Initial stay times for uncompensable occupational heat stress in young and older men: a preliminary assessment

Journal:	<i>Applied Physiology, Nutrition, and Metabolism</i>
Manuscript ID	apnm-2021-0550.R1
Manuscript Type:	Brief communication
Date Submitted by the Author:	27-Sep-2021
Complete List of Authors:	Notley, Sean; University of Ottawa Akerman, Ashley; University of Ottawa, Faculty of Health Sciences Kenny, Glen; University of Ottawa; Ottawa Hospital Research Institute
Novelty bullets: points that summarize the key findings in the work:	<ul style="list-style-type: none"> • We provide estimates of the moderate-intensity work duration before heat-mitigation is required in wet-bulb globe temperatur
Keyword:	chronic disease, hyperthermia, safety, thermal strain, thermoregulation < thermoregulation, work
Is the invited manuscript for consideration in a Special Issue? :	Not applicable (regular submission)

SCHOLARONE™
Manuscripts

**Initial stay times for uncompensable occupational heat stress in
young and older men: a preliminary assessment**

Sean R. Notley¹, Ashley P. Akerman^{1*}, and Glen P. Kenny^{1,2}

AFFILIATION:

¹Human and Environmental Physiology Research Unit, School of Human Kinetics,
University of Ottawa, Ottawa, Canada. ²Clinical Epidemiology Program, Ottawa Hospital
Research Institute, Ottawa, Canada.

*Current address: Ultromics, Oxford, United Kingdom

Running Head: Initial stay times for uncompensable heat stress

Key words: chronic disease; hyperthermia; safety; thermal strain; thermoregulation;
work

Word count: 2951/2750 (includes main text and references)

Address for correspondence:

Dr. Glen P Kenny
University of Ottawa,
School of Human Kinetics,
125 University, Room 367
Montpetit Hall
Ottawa, Ontario, Canada
K1N 6N5
(613) 562-5800 ext. 4282
email: gkenny@uottawa.ca

42 **Abstract** (75/75 words)

43 During uncompensable occupational heat stress, heat-mitigation controls are required to
44 prevent core temperature exceeding recommended limits ($\geq 38^{\circ}\text{C}$). However, the initial
45 stay time before employing controls remained unknown. We estimated these times for
46 moderate-intensity work at 26, 28, 30, and 32°C wet-bulb globe temperatures (WBGT) in
47 50 young (18-30 years) and older (50-70 years), non-heat acclimatized men. Initial stay
48 time was 111 min at 26°C WBGT and declined exponentially to 44 min at 32°C WBGT.

49 **Novelty point** (24/25 words)

- 50 • We provide estimates of the moderate-intensity work duration before heat-
51 mitigation is required in wet-bulb globe temperatures between $26\text{-}32^{\circ}\text{C}$ for young
52 and older, non-heat acclimatized men.

53 INTRODUCTION

54 To reduce the risk of occupational heat injury, the American Conference of Governmental
55 Industrial Hygienists (ACGIH) recommends upper heat stress limits defined by a workers'
56 metabolic rate, the prevailing wet-bulb globe temperature (WBGT), and protective
57 clothing (ACGIH 2017; Jacklitsch et al. 2016). Two sliding scale limits termed the Action
58 Limit Values (ALV) and Threshold Limit Values (TLV) are described, which are identical
59 to the Recommended Alert Limits (RAL) and the Recommended Exposure Limits (REL)
60 from the National Institute of Occupational and Environmental Hygienists (NIOSH)
61 (Jacklitsch et al. 2016). The primary objective of the ALV/RAL and TLV/REL is to prevent
62 rises in core temperature of $\geq 1^{\circ}\text{C}$ in non-heat acclimatized workers and $\geq 1.5^{\circ}\text{C}$ in heat
63 acclimatized workers which, assuming a resting core temperature of 37°C , would result
64 in absolute core temperatures $\geq 38^{\circ}\text{C}$ and $\geq 38.5^{\circ}\text{C}$, respectively.

65 In instances where the combination of work rate, environment, and clothing worn
66 cause the ACGIH/NIOSH upper heat stress limits to be exceeded (uncompensable heat
67 stress), controls such as work-rest cycles and cooling strategies are prescribed to prevent
68 excursions in core temperature beyond recommended limits (ACGIH 2017; Jacklitsch et
69 al. 2016). Despite this, no recommendations are provided for the initial work duration
70 before such controls should be employed (stay time). This is an important omission, as
71 initial stay times (e.g., start of the work shift, post-lunch resumption of work) that are too
72 long may result in core temperatures exceeding recommended limits, which are retained
73 throughout the work shift, despite the eventual introduction of controls.

