原著論文

The Effects of Two Dissimilar Environments with Equivalent Wet Bulb Globe Temperature on Performance of Manual Handling Tasks

同一ＷＢＧＴ（湿球黒球温度）設定時における環境条件の違いがヒトの作業パフォーマンスに及ぼす影響

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Abstract(要約)

Wet Bulb Globe Temperature (WBGT) is probably the most widely used of many heat stress indices. An underlying assumption is that differing combinations of temperature and relative humidity which yield the same WBGT will impose the same thermal load. Recent research has cast doubt on this assumption however. The purpose of this study was to investigate the effects of two dissimilar environments with an equivalent WBGT on participants performing an intermittent box-lifting task. 12 males (mean ± sd), age 25.2 ± 6 yrs, mass 74.9 ± 11.9 kg, stature 1.7 ± 0.1m were recruited and acclimated over five days (1 hr sessions) in an environmental chamber at 38°C, 70% relative humidity (RH). They completed 6x35-min trials on consecutive weekdays in two environments: warm-humid, 30°C, 65% RH (27°C WBGT); hot-dry, 39°C, 22% RH (27°C WBGT) and three lift frequencies: 1, 4.3 and 6.7 lifts.min^{-1}. There were no significant differences in physiological response (heart rate and core temperature), rating of perceived exertion (RPE) and maximum acceptable weight of lift (MAWL) between the two environments. These findings support the underlying assumption of WBGT and contradict recent research. It is possible that differences in response only manifest themselves at higher values of WBGT or during longer bouts of continuous exercise.

Key words: heat stress, WBGT, manual handling

熱ストレス→暑熱ストレス
湿球黒球→湿球黒球温度
人力作業→ヒトの作業 or 手動的作業

Introduction

Heat stress indices are intended to take account of the interactions between the variables that comprise the human thermal environment. Goldman (1988) reported that there may be more than 60 such indices but probably the most widely used is the Wet Bulb Globe Temperature (WBGT) which is usually attributed, slightly inaccurately, to Yaglou & Minard

(1957). WBGT has been granted its own international standard (ISO 7243, 1989). The scale is calculated as follows:

Inside buildings and outside without solar load:

$WBGT = 0.7t_{nw} + 0.3t_g$

Outside with solar load:

$WBGT = 0.7t_{nw} + 0.2t_g + 0.1t_a$

Where:

t_{nw} = natural wet bulb temperature

t_g = globe temperature

t_a = air temperature

(ISO 7243, 1989)

Consider the following two environments with equivalent WBGT:

WBGT 27.2 °C (dry bulb (DB)=30.5 °C, Relative Humidity (RH)=68%)

WBGT 27.1 °C (DB=38.7 °C, RH=22%).

The first, with a relative humidity of 68% may be termed 'warm-humid': the second 'hot-dry' but it is an underlying assumption of the scale that the different conditions will impose the same thermal load on a human subject if the WBGT remains constant. Recent research findings have cast doubt on the validity of this assumption however. Kellett *et al.* (2003) reported that rectal temperature (T_r), heart rate (HR) and fluid loss were all significantly higher after 60 minutes of continuous walking in the warm-humid environment (WBGT 32.1 °C, DB=33.4 °C, Globe Temp=34.1 °C, RH=88%) compared to a hot-dry environment (WBGT 32.3 °C, DB=45.6 °C, Globe=46.3 °C, RH=20%). Conversely, a study by Keatisuwan *et al.* (1996) found that heat strain was greater in hot-dry conditions (Hot Dry, DB=40 °C, RH=30%, WBGT=32 °C vs. Warm Humid, DB=31 °C, RH=80%, WBGT=32 °C). T_r , HR, mean skin temperature and fluid loss were all significantly higher after a mixed protocol on an exercise ergometer culminating in 60 mins of pedalling at 40% of $\dot{V}O_{2max}$.

The purpose of this study was to investigate the effects of two dissimilar environments with an equivalent WBGT on participants performing an intermittent box-lifting task.

Methods

With institutional ethical approval, 12 male participants (age=25.2

years ± 5.7, stature 1.7 m ± 0.1, mass 74.9 kg ± 11.9) were recruited. The study was conducted in the environmental chamber at the Centre for Sport and Exercise Science, Sheffield Hallam University, United Kingdom. Participants, wearing a standard industrial clothing ensemble (estimated Clo=0.65), acclimated for 5 x 1 hour sessions per day in the chamber set at 38 °C, 70% RH (WBGT 34.1 °C). The two environmental (ENV) test conditions were as follows: (ENV1) - Warm Humid, 30 °C DB, 65% RH, 27 °C WBGT; (ENV2) - Hot Dry, 39 °C DB, 25% RH, 27 °C WBGT.

