Do deep mechanized miners get better at working in the heat with age?

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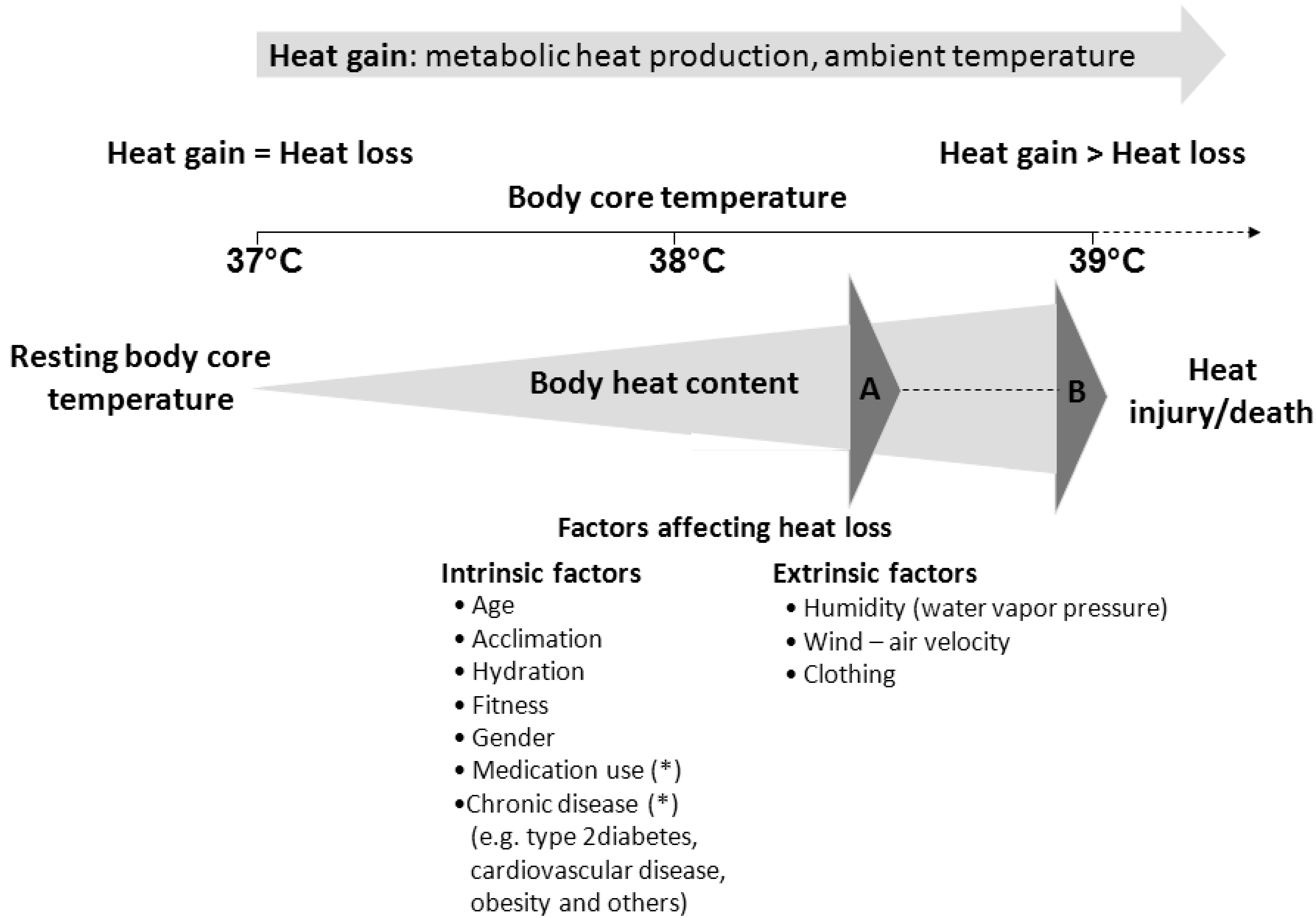
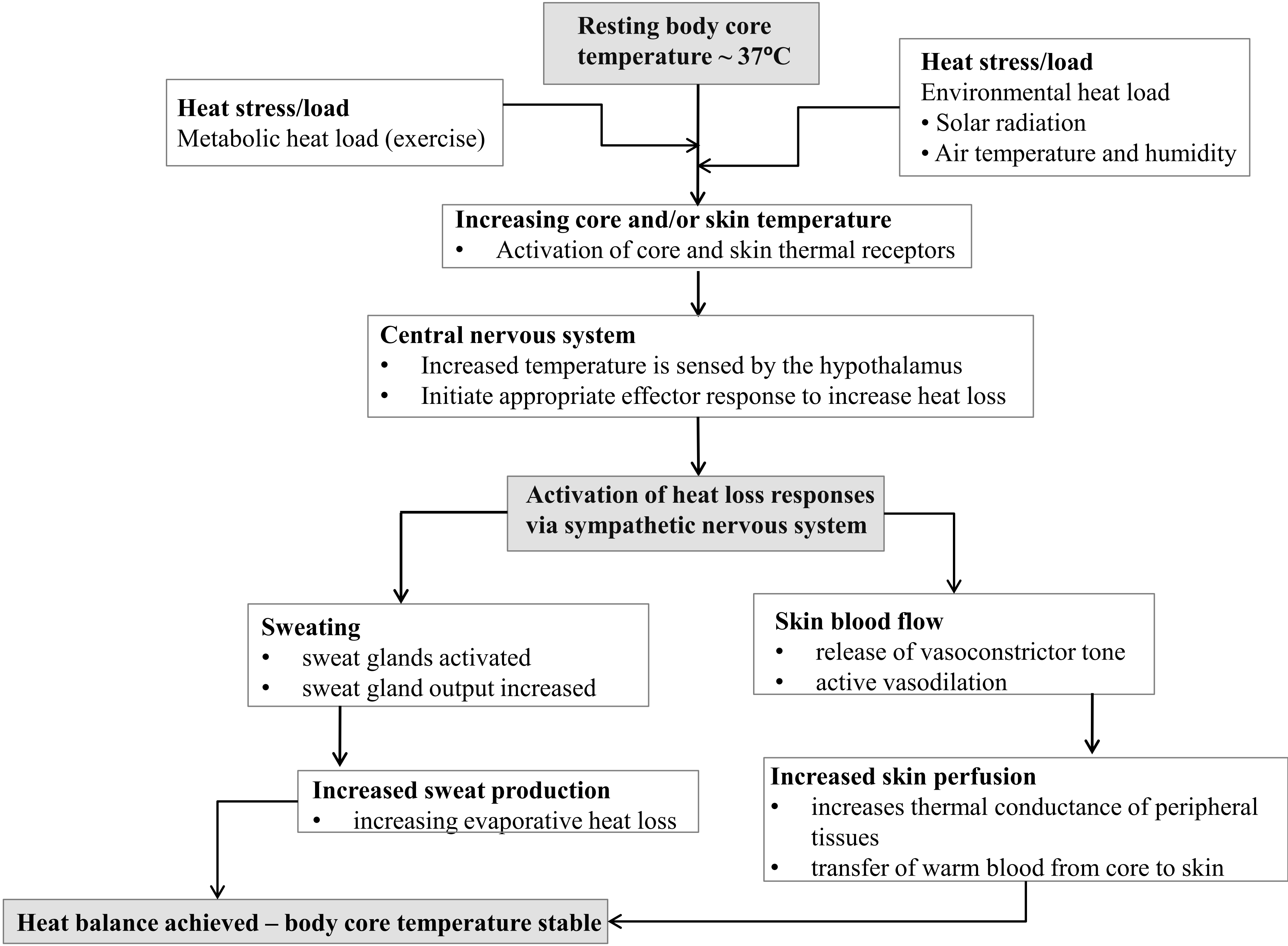
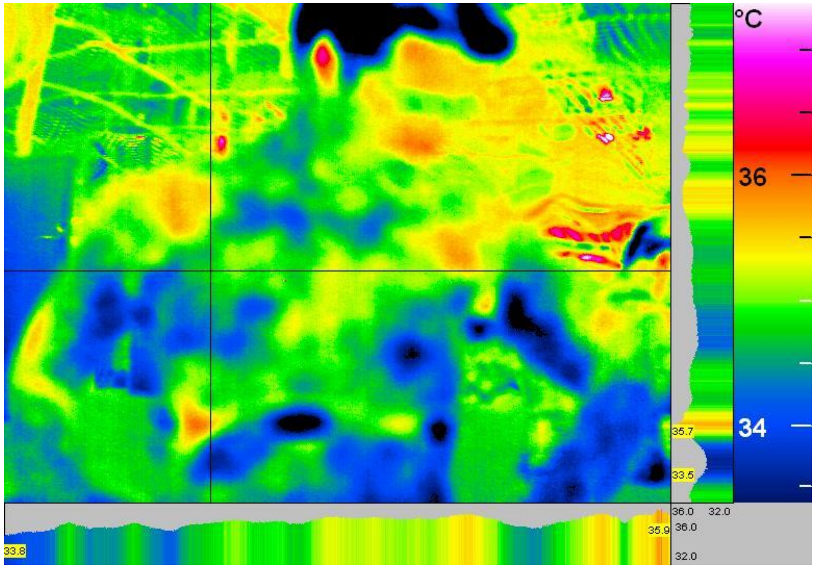
Overview of presentation