74 While several groups have proposed permissible heat exposure limits (ACGIH
75 2017; Bell et al. 1971; Bernard and Ashley 2009; Dasler 1974; Jacklitsch et al. 2016;
76 Ramsey 1994), these were developed for prolonged, intermittent work, rather than the

initial duration that continuous work could be performed. Consequently, we possess limited insight on appropriate initial stay times before controls must be employed in conditions exceeding the ACGIH/NIOSH upper heat stress limits. The purpose of this preliminary experiment was therefore to estimate these times in non-heat acclimatized young and older men performing moderate-intensity work in environments exceeding these limits (26°C, 28°C, 30°C, and 32°C WBGT).

METHODS

Ethical approval

The experiment was approved by the University of Ottawa Health Sciences and Science Research Ethics Board (H04-17-05) and agrees with the latest version of the *Declaration of Helsinki*, except for registration in a database. Written and informed consent was obtained from all volunteers prior to their participation.

Participants

Of the 190 men screened for the study during enrollment (April, 2018 to March, 2020), 50 meeting the inclusion criteria (Supplement 1) agreed to participate (Figure 1A). This included thirteen healthy young men, fourteen healthy older men, ten older men with type 2 diabetes (T2D), and thirteen older men with controlled hypertension (HTN). All participants were habitually active, non-smokers, and non-heat acclimatized. Participants were aged between 18-30 years (Young) or 50-70 years (Older, T2D, and HTN). Only participants diagnosed with T2D or HTN ≥ 5 y prior and with no associated complications or recent medication changes were included. This study was part of a larger experiment examining the effects of age, T2D and HTN on thermal and cardiovascular strain during prolonged work in environments below (16°C and 24°C WBGT) and above (28°C and

32°C WBGT) the ACGIH ALV/NIOSH RAL (Notley et al. 2021). Since our findings indicated that these factors did not significantly impact thermal or cardiovascular strain, or the resulting initial stay times, data from these participants were pooled to maximize our sample size (n=50) for the current investigation.

Experimental protocol

Participants completed one screening session where physical characteristics and peak oxygen uptake were determined and either two or four experimental trials in conditions above (26, 28, 30, and 32°C WBGT) the ALV/RAL (~25°C WBGT) for moderate-intensity work (metabolic rate: 130-200 W/m²) when wearing clothing insulation equal to ~1 Clo (ACGIH 2017; Jacklitsch et al. 2016). The 28°C and 32°C WBGT trials were completed by all participants, except for one with HTN who did not complete the 28°C WBGT (Figure 1A). Further, 18 of those participants completed all four conditions (Young: n=6; Older: n=5; T2D: n=4; HTN: n=3). Our main analysis therefore incorporates data from the 28°C and 32°C WBGT (Figure 1A), with data from the subset of participants who performed additional trials (26 and 30°C WBGT) being used to supplement our analysis (see *Statistical Analysis*). As noted above, data from the 28°C and 32°C WBGT have been reported elsewhere (Notley et al. 2021), and are analyzed retrospectively here.

Upon arrival for each trial, participants provided urine samples to confirm euhydration (urine specific gravity: ≤ 1.025). Following ~30-min instrumentation, where baseline core temperatures were recorded, participants donned a t-shirt, single-layer cotton-coveralls, socks, and shoes (insulation: ~1 Clo). They then entered a climate-controlled chamber with minimal air flow (<0.3 m/sec) regulated to 35% relative humidity and one of four air temperatures (34.1, 36.6, 39.0, and 41.4°C) eliciting differing WBGTs (26, 28, 30, and 32°C). After 30-min seated habituation, participants walked for 180 min

(or until volitional termination) on a treadmill (4Front, Woodway, Waukesha, WI, USA) at a metabolic rate of ~ 200 W/m². This work intensity and uniform were consistent with the average metabolic rate and minimal protective clothing of arduous occupations (Kenny et al. 2012; Meade et al. 2016). Chamber temperature water was consumed *ad libitum*. All trials were completed at the same time of day (within participant), separated by >48 h. Prior to each visit, participants were asked to refrain from exercise, alcohol or caffeine, and non-steroidal anti-inflammatory drugs for >24 h.

