for falling. Interestingly, this measurement may also be used to non-invasively predict the severity of heat stress in workers wearing PPE in hot and humid environments.

Measurement of the severity of heat stress is essential for worker safety in hot and humid environments. However, quantification of physiological heat strain relies on an accurate measurement of T_{re}, which has traditionally been accomplished by the use of either an esophageal or rectal thermistor (Moran and Mendal 2002) or ingestible pills. The obvious practical limitations to both of these measurement techniques exist in the field. Thus, the development of non-invasive methods to quantify the level of heat stress an individual is experiencing is extremely important (Moran and Mendal 2002). Recent literature exploring possible non-invasive measurements' correlations with T_{re} include the Zephyr BioHarness (Seo et al. 2016), umbilical temperature (Roberge et al. 2017), auditory canal temperature (Nakada et al. 2017), and skin temperature (Roberge et al. 2017). While promising results have been presented regarding these relationships, the development of a non-invasive body sensor to predict T_{re} will likely require several reliable measurement variables combined to provide an accurate predication algorithm. Therefore, this study proposes that an association between trunk posture during walking and T_{re} may exist and, furthermore, that trunk posture may be used as a surrogate measurement to quantify heat stress when T_{re} measurement is not possible.

Consequently, the main purpose of this data analysis was to determine if changes in trunk posture, specifically increased trunk flexion during treadmill walking while wearing PPE, is related to increases in T_{re}. A secondary purpose is to identify possible moderators of this relationship (e.g. BMI and age). Therefore, the hypotheses set forth at the onset of this investigation were as follows:

Hypothesis 1 (H1): Trunk posture (increased trunk flexion) will increase in magnitude with increases in T_{re}.

Hypothesis 2 (H2): The effect of T_{re} on trunk posture will be moderated by BMI (increases in body size will counteract subject trunk flexion with increases in T_{re}).

Hypothesis 3 (H3): The effect of T_{re} on trunk posture will be moderated by age (increases in age will increase the magnitude of effect of T_{re} on trunk posture).

Methods

The current study included 24 male subjects (age = 23.2 ± 2.7, BMI = 25.1 ± 2.4) who all completed written and verbal informed consent and completed a physical health screening by a licensed physician prior to participation in the study. Each subject was instructed to abstain from alcohol, caffeine, and strenuous exercise for at least 24 h prior to their test visit. The study was approved by the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board (15-NPPTL-01 and 16-NPPTL-02).

Each subject completed one of four experiments which included various environmental conditions wearing one of two different PPE ensembles to represent a wide variety of working conditions that would induce various levels of hyperthermia.

Experiment 1: Subjects ($n = 5$) treadmill walked at 3.0mph and 0% grade for three bouts of 10 min separated by about 15 min of simulated light healthcare work activities (~3 METs) (i.e. disrobing, decontaminating, and splinting a life-size manikin) each in environmental conditions of 20 °C and 50% relative humidity (RH). Subjects wore first receiver healthcare worker (HCW) PPE which consisted of medical scrubs, socks and rubber boots, Tychem® QC highly impermeable coverall (DuPont, Wilmington, DE), surgical nitrile inner gloves, heavy-duty nitrile outer gloves, and a shrouded powered air purifying respirator (Versaflow Easy Clean PAPR, 3 M, St. Paul, MN).

Experiment 2: Subjects ($n = 5$) treadmill walked at 3.0mph and 0% grade for three bouts of 10 min separated by approximately 15 min of simulated light healthcare working activities (~3 METs) each in environmental conditions of 27.5 °C and 60% RH. Subjects wore the same first receiver healthcare PPE as in experiment 1.

Experiment 3: Subjects ($n = 5$) treadmill walked at 3.0 mph and 0% grade for three bouts of 10 min separated by approximately 15 min of simulated light healthcare working activities (~3 METs) each in environmental conditions of 32.5 °C and 70% RH. Subjects wore the same first receiver healthcare PPE as in experiment 1.

Experiment 4: Subjects ($n = 9$) treadmill walked at 40% VO_2max for 40 min in environmental conditions of 30 °C and 70% RH. Subjects wore cotton shorts and t-shirts under full firefighter personal protective gear consisting of jacket, pants, boots, helmet, gloves, and hood (Morning Pride Manufacturing Co., Dayton, OH), and an inactivated self-contained breathing apparatus with a full face piece respirator.