1. Brief review of human thermoregulation.
2. Discuss industry-based exposure limits for work in the heat.
3. Whole-body calorimetry: a tool for measuring heat loss.
4. Examine work demands in the mining industry.
5. Discuss current research: aging and heat dissipation.
6. Heat adaptation: can it improve heat dissipation as we age?


Heat gain: metabolic heat production, ambient temperature
Heat gain = Heat loss
Heat gain > Heat loss
Body core temperature
37°C
38°C
39°C
Resting body core temperature
Body heat content
A
B
Heat injury/death
Factors affecting heat loss
Intrinsic factors
• Age
• Acclimation
• Hydration
• Fitness
• Gender
• Medication use (*)
•Chronic disease (*) (e.g. type 2diabetes, cardiovascular disease, obesity and others)
Extrinsic factors
• Humidity (water vapor pressure)
• Wind – air velocity
• Clothing


Resting body core temperature ~ 37°C
Heat stress/load
Metabolic heat load (exercise)
Heat stress/load
Environmental heat load
• Solar radiation
• Air temperature and humidity
Increasing core and/or skin temperature
• Activation of core and skin thermal receptors
Central nervous system
• Increased temperature is sensed by the hypothalamus
• Initiate appropriate effector response to increase heat loss
Activation of heat loss responses via sympathetic nervous system
Sweating
• sweat glands activated
• sweat gland output increased
Skin blood flow
• release of vasoconstrictor tone
• active vasodilation
Increased sweat production
• increasing evaporative heat loss
Increased skin perfusion
• increases thermal conductance of peripheral tissues
• transfer of warm blood from core to skin
Heat balance achieved – body core temperature stable

Despite our increasing knowledge of the mechanisms governing human temperature regulation, *there remains a paucity of information about the effects that aging may have on the body's physiological capacity to dissipate heat*.



Exposure limits for work in the heat

Allocation of Work in a Cycle of Work and Recovery	TLV® (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy
75% to 100%	31.0	28.0	—	—
50% to 75%	31.0	29.0	27.5	—
25% to 50%	32.0	30.0	29.0	28.0
0% to 25%	32.5	31.5	30.5	30.0

Note: TLVs assumes workers are adequately hydrated, not taking medication and are in generally good health.

Factors to consider?

Age

Hydration Status

Body composition

Fitness and health status

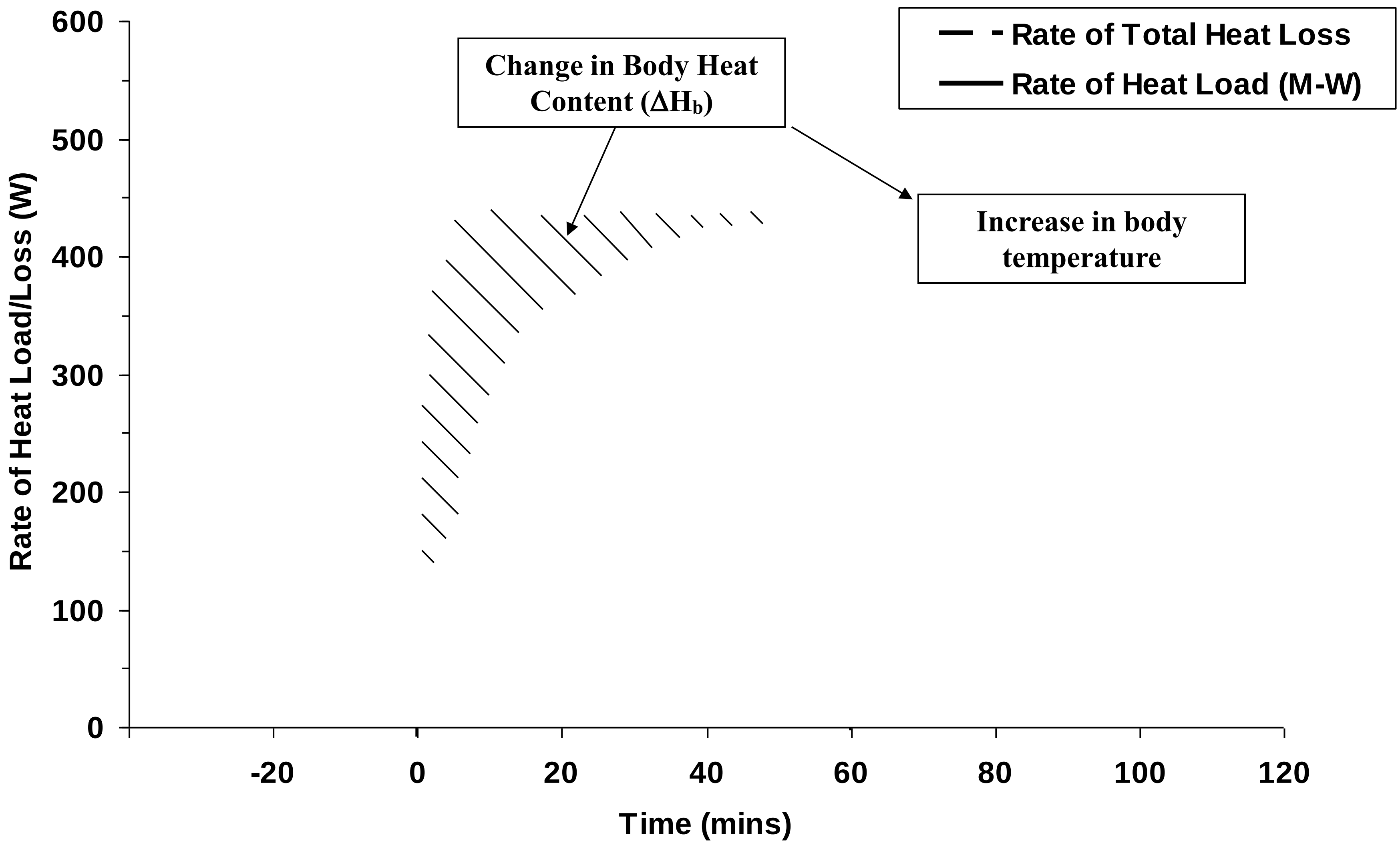
The Snellen whole-body calorimeter

Precisely temperature controlled air flows at a constant rate partly into a ~1.8 m high and ~1.6 m diameter cylinder (with a volume of ~4000 L) and into the surrounding air space (climatic chamber) producing a zero temperature gradient across the walls of the calorimeter.