Furthermore, the lifting task was performed at three different lifting frequencies (FREQ): (FREQ1) – 1 lift.min^{-1}, (FREQ2) – 4.3 lifts.min^{-1}, (FREQ3) – 6.7 lifts.min^{-1}. A counter-balanced, within-subjects, repeated measures design was used so each participant completed all six test conditions on consecutive weekdays. In each session, the participants lifted a box from the floor to a shelf set at knuckle height for 35 minutes. After each lift the box was returned to the floor by an assistant. They were allowed to adjust the box-weight for the first 20 minutes by adding or removing bags of ball-bearings.

After 20 minutes the box weight was recorded and no further adjustments were allowed. The recorded box weight was deemed to be the maximum acceptable weight of lift (MAWL) (see Snook & Ciriello, 1991). Aural temperature (T_a), skin temperature (T_s) and HR were logged continuously throughout the session. Ratings of perceived exertion (RPE)(Borg, 1970) were recorded every five minutes. There were two null hypotheses: ($H_0$1) There is no difference in MAWL when lifting in two dissimilar environments (warm-humid and hot-dry) with an equivalent WBGT. ($H_0$2) Lifting in two dissimilar environments (warm-humid and hot-dry) with an equivalent WBGT imposes the same physiological strain.

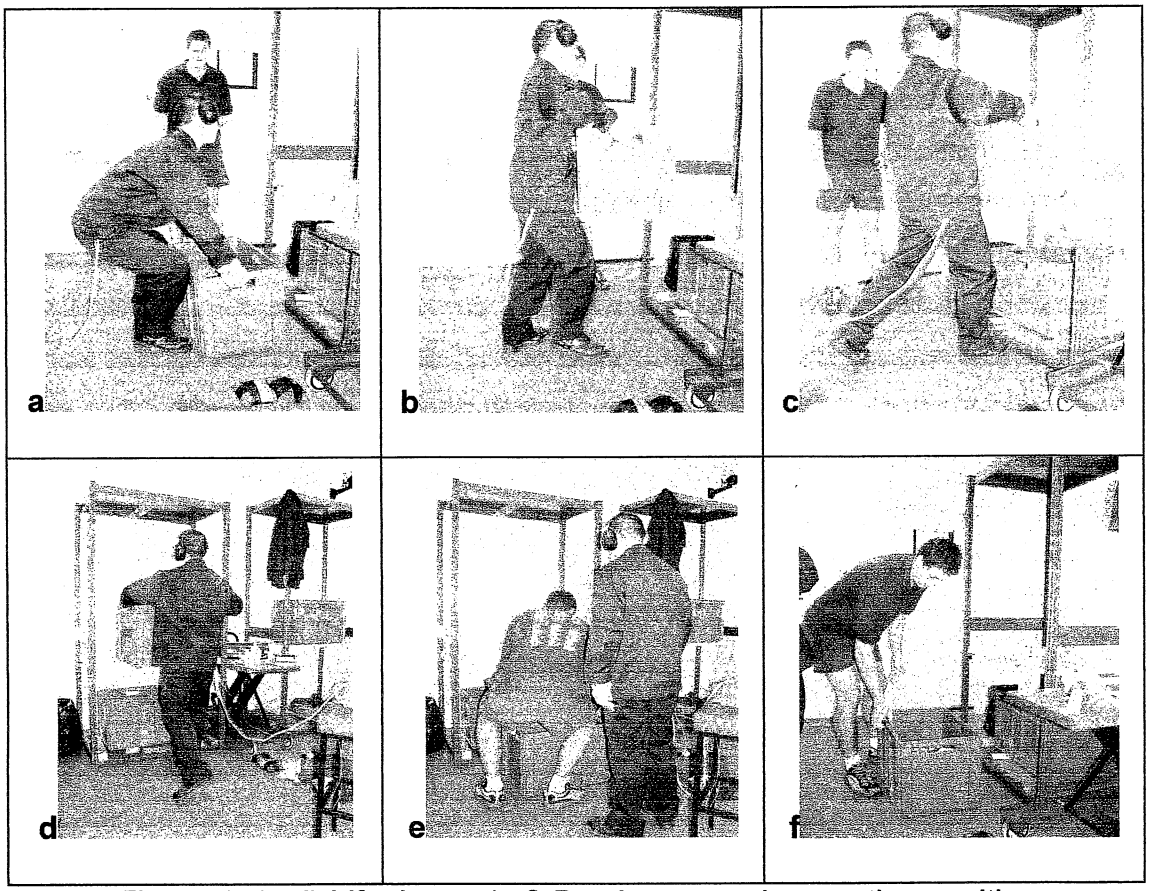

Figure 1. (a-d) Lift phase. (e-f) Box is returned to starting position.