Measurements

Metabolic rate was estimated from indirect calorimetry (Moxus, AEI Technologies, Bastrop, TX, USA). During the first trial, participants were asked to select a comfortable treadmill grade between 2-4%. Treadmill speed was then controlled to clamp metabolic rate at ~ 200 W/m² within the first 10 min of work. This treadmill speed and grade was then fixed (within participant) throughout all trials and averaged (SD) 4.8 (0.5) km/h and 2.4 (0.7) %, respectively. Core temperature was measured with a temperature probe (Mallinckrodt Medical, St. Louis, MO, USA) inserted 12 cm past the anal sphincter and recorded at 15 s intervals (HP Agilent, model 2497A, Santa Clara, CA, USA).

Initial stay time was calculated from two criteria, since not all participants possessed a baseline core temperature (37°C) considered to be normal by the ACGIH. This included: i) the work duration before a sustained absolute core temperature $\geq 38^\circ\text{C}$, and ii) the work duration before a sustained rise in core temperature $\geq 1^\circ\text{C}$ from baseline. In instances where a participant voluntarily terminated work prematurely before the rise in core temperature was $\geq 1^\circ\text{C}$ (n=5) or the absolute core temperature was $\geq 38^\circ\text{C}$ (n=3), the time of termination was taken as the initial stay time.

147 **Statistical analysis**

148 Stay times derived from both the absolute ($\geq 38^{\circ}\text{C}$) and change in core temperature
149 ($\Delta \geq 1^{\circ}\text{C}$) were visualized with the Kaplan-Meier method and compared between the 28°C
150 and 32°C WBGT using a log-rank test. The resulting Kaplan-Meier curves were used to
151 identify the initial stay time for which work could be performed before 20% of participants
152 displayed a core temperature above recommended limits. This proportion was selected
153 based on previous work (Kuhlemeier and Wood 1979; Notley et al. 2021), which
154 demonstrated that ~20% of participants displayed core temperatures exceeding
155 recommended limits in conditions below the ALV/RAL, and aimed to ensure our estimates
156 would be equally as effective.

157 To increase the practical utility of our data, we assumed a negative exponential
158 association between the stay time that would be expected if working below the ALV/RAL
159 (i.e., ≥ 180 min at $\leq 25^{\circ}\text{C}$ WBGT) and the stay times obtained for the 28°C and 32°C WBGT
160 to estimate stay times for 26°C , 27°C , 29°C , 30°C , and 31°C WBGT. To support these
161 estimates, the stay times from the subset of participants who completed additional trials
162 at 26°C and 30°C WBGT ($n=18$) were used to identify the number of individuals falling
163 above and below this threshold. These counts were then compared to projected counts
164 assuming ~80% ($n=14$) and 20% ($n=4$) of these times would fall above and below the
165 estimated stay times, using Fisher's exact test. *Alpha* was 0.050 for all comparisons. All
166 analyses were performed using Prism 9 (GraphPad, San Diego, CA).

167 **RESULTS**

168 The physical characteristics and baseline core temperature across conditions (mean
169 (SD)) of the 50 participants completing trials under 28°C and 32°C WBGT were; age: 50
170 (17) years; height: 175 (6) cm; mass: 82.2 (10.4) kg; surface area: 2.0 (0.1) m^2 ; body fat:

23 (7)%; and peak oxygen uptake: 38 (9) mL/kg/min; core temperature: 37.0 (0.3)°C. As noted above, a subset of those participants (n=18) completed additional trials at 26°C and 30°C WBGT. Their physical characteristics and baseline core temperature across conditions were; age: 48 (17) years; height: 175 (6) cm; mass: 79.4 (8.3) kg; surface area: 1.9 (0.1) m²; body fat: 21 (6)%; and peak oxygen uptake: 41 (9) mL/kg/min; core temperature: 36.9 (0.3)°C.

Stay times were lower in the 32°C compared to the 28°C WBGT when determined from either the absolute or change in core temperature (both $p < 0.001$; Figure 1). The stay times required to ensure 80% of the sample did not demonstrate an absolute core temperature $\geq 38^\circ\text{C}$ in the 28°C and 32°C WBGT were 60 and 44 min, respectively. The stay times required to ensure 80% of the sample did not demonstrate rises in core temperature $\geq 1^\circ\text{C}$ in the 28°C and 32°C WBGT were 89 and 53 min, respectively. We then used these data to estimate stay times at 1°C increments for 26-32°C WBGT, which ranged from 111 to 44 min when determined from the absolute core temperature (Figure 1D), and 138 to 53 min when determined from the change in core temperature (Figure 1E). Importantly, the proportion of participants with stay times above and below this threshold did not differ from the expected counts in the 26°C or 30°C WBGT when determined using the absolute core temperature ($p = 0.338$ and $p > 0.999$, respectively) or the change in core temperature ($p = 0.658$ and $p > 0.999$, respectively).