Reflective walls on the inside of the cylinder deflect any radiant heat emitted by the participant.

The modified Snellen whole-body air calorimeter yields an accuracy ±2.3 W for the measurement for the rate of total body heat loss and with a short response time and low thermal inertia it permits the minute-by-minute assessment of dynamic human heat balance across a range of exercise intensities and environmental conditions.

How do we interpret the calorimetry-based data?



A field evaluation of the physiological demands of miners in Canada's deep mechanized mines

J Occupational and Environmental Hygiene, 2012;9(8):491-501.

[1]Glen P. Kenny, [1]Matthieu Vierula, [2]Joseph Maté, [1]Francois Beaulieu, [3]Stephen G. Hardcastle and [1]Francis Reardon

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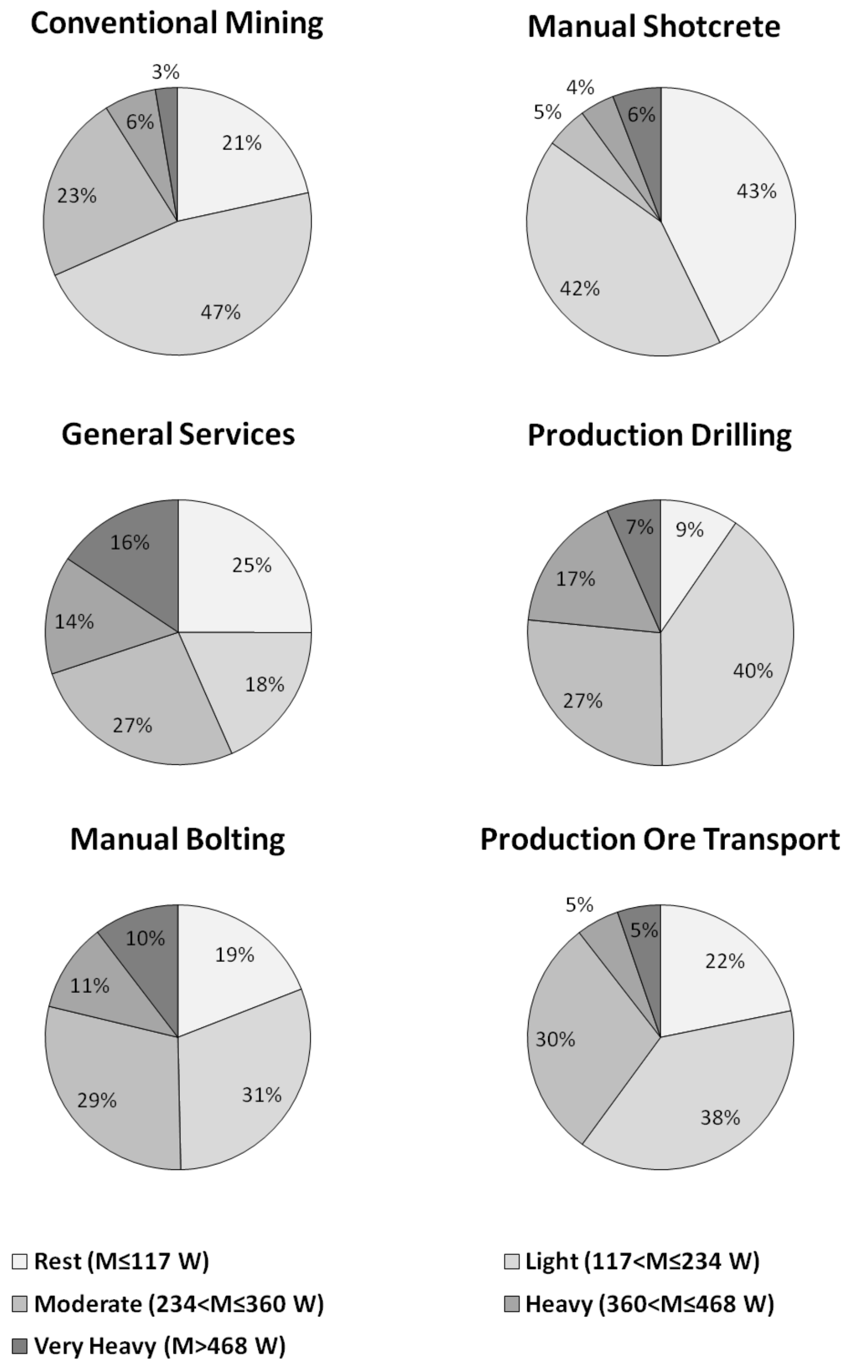


Figure. Mean percentage of time spent at different levels of physical effort during the work shift for the different mining jobs. Values include the work shift lunch break during which time the participants remained seated resting. The classification of levels of metabolic rate (M) are as defined by ISO 7243 .

With the exception of manual shotcrete, 46% of time is spent performing at moderate to very heavy work loads (i.e., 234<M>468 W).