Results

The four dependent variables (HR, T_a, RPE and MAWL) were each analysed for significant differences using a two-factor ANOVA with repeated measures on both factors. α was initially set at 0.05 but subsequently adjusted using a Bonferroni correction to account for the four ANOVA tests (Huck, 2000). HR and T_a were calculated means of the final two minutes of lifting (34-35 minutes). MAWL was established after 20 minutes and RPE was calculated as a mean of the final three ratings (at 25, 30 and 35 minutes). T_s data were incomplete due to problems keeping the thermistors attached during the sessions.

There were no significant differences between the two environments (ENV1 & ENV2) for any of the dependent variables.

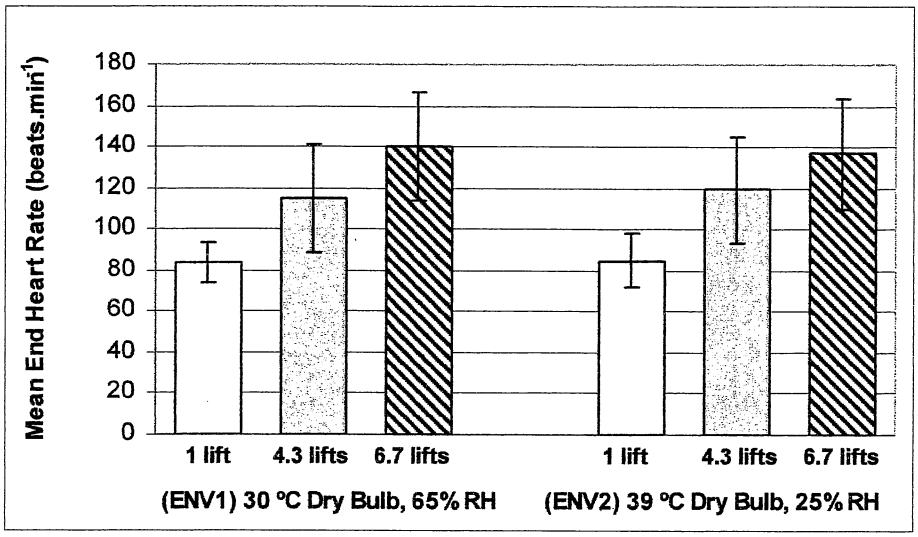

Figure 2. Mean end heart rate for each test condition (columns represent means, error bars represent ± 1 standard deviation).

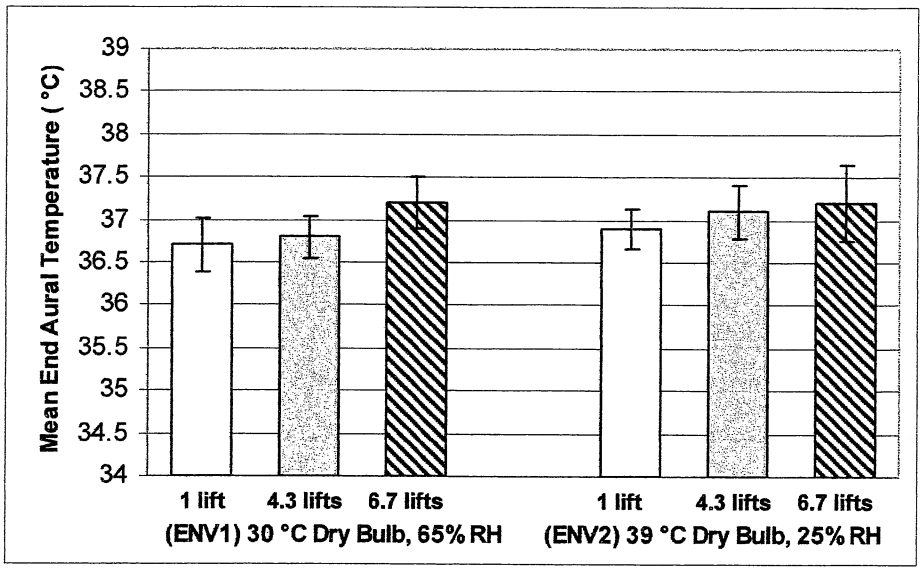

Figure 3. Mean end aural temperature for each test condition (columns represent means, error bars represent ± 1 standard deviation).