DISCUSSION

This preliminary investigation was designed to estimate the maximal work duration (initial stay time) that could be performed by non-heat acclimatized young and older men before heat-mitigation controls would need to be employed in environments above ACGIH/NIOSH upper heat stress limits (26°C, 28°C, 30°C, and 32°C WBGT) during

moderate-intensity work while wearing a single clothing layer (~ 1 Clo). Initial stay time, determined from the absolute core temperature ($\geq 38^{\circ}\text{C}$) and change in core temperature ($\Delta \geq 1^{\circ}\text{C}$) at 26°C WBGT was 111 min and 138 min, respectively, with those times declining exponentially to 44 min and 53 min at 32°C WBGT, respectively,. While there is a need to confirm and extend these estimates, we hope they may provide a foundation for developing revisions to existing guidance that will help safeguard worker health.

In circumstances where the ACGIH ALV/NIOSH RAL are exceeded (due to a workers' metabolic rate, clothing, or the prevailing WBGT), heat-mitigation controls are prescribed to prevent excursions in core temperature $\geq 1^{\circ}\text{C}$ or an absolute core temperature of $\geq 38^{\circ}\text{C}$ (ACGIH 2017; Jacklitsch et al. 2016). Despite this, no guidance is provided for the initial stay time before such controls should be employed. We therefore estimated initial stay times for which work could be performed before 20% of participants would exceed these limits in conditions above the ALV/RAL ($>25^{\circ}\text{C}$ WBGT). These ranged from 111 min at 26°C WBGT to 44 min at 32°C WBGT based on the absolute core temperature (Figure 1D), with slightly less conservative estimates when derived from the change in core temperature (138 min at 26°C WBGT to 53 min at 32°C WBGT; Figure 1E). This discrepancy is possibly because participants who experienced the most rapid rises in core temperature also possessed a higher baseline core temperature, which thereby reduced the stay time required to prevent core temperatures $\geq 38^{\circ}\text{C}$ in 80% of the sample relative to utilizing a criterion derived from the change in core temperature ($\geq 1^{\circ}\text{C}$). Nonetheless, the number of participants that would be appropriately classified as falling above (80%) and below (20%) these thresholds did not differ significantly from the expected counts in the 26°C and 30°C WBGT, indicating that the initial stay times estimated would likely be appropriate had the full sample ($n=50$) performed these

additional trials. While we were unable to verify the suitability of these estimates at 27, 29, and 31°C WBGT, we hope they may serve as the initial framework to develop guidance on initial stay times for uncompensable heat stress, which may be particularly useful for emergency situations (e.g., repairing power lines during a storm).

Of note, these stay times were suitable for 80% of workers, with the remaining 20% expected to display rises in core temperature exceeding recommended limits. As noted above, this level of precision (80%) was selected to be consistent with the effectiveness of current guidelines in conditions below the ACGIH/NIOSH upper heat stress limits (Kuhlemeier and Wood 1979; Notley et al. 2021). If one was intent on preventing core temperature exceeding recommended limits in all workers (100%), these stay times should be lowered to ≤ 19 min across conditions (Figure 1E). However, doing so would heavily compromise productivity. As such, a more effective approach to protect all workers, while maintaining productivity, may be to leverage wearable technology to monitor one or more direct or indirect indices of core temperature (Notley et al. 2018).

Despite the potential utility of these initial stay times, there are several noteworthy considerations. First, since not all participants possessed a baseline core temperature considered to be normal by the ACGIH (37°C), we derived initial stay times based on both the absolute core temperature ($\geq 38^\circ\text{C}$) and the rise in core temperature ($\geq 1^\circ\text{C}$). However, to our knowledge, it remains uncertain as to which criteria is of greater importance for occupational heat-injury risk, and this represents an important area of further study. In the interim, it would seem logical to utilize the more conservative estimates associated with the absolute core temperature ($\geq 38^\circ\text{C}$) (Figure 1D). Second, there is a need for further research to verify and extend these estimates to broader environmental conditions, clothing conditions, and work intensities including self-paced work. Third, we were unable

to determine whether the implementation of controls (e.g., work-rest cycles, cooling strategies) following these initial stay times would prevent excursions in core temperature beyond recommended limits over the course of a work shift or over consecutive work shifts. Finally, our experiment was not designed to identify the factors (e.g., disease severity, aerobic fitness) explaining individual variation in the work duration performed before core temperature exceeded recommended limits, which was relatively large in the 28°C WBGT (Figure 1). As such, further studies are required to identify these factors and to determine whether they differ according to the work intensity and/or prevailing WBGT.