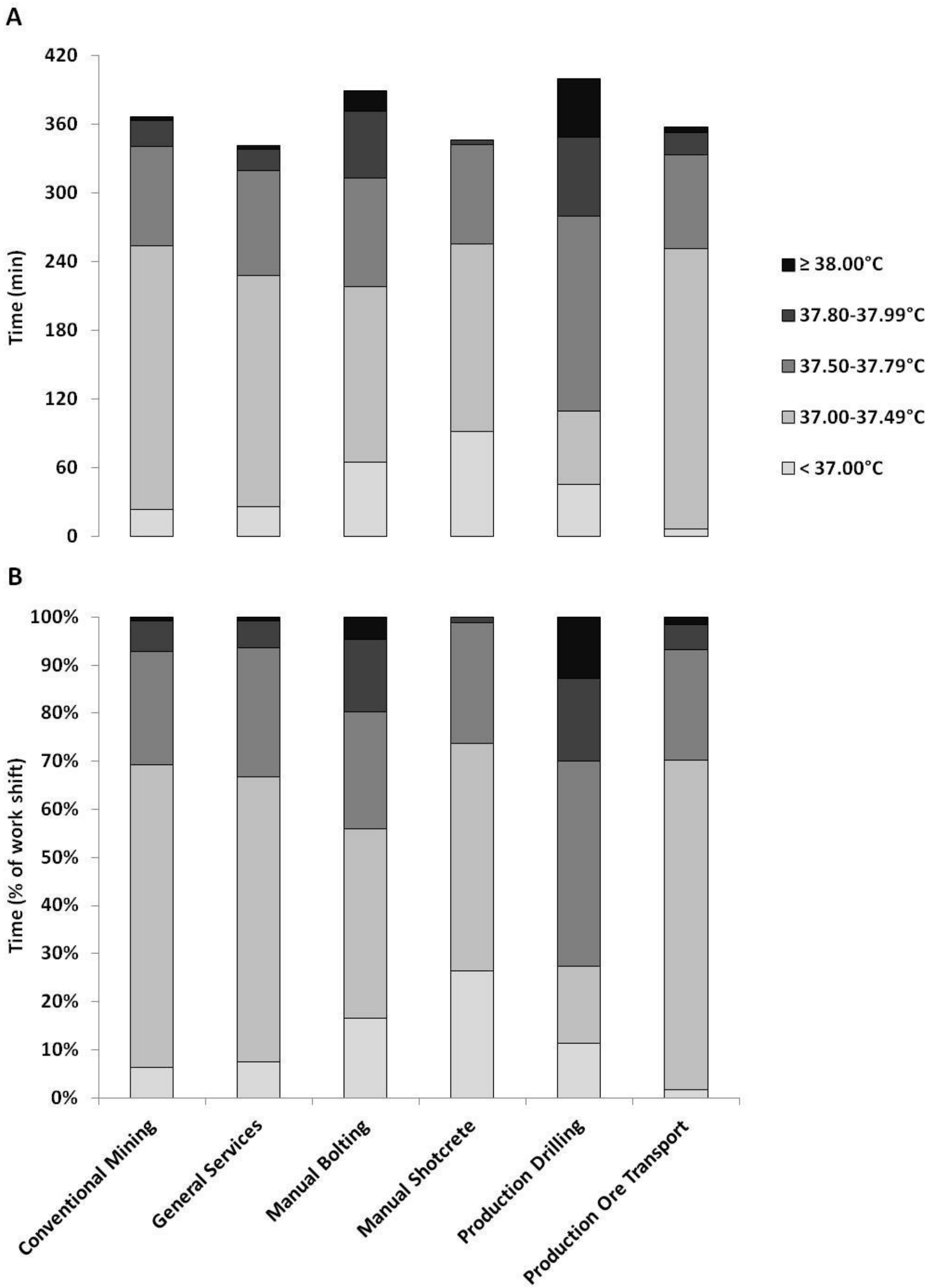


Figure. Mean work time expressed as a time weighted average (A, top panel) and percentage of total work shift duration (B, bottom panel) spent at different levels of core temperature (°C) during the work shift.

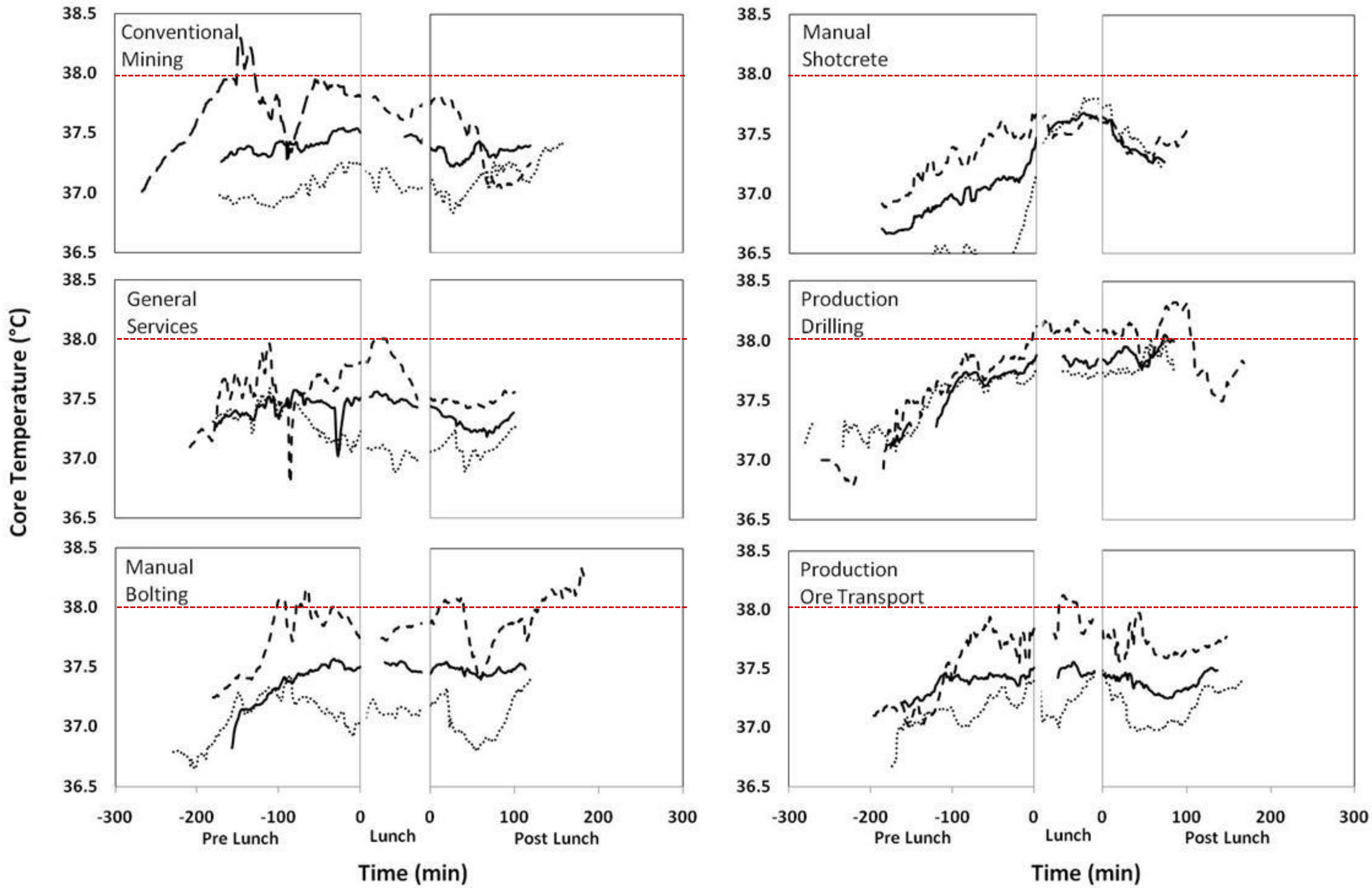


Figure. Mean (solid line) as well as lowest (dotted line), and highest (dashed line) individual core temperature (°C) responses measured over the course of the work shift prior to and after the lunch break. Note: average (±SD) mid-shift (typically lunch) break duration was 44 (21) minutes for Manual bolting, 28 (16) minutes for Conventional Mining, 40 (13) minutes for Production drilling, 52 (11) minutes for Production ore transport, 61 (14) minutes for General services and 67 (12) minutes for Manual shotcrete

Are older workers at greater risk of developing heat-related injuries when performing the same job?

The young versus the older worker: a face to face comparison!