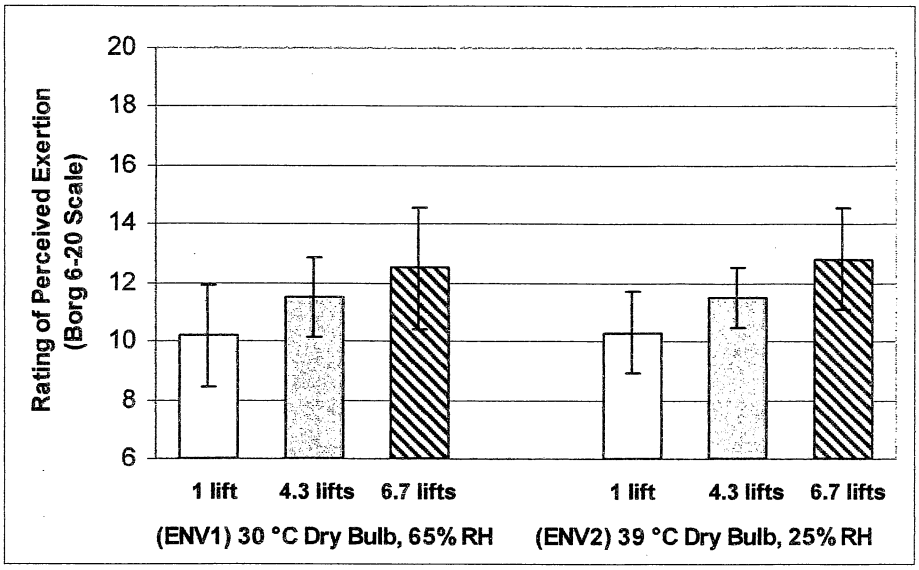

Figure 4. Mean end RPE for each test condition (columns represent means, error bars represent ± 1 standard deviation).

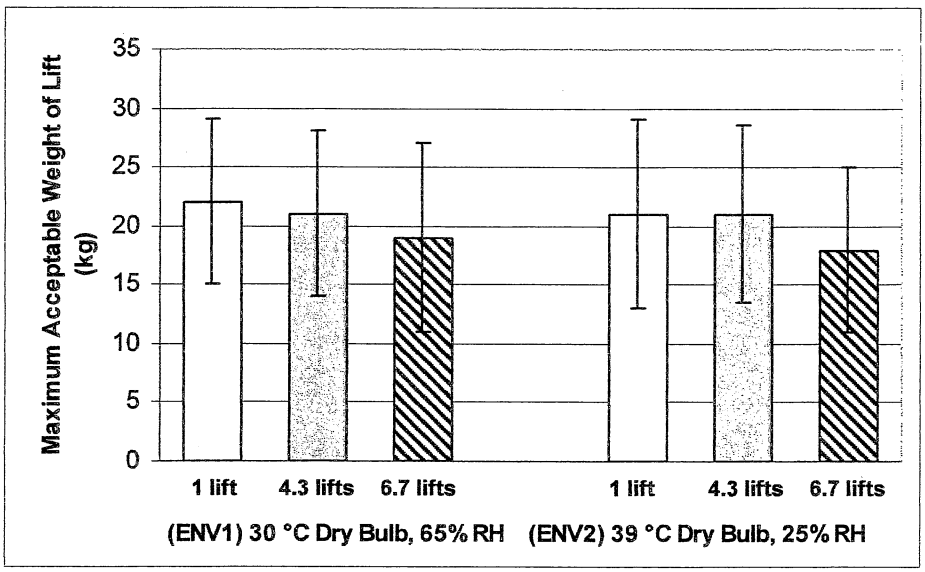

Figure 5. Mean Maximum Acceptable Weight of Lift for each test condition (columns represent means, error bars represent ± 1 standard deviation).

Discussion

The purpose of this study was to investigate the physiological strain and the amount of weight lifted when participants were exposed to two dissimilar environments with an equivalent wet bulb globe temperature (WBGT). No significant differences were found in any of the dependent variables between the

two environments and the null hypotheses are retained. These findings lend support to the underlying assumption of the WBGT scale; i.e. that dissimilar environments with an equivalent WBGT will impose the same physiological strain. The findings of the present study run contrary to those of Keatisuwan *et al.* (1996) and Kellett *et al.* (2003) however. The results of Kellett *et al.* (2003) have yet to be replicated so the fact that there were no significant differences in physiological strain between the hot-dry and warm-humid conditions (both ~27 °C WBGT) in the present study should perhaps not come as a complete surprise. It is possible that the variation in response, if indeed it is a true response, only manifests itself at higher WBGT levels (Kellett *et al,* 2003 tested their participants at 32 °C WBGT). A second possibility is that the response is only observed during longer-term, continuous exercise such as the 60-minute treadmill walking protocol adopted by Kellett *et al.* (2003). Keatisuwan *et al.* (1996) also used a 60-minute exercise protocol at 32 ºC WBGT.

Regarding the generalizability of the findings, some factors should be borne in mind. Only males under the age of 40 years (most of whom had no industrial experience) were studied so care should be taken when interpreting the results with respect to other populations. The results are also only applicable to the floor to knuckle-height lifting task. They should not be generalized to any other type of lift (floor to shoulder-height or knuckle to shoulder-height for example) or other manual handling task.

It is recommended that the physiological and subjective responses of lifters in dissimilar environments with an equivalent WBGT should be investigated at 32 °C WBGT.

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