It is of importance to note that these 4 experiments were originally conducted with different primary purposes than explored in this analysis. Experiments 1–3 were conducted to analyze the injury potential of healthcare workers during simulated working activities. Experiment 4 was conducted to determine the effect of hyperthermia on postural stability and balance while wearing firefighter PPE. This analysis, however, pooled these data sets to explore the purpose and hypotheses set forth previously in this paper. Combining these four protocols allowed for greater external validity of the relationships described to various types of PPE and environmental conditions. Additionally, using the combined protocols resulted in greater range in T_{re} and trunk posture, advantageous to testing the hypotheses in question.

The measurement techniques for all variables were the same for all four experimental trials. Trunk posture was continuously monitored throughout exercise using a 3-axis accelerometer built into the Zephyr BioHarness 3 (Zephyr Technology Corp. Annapolis, MD) placed on the chest strap directly under the subject's left axillary area, as directed by the manufacturer's instructions (Kim et al. 2013). The trunk posture measurement from the BioHarness provides a value, in continuous degrees of displacement on the anterior-posterior axis, both positive and negative, from a vertical trunk position (0°). The measurement ranges from vertical (0°) to an inverted trunk position (180° or −180°). A positive posture value represents anterior inclination of the trunk (trunk flexion) in degrees and a negative value represents posterior inclination of the trunk (trunk extension) in degrees (Figure 1). The trunk posture value is not affected by medio–lateral inclination of the trunk. This measurement was used to determine the change in magnitude of trunk flexion throughout exercise time.

T_{re} was monitored continuously throughout exercise using a rectal thermistor (Model: REF-4491, YSI Temperature, Dayton, Ohio) inserted 13 cm beyond the anal sphincter. Heart rate (HR) was continuously monitored throughout exercise using the Zephyr BioHarness 3 (Zephyr Technology Corp. Annapolis, MD). If pre-determined test termination criteria were met during exercise (rectal temperature (T_{re}) $\geq$ 39.0 °C, HR $\geq$ 95% HR_{max} (as determined using the formula 220-age) $>$ 2 min, volitional fatigue (rating of perceived exertion $\geq$19 on the 6-20 Borg scale) (Borg 1982), subject's desire to stop), the testing was stopped immediately and the subject was asked to repeat the testing session on another day. Only periods of treadmill walking were used in this analysis.

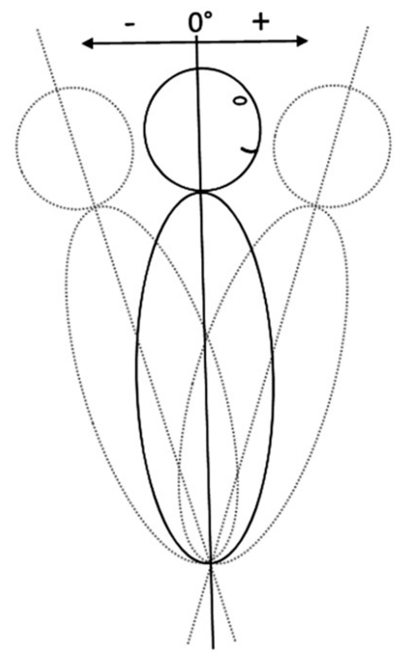

Figure 1. Trunk posture measurement.

Analytical approach

Four different experiments were conducted. Three were designed to simulate work in a healthcare setting. Each of these three experiments included 5 individuals. A fourth experiment included 9 individuals. The total number of subjects involved in the current study was 24. This combining was done to allow for a more diverse and externally valid analysis of the variables of interest to different occupational settings.

The age, height, and BMI were recorded for each subject involved in the study. During each of the experiments T_{re}, HR, and trunk posture were measured continuously over time (each second). The second-by-second measurements were smoothed by taking the average within 60 s intervals. This step resulted in a nested dataset that included multiple cases for each individual over time—one for each minute of the experiment.