Young adult:
Age: 25
VO_{2max}: 55 mLO_2/kg/min
Body fat %: 14
Medical conditions: none

Older adult:
Age: 60
VO_{2max}: 31 mLO_2/kg/min
Body fat %: 35
Health conditions: diabetes

Assuming that both workers are performing same physical task:

↓ in physical work capacity = ↑ in physical effort = early onset of fatigue

↓ in heat loss responses = greater heat gain = ↑ risk of heat-related injury

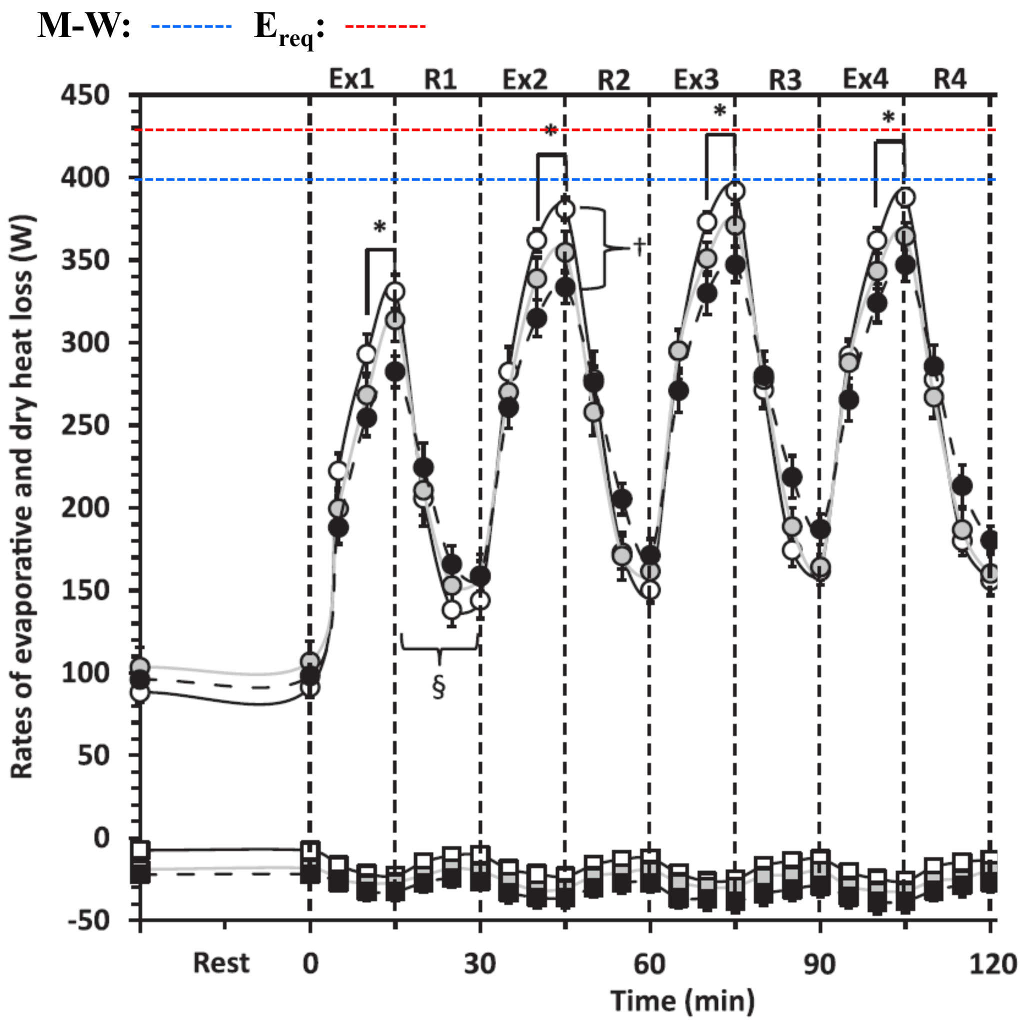


Fig. 1. Values are presented as means ± SE. Rate of evaporative heat loss (H_E) (circles) and dry heat exchange (H_D) (squares) in young (white), middle-aged (gray) and older (black) males during intermittent exercise at 35°C/20% RH. H_E was analyzed at 5-min intervals during the exercise periods. *Significant difference between young and older males at 10- and 15-min of exercise. †Significant difference in H_E compared with the previous exercise bout. §Significant difference in H_E compared with the previous recovery period. Significance level was accepted at $P \leq 0.05$.

○ Young (20-30 yrs)

◉ Middle-aged (40-45 yrs)

● Older (60-65 yrs)

Am J Physiol 305:R619-R629, 2013

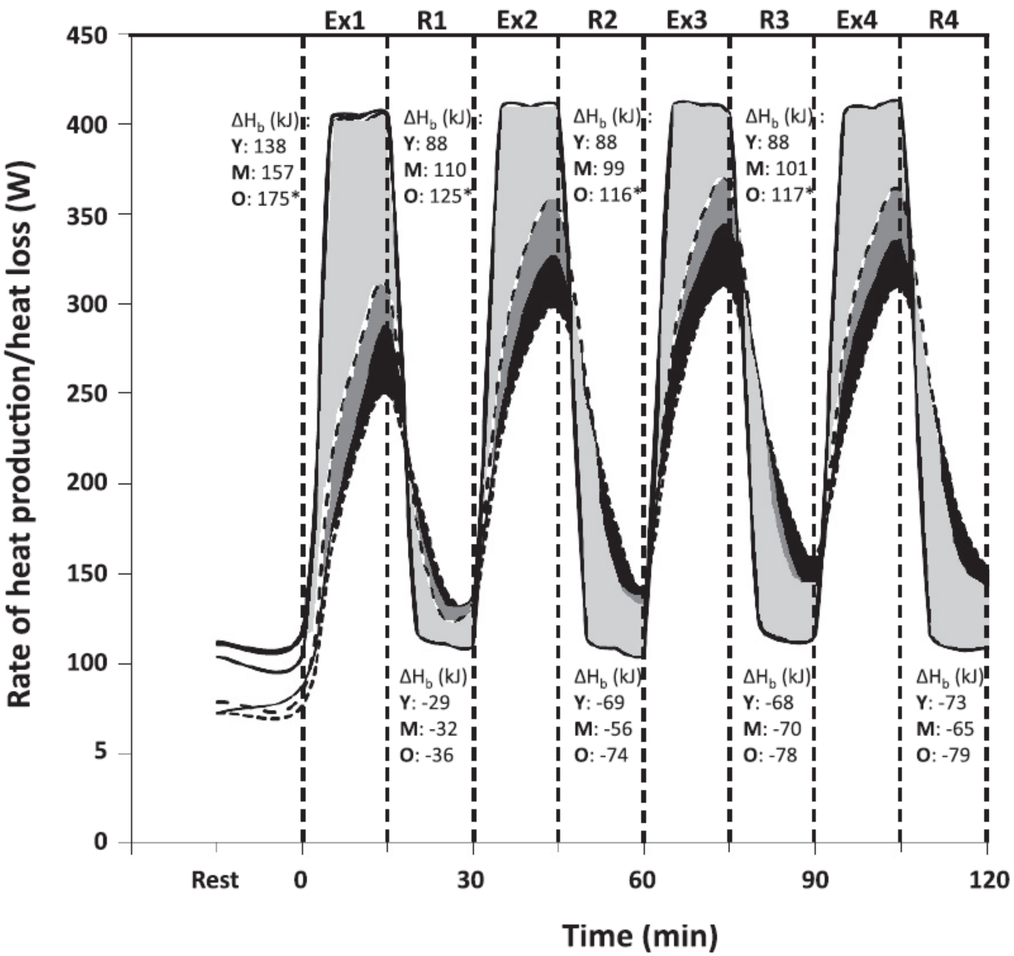


Fig. 2. Mean rates of heat production and whole body total heat loss for young (Y), middle-aged (M), and older (O) males during four successive exercise (Ex1, Ex2, Ex3, Ex4)/recovery (R1, R2, R3, R4) cycles. Changes in body heat content (ΔH_b) are presented as shaded areas and numerically for each exercise and recovery period. Light gray area shows ΔH_b in young males; dark gray area shows the additional amount of heat stored (exercise) or lost (recovery) by middle-aged males compared with young males; and black area denotes the additional amount of heat stored (exercise) or lost (recovery) by older males relative to young and middle-aged males. *Significant differences in ΔH_b compared with young males.