CONCLUSION

When performing moderate-intensity work while wearing a single clothing layer (~1 Clo) in environments above ACGIH/NIOSH limits (26°C, 28°C, 30°C, and 32°C WBGT), non-heat acclimatized young and older men could work for 111 min at 26°C WBGT before controls are required to maintain core temperature within recommended limits (<38°C), with that stay time declining exponentially to 44 min at 32°C WBGT. Nonetheless, there is a need for larger studies to validate and extend these preliminary estimates.

ACKNOWLEDGEMENTS

We thank all participants as well as past and present members of the Human and Environmental Physiology Research Unit for their assistance with data collection.

DISCLOSURES

No conflict of interest, financial or otherwise, are declared by the author(s). Data are available from the corresponding author upon reasonable request.

GRANTS

This research was supported by the Government of Ontario and the Canadian Institutes of Health Research (all funds held by G.P. Kenny). S.R. Notley and A.P. Akerman are supported by Postdoctoral Fellowships from the Human and Environmental Physiology Research Unit.

AUTHOR CONTRIBUTIONS

S.R.N. drafted the manuscript and prepared figures. S.R.N., and A.P.A. performed statistical analysis. All authors conceptualized and designed the research, interpreted results of experiments, revised the manuscript, and approved the final version.

273 REFERENCES

- 274 ACGIH. 2017. Heat stress, TLVs and BEIs: threshold limit values for chemical substances
275 and physical agents & biological exposure indices. ACGIH Cincinnati, OH.
- 276 Bell, C., Crowder, M.J., and Walters, J. 1971. Durations of safe exposure for men at work
277 in high temperature environments. *Ergon.* **14**(6): 733-757. doi:
278 10.1080/00140137108931296
- 279 Bernard, T.E., and Ashley, C.D. 2009. Short-term heat stress exposure limits based on
280 wet bulb globe temperature adjusted for clothing and metabolic rate. *J Occup Environ*
281 *Hyg* **6**(10): 632-638. doi: 10.1080/15459620903133642.
- 282 Dasler, A. 1974. Ventilation and thermal stress, ashore and afloat. In: Department of the
283 Navy, Bureau of Medicine and Surgery. Manual of naval preventive medicine. Chapter 3.
- 284 Jacklitsch, B., Williams, J., Musolin, K., Coca, A., Kim, J.-H., and Turner, N. 2016. Criteria
285 for a recommended standard: occupational exposure to heat and hot environments.
286 NIOSH Publ. 2016-106.
- 287 Kenny, G.P., Vierula, M., Maté, J., Beaulieu, F., Hardcastle, S.G., and Reardon, F. 2012.
288 A field evaluation of the physiological demands of miners in Canada's deep mechanized
289 mines. *J Occup Environ Hyg* **9**(8): 491-501. doi: 10.1080/15459624.2012.693880.
- 290 Kuhlemeier, K.V., and Wood, T.B. 1979. Laboratory evaluation of permissible exposure
291 limits for men in hot environments. *Am Ind Hyg Assoc J* **40**(12): 1097-1103.
292 doi:10.1080/15298667991430758.
- 293 Meade, R.D., Lauzon, M., Poirier, M.P., Flouris, A.D., and Kenny, G.P. 2016. The physical
294 demands of electrical utilities work in North America. *J Occup Environ Hyg* **13**(1): 60-70.
295 doi:10.1080/15459624.2015.1077966.
- 296 Notley, S.R., Flouris, A.D., and Kenny, G.P. 2018. On the use of wearable physiological
297 monitors to assess heat strain during occupational heat stress. *Appl Physiol Nutr Metab*
298 **43**(9): 869-881. doi:10.1139/apnm-2018-0173.
- 299 Notley, S.R., Akerman, A.P., Friesen, B.J., Poirier, M.P., Sigal, R.J., Flouris, A.D., et al.
300 2021. Heat Tolerance and Occupational Heat Exposure Limits in Older Men with and
301 without Type 2 Diabetes or Hypertension. *Med Sci Sports Exerc.* **53**(10): 2196-2206. doi:
302 10.1249/MSS.0000000000002698.
- 303 Ramsey, J.D. 1994. Heat and clothing effects on stay times. *Int J Ind Ergon.* **13**(2): 157-
304 163. doi.org/10.1016/0169-8141(94)90082-5.