Given that the length of the experiment, an individuals' height, and HR could conceptually influence the dependent variable, these variables were included as controls and entered into each model as covariates. Both height and HR were entered as continuous covariates and exercise time was entered as a 3-level categorical predictor corresponding to the number of minutes the subjects exercised on the treadmill with 1 being the first third of each experiment and 3 being the last third. For experiments 1–3, each of the three treadmill walking sessions was coded time, 1–3 with Time 1 corresponding with the first walking session, Time 2 with the second, and Time 3 with the third session. Experiment 4 was divided into three time categories: Time 1 = first 14 min, Time 2 = second 13 min, and Time 3 = last 13 min of each 40 min exercise session.

The analytical approach had to take into account the nested nature of the dataset. In lieu of a multiple regression approach which assumes independence between observations, a Generalized Estimating Equations (GEE) was used to examine the three hypotheses.

The three hypotheses were examined in a single GEE model. The model took the form of:

$$\text{Trunk Posture} = B_0 + B_1 (\text{Age}) + B_2 (\text{Height}) + B_3 (\text{BMI}) + B_4 (\text{Rectal Temperature}) + B_5 (\text{Heart Rate}) + B_6 (\text{Rectal Temperature} * \text{Age}) + B_7 (\text{Rectal Temperature} * \text{BMI}) + B_8 (\text{Exercise Time})$$

Given the interest of the interaction terms and the increased potential for multicollinearity, within the model, each of the variables was centered. The interpretation of each of the coefficients, therefore, corresponds to the multiplicative change expected in trunk posture for a single standard deviation increase in the independent variable of interest.

Results

The descriptive statistics and correlations among the dependent variable (trunk posture), the predictor of interest (T_{re}), the hypothesized moderators (subject age and BMI), and the control variables (subject height and HR) are provided in Table 1. Average end exercise T_{re} for all experiments and individuals was 37.9 ± 0.6 °C.

Table 1 shows that trunk posture had a significant bivariate relationship with each of the variables in the model. Trunk posture displayed a significant positive relationship with age (r = 0.43) and T_{re} (r = 0.31) along with the control variables HR (r = 0.34) and height (r = 0.14). Trunk posture was significantly negatively related to BMI (r = −0.08). The significant bivariate relationship between trunk posture and T_{re} provides initial support for hypothesis 1.

Table 1. Descriptive statistics and correlations among the variables in the study.

Variable	Mean	SD	(1)	(2)	(3)	(4)	(5)
(1) Age	23.18	2.73	–	–	–	–	–
(2) BMI	25.09	2.42	0.40*	–	–	–	–
(3) Rectal Temp	37.32	0.56	0.18*	0.02	–	–	–
(4) HR	126.05	28.41	0.30*	0.14*	0.72*	–	–
(5) Height	178.66	7.16	−0.01	−0.16*	0.20*	0.12*	–
(6) Trunk Posture	0.47	6.79	0.43*	−0.08*	0.31*	0.34*	0.14*

Note: *$p < .05$.

Table 2. Results for GEE estimated coefficients.

	B	Std Er.	Wald C.I.(95%)	Wald χ^2	*p*
Age	1.19	0.09	1.03, 1.36	194.50	<.001
Height	0.02	0.03	−0.03, 0.08	0.67	0.41
BMI	−1.07	0.09	−1.25, −0.88	131.52	<.001
Rectal Temperature	3.49	0.67	2.16, 4.81	26.73	<.001
Heart Rate	0.01	0.01	−0.01, 0.03	1.90	0.17
Rectal Temperature × Age	0.76	0.18	0.41, 1.11	18.46	<.001
Rectal Temperature × BMI	−1.85	0.17	−2.19, −1.51	113.65	<.001
Exercise Time 1	1.13	0.67	−0.20, 2.45	2.79	.10
Exercise Time 2	1.03	0.55	−0.05, 2.10	3.53	.06
Exercise Time 3	–	–	–	–	–

Note: B: GEE estimated regression coefficients; Std Er.: is the standard error of the regression coefficient; Wald C.I. (95%): the Wald 95% confidence interval for B; Wald χ^2: the test statistic for B; p: significance level of the Wald χ^2 test statistic for the regression coefficient. Exercise time was entered as a categorical variable with time 3 as the reference group.