- Young (20-30 yrs)
- Middle-aged (40-45 yrs)
- Older (60-65 yrs)

Am J Physiol 305:R619-R629, 2013

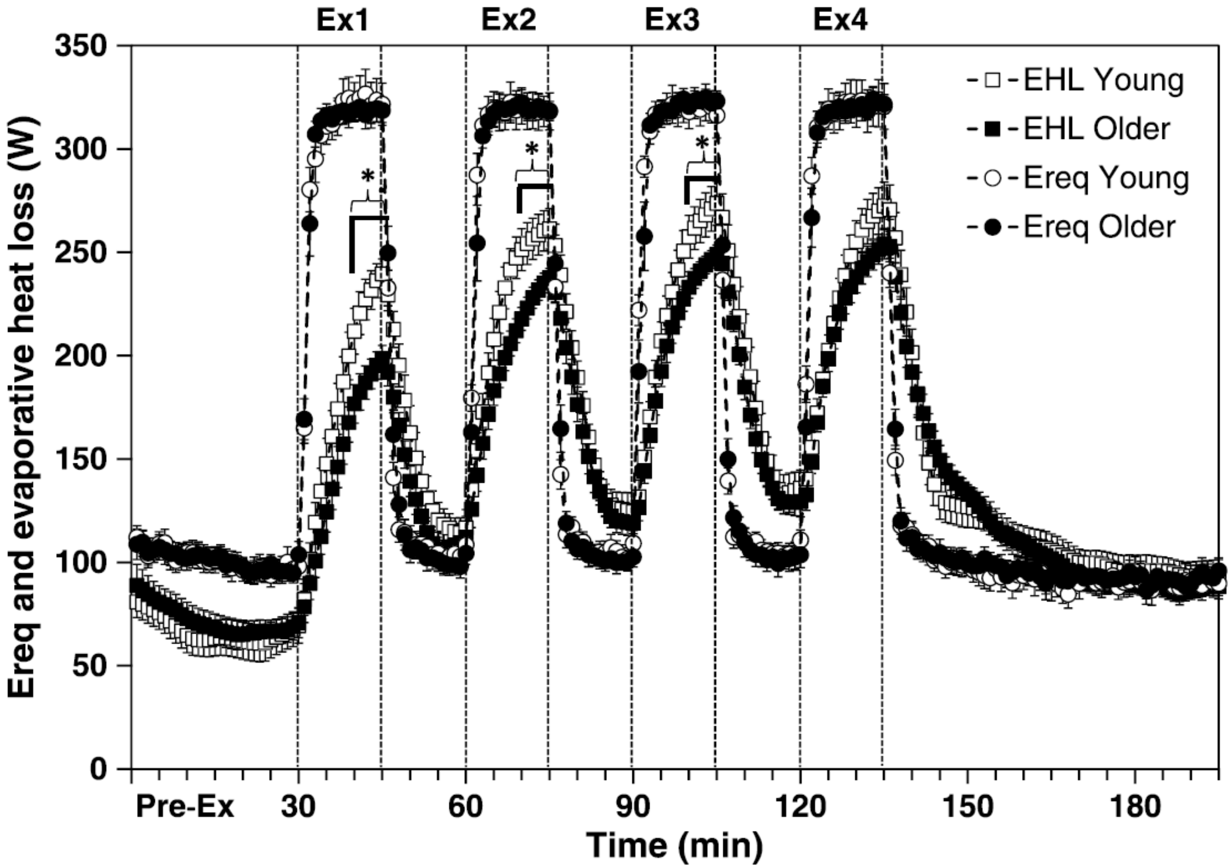


FIGURE 1—Values are presented as mean ± SE. Evaporation required (E_{req}) (circles) and EHL (squares) in young (white) and older (black) females during a 195-min intermittent exercise protocol at 35°C, 20% RH. EHL was analyzed at 5-min intervals during the exercise periods. *Significant difference between age groups at 10 and 15 min of exercise. Significance level was accepted at $P \leq 0.05$.

Med Sci Sports Exerc 45(12):2265-2276, 2013

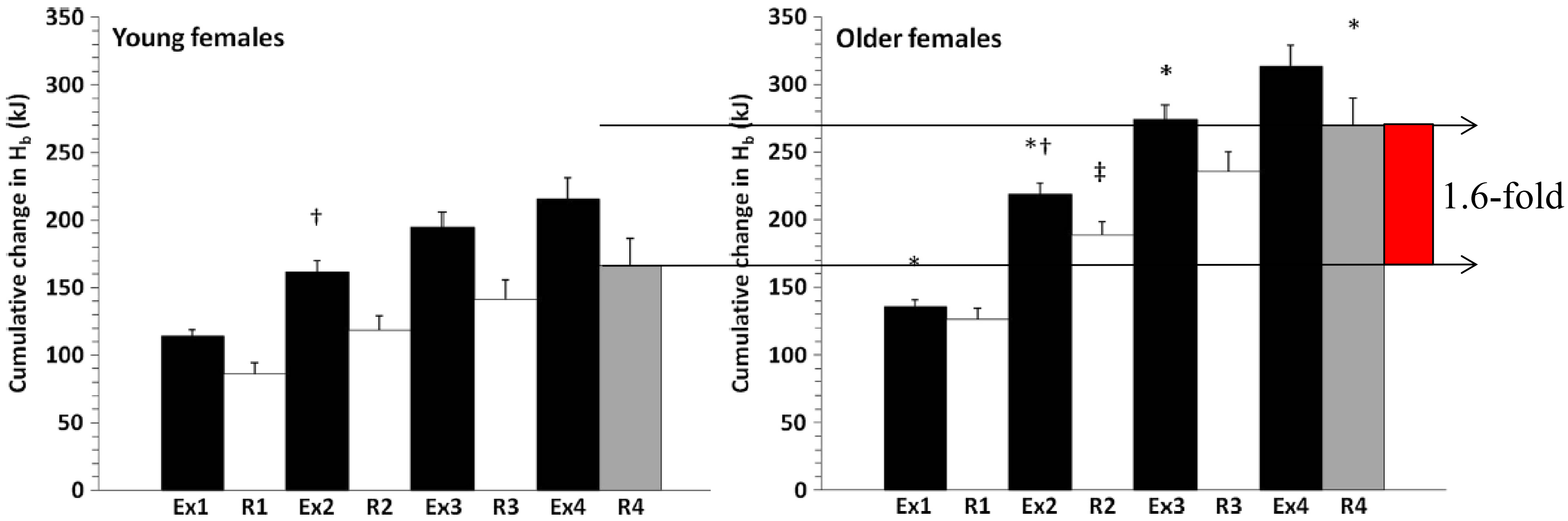


FIGURE 2—Values are presented as mean ± SE. Cumulative change in body heat content (H_b) in young (top panel) and older females (bottom panel) during the 15-min exercise for Ex1, Ex2, Ex3, and Ex4 and the 15-min recovery (R1, R2, R3, and R4) during a 2-h intermittent exercise protocol at 35°C, 20% RH. The last recovery period (R4; gray shaded bar) reflects the net residual change in body heat content at the 15-min mark of the final 60-min rest period. *Significantly different change in body heat content compared with young females. †Significantly different value compared with the previous exercise bout. ‡Significantly different value compared with the previous recovery bout. Significance level was accepted at $P \leq 0.05$.