305

306

Figure 1A: Adapted with permission from Notley et al. 2021. Of the 190 men screened, thirteen healthy young men (Young), fourteen healthy older men (Older), ten older men with type 2 diabetes (T2D), and thirteen older men with controlled hypertension (HTN) participated. All participants completed two trials in 28°C and 32°C wet-bulb globe temperatures (WBGT), whereas a subset of participants (n=18) completed two additional trials at 26°C and 30°C (one participant with HTN did not complete the 28°C WBGT; *). Inclusion criteria presented in Supplement 1. **Figure 1B and Figure 1C:** The proportion of participants (n=50) with a core temperature (T_c) $\leq 38^\circ\text{C}$ (Figure 1B) or (ΔT_c) $\leq 1^\circ\text{C}$ (Figure 1C) during work at 28°C and 32°C WBGT. The horizontal and vertical dashed lines denote the time (stay time) for which work could be performed before 20% of participants displayed a core temperature $\geq 38^\circ\text{C}$ (Figure 1B) or $\geq 1^\circ\text{C}$ (Figure 1C) in each condition. **Figure 1D and Figure 1E:** The negative exponential association assumed between initial stay time and WBGT. Initial stay time refers to the duration (min) of work before each participant experienced a sustained absolute core temperature $\geq 38^\circ\text{C}$ (Figure 1D) and a sustained elevation in core temperature $\geq 1^\circ\text{C}$ (Figure 1E). The black symbols indicate the actual stay times, the white symbols show the estimated stay times, while the area below the curve shows the stay times that would be expected to ensure 80% of participants display core temperatures within such limits. Each participant's work duration is indicated with a unique symbol. Note that the individual stay times for the 26°C and 30°C WBGT are provided for only a subset of participants (n=18). Based on these estimates, initial stay time was 111 min 138 min at 26°C WBGT when derived from the absolute and change in core temperature, respectively, with an exponential decline in those stay times (as described using the equation on the right side of each panel).

Created with BioRender.com.

Figure 1A: Adapted with permission from Notley et al. 2021. Of the 190 men screened, thirteen healthy young men (Young), fourteen healthy older men (Older), ten older men with type 2 diabetes (T2D), and thirteen older men with controlled hypertension (HTN) participated. All participants completed two trials in 28°C and 32°C wet-bulb globe temperatures (WBGT), whereas a subset of participants (n=18) completed two additional trials at 26°C and 30°C (one participant with HTN did not complete the 28°C WBGT; *). Inclusion criteria presented in Supplement 1. Figure 1B and Figure 1C: The proportion of participants (n=50) with a core temperature (T_c) $\leq 38^\circ\text{C}$ (Figure 1B) or (ΔT_c) $\leq 1^\circ\text{C}$ (Figure 1C) during work at 28°C and 32°C WBGT. The horizontal and vertical dashed lines denote the time (stay time) for which work could be performed before 20% of participants displayed a core temperature $\geq 38^\circ\text{C}$ (Figure 1B) or $\geq 1^\circ\text{C}$ (Figure 1C) in each condition. Figure 1D and Figure 1E: The negative exponential association assumed between initial stay time and WBGT. Initial stay time refers to the duration (min) of work before each participant experienced a sustained absolute core temperature $\geq 38^\circ\text{C}$ (Figure 1D) and a sustained elevation in core temperature $\geq 1^\circ\text{C}$ (Figure 1E). The black symbols indicate the actual stay times, the white symbols show the estimated stay times, while the area below the curve shows the stay times that would be expected to ensure 80% of participants display core temperatures within such limits. Each participant's work duration is indicated with a unique symbol. Note that the individual stay times for the 26°C and 30°C WBGT are provided for only a subset of participants (n=18). Based on these estimates, initial stay time was 111 min 138 min at 26°C WBGT when derived from the absolute and change in core temperature, respectively, with an exponential decline in those stay times (as described using the equation on the right side of each panel). Created with BioRender.com.

713x403mm (118 x 118 DPI)