The results of the GEE analysis are reported in Table 2. The results suggest that, while adjusting for the remaining covariates, an individual's height and BMI and the length of exercise time were not significant predictors of posture. However, within the model, subject T_{re} was significantly related to trunk posture while controlling for the other covariates (B = 3.49, $p < .001$). This finding suggests that, on average, trunk posture may be expected to increase by 3.49 degrees for each single standard deviation increase in T_{re} while holding age, BMI, height, and heart rate constant. This result provides further support for hypothesis 1. Within the model, both suspected moderators were also significantly related to trunk posture: Age, B = 1.19, $p < .001$; and BMI, B = −1.07, $p < .001$. Within the GEE model neither of the control variables significantly predicted trunk posture.

In order to examine H2 and H3, two interaction terms were included in the model. Both interaction terms were significant: T_{re} × age, B = 0.76, $p < .001$; T_{re} × BMI, B = −1.85, $p < .001$. The results provide support for both H2 and H3—that the effect of T_{re} on trunk posture depends on both a subject's age and BMI. These moderated effects are depicted in Figures 2 and 3.

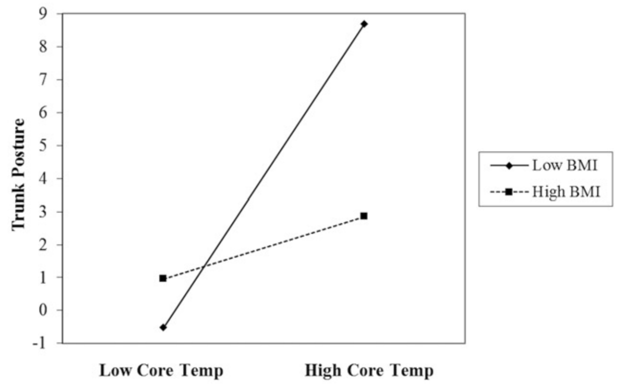

Figure 2. Interaction between Rectal Temperature and BMI.

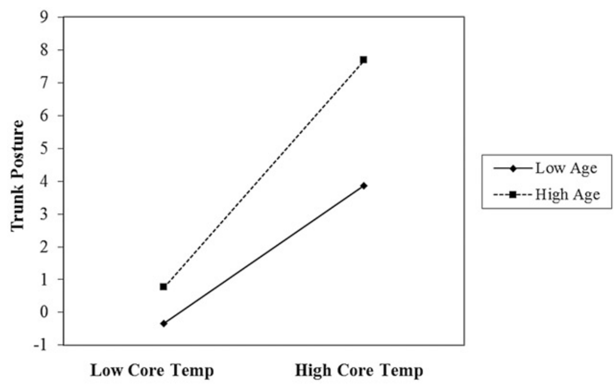

Figure 3. Interaction between Rectal Temperature and Age.

Discussion

These pilot results provide preliminary support for the three hypotheses proposed at the onset of this study. Firstly, H1 was supported in this study which showed a significantly positive relationship between T_{re} and trunk posture. Secondly, the current results showed that this relationship was moderated by age and BMI, supporting H2 and H3.

The benefits to confirmation of this relationship are, most notably, two-fold. First, changes in trunk posture can be associated with previously described increased falling potential of workers during heat stress. Secondly, after further confirmation, the relationship between T_{re} and trunk flexion could potentially be used to non-invasively monitor levels of heat stress in individuals through simple measurement techniques.

From an ergonomic perspective, this finding is of importance in that this novel measurement may provide an easy way to monitor the potential for slips, trips, and falls among workers experiencing hyperthermia. The imperative for such novel countermeasures to slips, trips, and falls has been outlined previously (Chang et al. 2016). Firefighter PPE specifically has been previously shown to increase postural sway (White and Hostler 2017) and increase trunk flexion (Hur et al. 2015). Additionally, it has been shown previously that an anteriorly leaning trunk posture represents the beginning phases of a fall (Do, Breniere, and Brenguier 1982). Because the trunk accounts for approximately 50% of the body's total mass (Saha, Gard, and Fatone 2008), even small changes in trunk posture may contribute to changes in gait variability as seen in previous studies due to changes in the center of gravity characteristics of the individual (Kong et al. 2010; Saha, Gard, and Fatone 2008). Increased prediction power of falling potential during hyperthermia, using this simple measurement of trunk flexion, can increase worker safety and reduce the amount of slips, trips, and falls experienced by workers wearing PPE in hot and humid environments. Because this study did not specifically measure fall potential, further investigation is necessary to explore the magnitude of trunk flexion during walking as a predictor of gait variability (gait speed, step length, double-stance time, etc.) and of biomechanical injury potential during heat stress (Maki 1997). The current study provides a hypothesis-generating pilot data as a foundation from which to develop this prediction using simple and effective measurement techniques.