Med Sci Sports Exerc 45(12):2265-2276, 2013

Age-Related Decrements in Heat Dissipation during Physical Activity Occur as Early as the Age of 40

Joanie Larose[1], Pierre Boulay[2], Ronald J. Sigal[3,4], Heather E. Wright[1], Glen P. Kenny[1]*

PLoS ONE 8(12): e83148. doi:10.1371/journal.pone.0083148

Table 1. Participant characteristics.

Group	n	Age, *years*	A_D, m^2	Weight, *kg*	BF, *%*	LBM, *kg*	VO_{2peak}, $mLO_2 \cdot kgLBM^{-1} \cdot min$
20–31	18	25.9±0.7	1.99 (1.67–2.31)	80.6 (59.8–95.5)	17.5 (8.6–30.9)	66.4 (46.9–80.9)	53.1 (41.2–64.7)
40–44	15	41.8±0.5*	2.10 (1.82–2.55)	90.1 (70.1–130.1)	22.8 (12.5–31.1)	68.8 (57.8–89.7)	53.1 (40.3–65.7)
45–49	15	47.1±0.3*§	2.10 (1.88–2.38)	89.3 (73.9–116.0)	24.9 (14.9–37.5)*	66.6 (53.2–78.6)	55.4 (38.3–68.9)
50–55	21	52.2±0.4*§‡	2.05 (1.73–2.29)	87.6 (65.5–101.9)	22.6 (6.9–35.4)	67.4 (52.3–84.8)	49.8 (39.4–62.0)
56–70	16	61.4±1.0*§‡†	2.02 (1.75–2.41)	86.9 (70.8–130.1)	27.0 (12.6–39.8)*	62.7 (52.6–74.7)	47.9 (34.1–57.8)

Values for age are mean ± SE. Values for all other variables are mean with minimum and maximum for each group. A_D = body surface area; BF = body fat; LBM = lean body mass; VO_{2peak} = peak oxygen uptake. * Significantly different than males 20–31 years. § Significantly different than males 40–44 years. ‡ Significantly different than males 45–49 years. † Significantly different than males 50–55 years.
doi:10.1371/journal.pone.0083148.t001

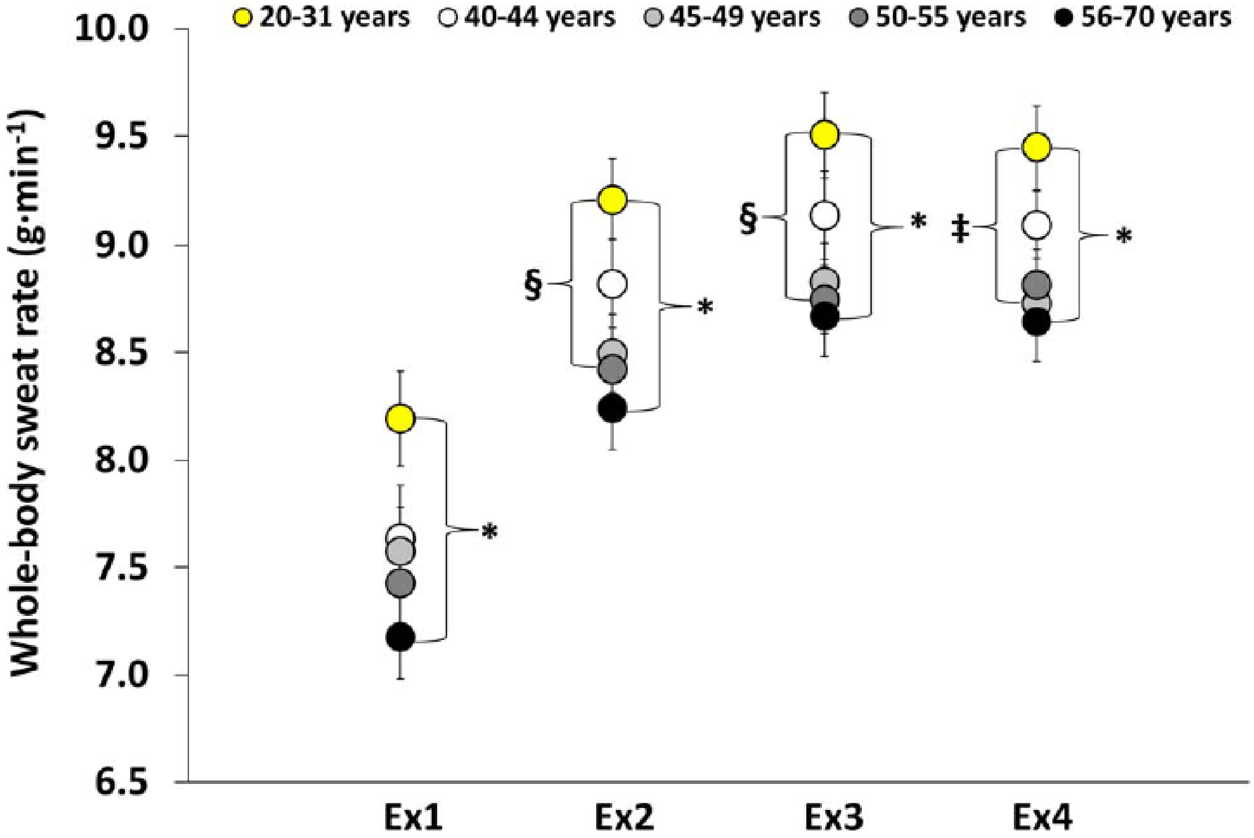


Figure 1. Whole-body sweat rate during repeated bouts of physical activity. Whole-body sweat rates at the end of each exercise bout performed in a direct calorimeter regulated to 35°C and 20% relative humidity. * Significant difference between males 56–70 and 20–31 years. § Significant difference between males 50–55 and 20–31 years. ‡ Significant difference between males 45–49 and 20–31 years. Values are presented as mean ± SE. Significance level accepted at $P \leq 0.05$. PLoS ONE 8(12): e83148. doi:10.1371/journal.pone.0083148