Secondarily, the support of H1 in the current study provides a groundwork to use trunk posture measurement to monitor heat strain in individuals wearing PPE in hot and humid environments. There are clear practical difficulties in measuring physiological variables in order to monitor the health status of workers while in the field. This data represents an easy and effective way to monitor individuals' health and safety through measurement of their change in posture over time. Drawing on the positive relationship found between T_{re} and trunk posture, even a simple visual observation of the magnitude of change in trunk flexion may provide valuable information about the level of heat strain being experienced by the worker. However, potential external environmental and physiological factors contributing to this relationship must be addressed in future work. Furthermore, the development of non-invasive T_{re} measurement is extremely valuable. However, a strong prediction algorithm will likely require the collaboration of many individual physiological variables associated with heat stress (Moran and Mendal 2002). Using the magnitude of trunk flexion in such a prediction algorithm may prove to be advantageous based on these preliminary results. Future examination of this topic should provide confirmation of the relationship, utilizing a larger absolute change in T_{re} as well as larger, more heterogeneous sampling to support the current preliminary findings.

It was suspected at the onset of this analysis that the effect of exercise fatigue over time may influence the magnitude of trunk flexion due to muscular fatigue from exercise rather than increased T_{re}. The potential effect of time and corresponding exercise fatigue can be understood in two ways. First, the exercise stimuli used in this investigation were of only moderate intensity (3.0 mph with 0% grade and 40% VO_2 max) and short duration (30 minutes and 40 minutes) which would not likely initiate significant exercise fatigue. Secondly, as seen in Table 2, time (and the related exercise fatigue) was ruled out as a factor contributing to changes in trunk flexion. Given these two factors, it can, therefore, be said with confidence that the changes in trunk flexion seen in this analysis are due to changes in T_{re} rather than the effect of time or related exercise fatigue.

The current results show no relationship between HR and trunk posture throughout exercise. These results are not surprising, as HR during steady-state exercise, as seen in this experiment, would most notably be affected by cardiac drift from dehydration and hyperthermia (González-Alonso, Crandall, and Johnson 2008). While HR is likely to drift up throughout steady-state exercise in the heat, the relative increase in HR is small compared to increases seen in T_{re} (González-Alonso, Crandall, and Johnson 2008). Therefore, no significant relationship was found between changes in trunk posture and HR.

A significant interaction between BMI and the relationship between T_{re} and trunk posture was found in the current investigation. The results indicate that individuals of higher BMI show a decreased effect of T_{re} on trunk posture, showing less trunk flexion with increased temperature than those of lower BMI. This result is somewhat surprising given that the current literature shows that higher BMI is associated with greater standing trunk flexion (Gilleard and Smith 2007; Mitchell et al. 2008), decreased gait stability (Sheehan and Gormley 2012), reduced back and core muscular endurance in firefighters (Mayer et al. 2012), and increased musculoskeletal injuries in firefighters (Jahnke et al. 2013). However, the direction of the interaction seen in the current study can likely be attributed to a limitation in the measurement of BMI in the current study sample. BMI is well known to be limited in its ability to properly identify adiposity, especially in individuals of higher muscle mass, classifying individuals with high muscle mass as also having higher BMI (Nevill et al. 2006). Anecdotally, the current study utilized a young, healthy, male sample population of whom several were of athletic body type, with high muscle mass. While body composition of the subjects was not measured because BMI was a secondary outcome in this investigation, it is likely that those subjects of higher BMI actually had a higher muscle mass than those of lower BMI. The higher muscle mass allowing those subjects to maintain trunk posture in hyperthermia was better than those of lower BMI and lower muscle mass. Further investigation into this moderation effect of BMI is certainly warranted and measurement of body composition directly as a moderator of the effect of T_{re} on trunk posture should be explored. Additionally, recent literature has demonstrated that fitness level may affect gait and postural balance while wearing PPE in the heat (Kong et al. 2012; Colburn et al. 2017). While this study was limited in its ability to detect the effect of fitness, future research should investigate this relationship in trunk flexion specifically in addition to BMI.

In the current study, the relationship between T_{re} and trunk flexion was shown to be moderated by age, with the effect of T_{re} on posture being stronger in those of older age. While this topic has not been previously explicitly explored, this finding is in agreement with current understanding of the effect of fatigue and hyperthermia on gait and balance with aging. Deviations in trunk posture have been shown to be associated with balance (Sinaki et al. 2005) and standing balance has been shown previously to degrade with age (Punakallio 2003; Punakallio, Lusa, and Luukkonen 2003; Punakallio, Hirvonen, and Grönqvist 2005). Also, older individuals have been previously shown to have increased risk for slip-, trip-, and fall-related injuries (Kemmlert and Lundholm 2001). Furthermore, aging has been shown to decrease muscle mass (Goodpaster et al. 2006; Frontera et al. 2000), force production (Goodpaster et al. 2006), and endurance (Frontera et al. 2000). Taking all of these aging effects into account, it is expected that the effect of T_{re} on trunk posture would be exaggerated in those of higher ages. The current moderation effect by age is therefore aligned with the study expectations; however, this relationship warrants further examination as a primary outcome in a larger range of sampled ages and relatively low correlations found.

Strengths

This study benefited from several strengths that should be noted. Primarily, after literature review, this study was found to be the first to examine this novel measurement of trunk posture and its relationship with T_{re} during hyperthermia. Secondly, the utilization of four different experimental protocols of varying environmental conditions and PPE ensembles to confirm the hypotheses in heterogeneous conditions strengthen these results. Finally, the ability to determine significant moderators of the main outcome relationship strengthens the external application and future interpretation of this study's results.

Limitations

Firstly, this study was limited in its design as the 4 experiments were originally conducted with different primary purposes than explored in this analysis. While this method increased external validity of the results, future efforts should be made to design purpose-built protocols to address these preliminary hypotheses. Secondly, the current investigation was limited most notably by homogeneous nature and small size of the sample population. While significant relationships and interactions were able to support the hypotheses, future examination should utilize a more heterogeneous sample to improve external validity and provide confirmation to the interactions with BMI and age found in this study. This study was also limited to male subjects only. Inclusion of female subjects in future research would be beneficial to improve the generalizability of these results, especially to HCW who tend to be largely female. PPE weight may potentially affect the relationship between T_{re} and trunk flexion. This study, while only examining two different PPE ensembles of two different weights, did not examine this specific effect. However, trunk flexion was shown in both ensembles. Future investigation is warranted in this area to determine the specific effect the PPE weight may have on trunk flexion. Finally, the measurement of trunk posture via the Zephyr BioHarness, uses a 3-axis accelerometer technique to measure trunk posture. While this measurement has been shown to be simple and effective (Wong and Wong 2008), more advanced methods for trunk posture measurement exist and the accelerometer technique tends to drift and fluctuate to some degree (Wong and Wong 2008). Future investigations should consider other, more precise measurement techniques such as using a gyroscope or video motion analysis, to possibly identify stronger relationships.

Conclusions

In conclusion, this investigation provided preliminary support for the three hypotheses set forth at the onset of the study. A significantly positive relationship was found between T_{re} and the magnitude of trunk flexion in hyperthermia. This relationship was shown to be moderated by BMI and age in the current investigation. The current data provide pilot evidence that measurement of trunk posture could be useful in monitoring heat strain in workers wearing PPE in hot and humid environments. Further investigations specifically designed to test these hypotheses are necessary to draw strong conclusions.

Ethical approval

The study was approved by the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board (15-NPPTL-01 and 16-NPPTL-02).

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Disclosure statement

The authors have no relevant information or relationships to disclose.

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