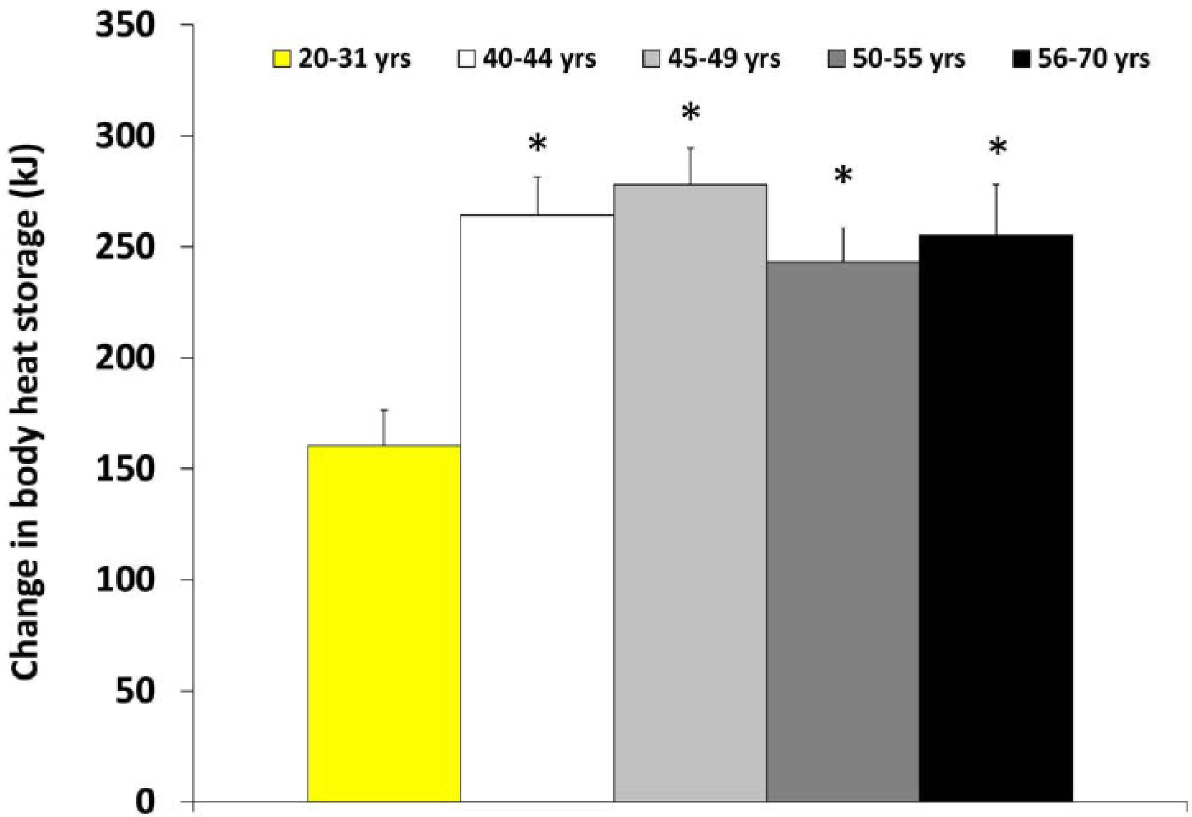
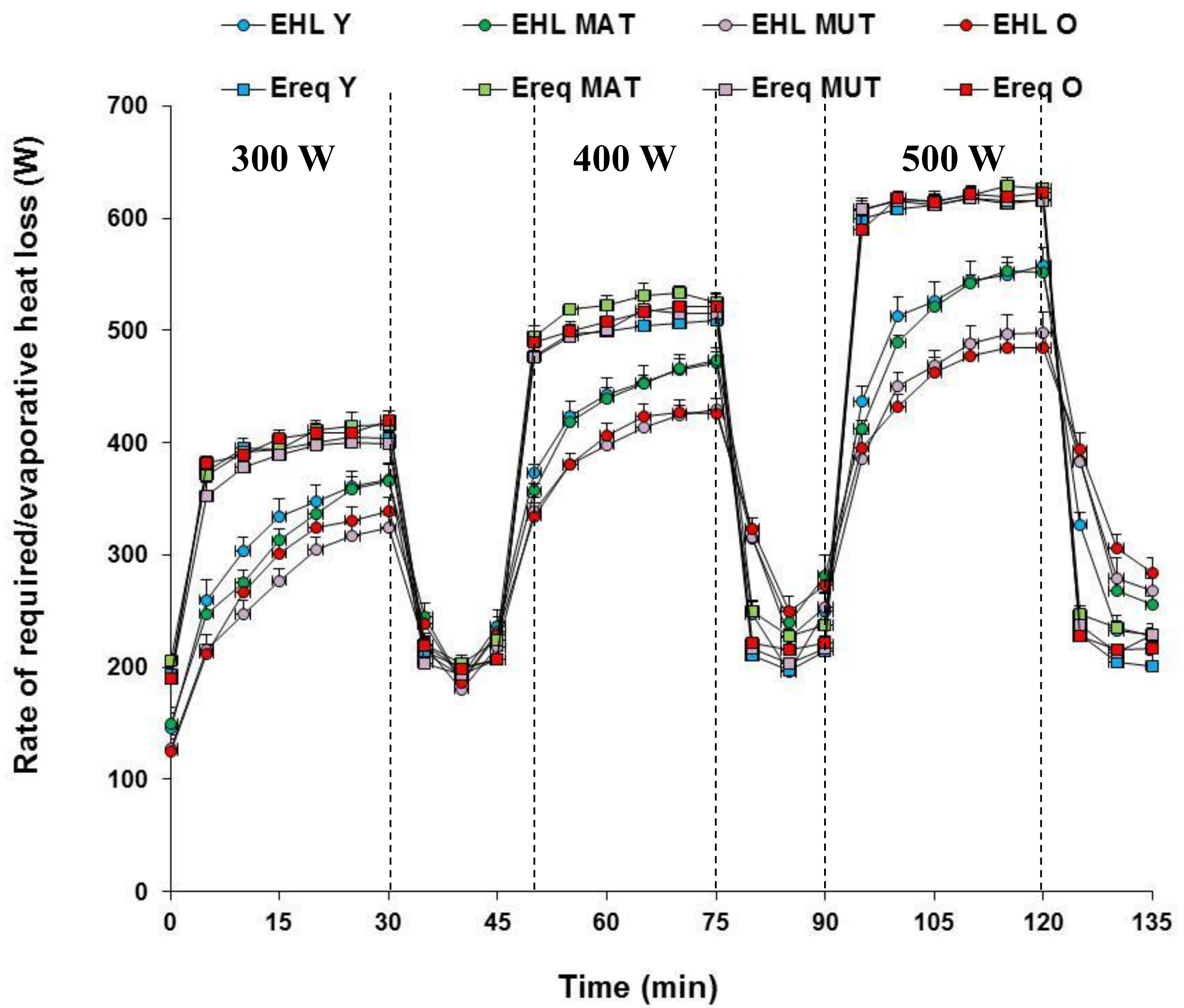


Figure 2. Cumulative change in body heat storage over two hours of physical activity/rest in the heat. Total amount of heat stored in the body after four 15-min bouts of cycling at an external workload of ~80 W separated by 15-min rest periods at an ambient air temperature of 35°C and 20% relative humidity. * Significantly different from age group 20–31 years. Values are presented as mean ± SE. Significance level accepted at $P \leq 0.05$.

To what extent does aging attenuate the body's maximal capacity to dissipate heat?

Group	N	Age (years)	Height (m)	Weight (kg)	BSA (m^2)	VO_2max ($mL \cdot kg \cdot min^{-1}$)
Young	10	21†‡§ ± 1	1.79 ± 0.06	79.4 ± 9.4	1.98 ± 0.12	50.0‡§ ± 3.7
MAT	10	49*§ ± 5	1.81 ± 0.05	81.6 ± 7.9	2.02 ± 0.11	50.9‡§ ± 6.8
MUT	9	48*§ ± 5	1.79 ± 0.08	82.1 ± 12.5	2.01 ± 0.19	37.5*† ± 3.6
Older	10	65*†‡ ± 3	1.76 ± 0.05	79.9 ± 7.0	1.96 ± 0.06	37.9*† ± 7.4

Note: Values ± mean SD.
BSA: body surface area; **MAT**: middle-aged trained; **MUT**: middle-aged untrained;
*, denotes significantly different from Young
†, denotes significantly different from MAT
‡, denotes significantly different from MUT
§, denotes significantly different from Older



Ex 1 (300 W)

Young – MUT = 11.8%

Young – Old = 7.8%

MAT – MUT = 11.5%

MAT – Old = 7.5%

Ex2 (400 W)

Young – MUT = 8.9%

Young – Old = 9.8%

MAT – MUT = 9.4%

MAT – Old = 10.2%

Ex3 (500 W)

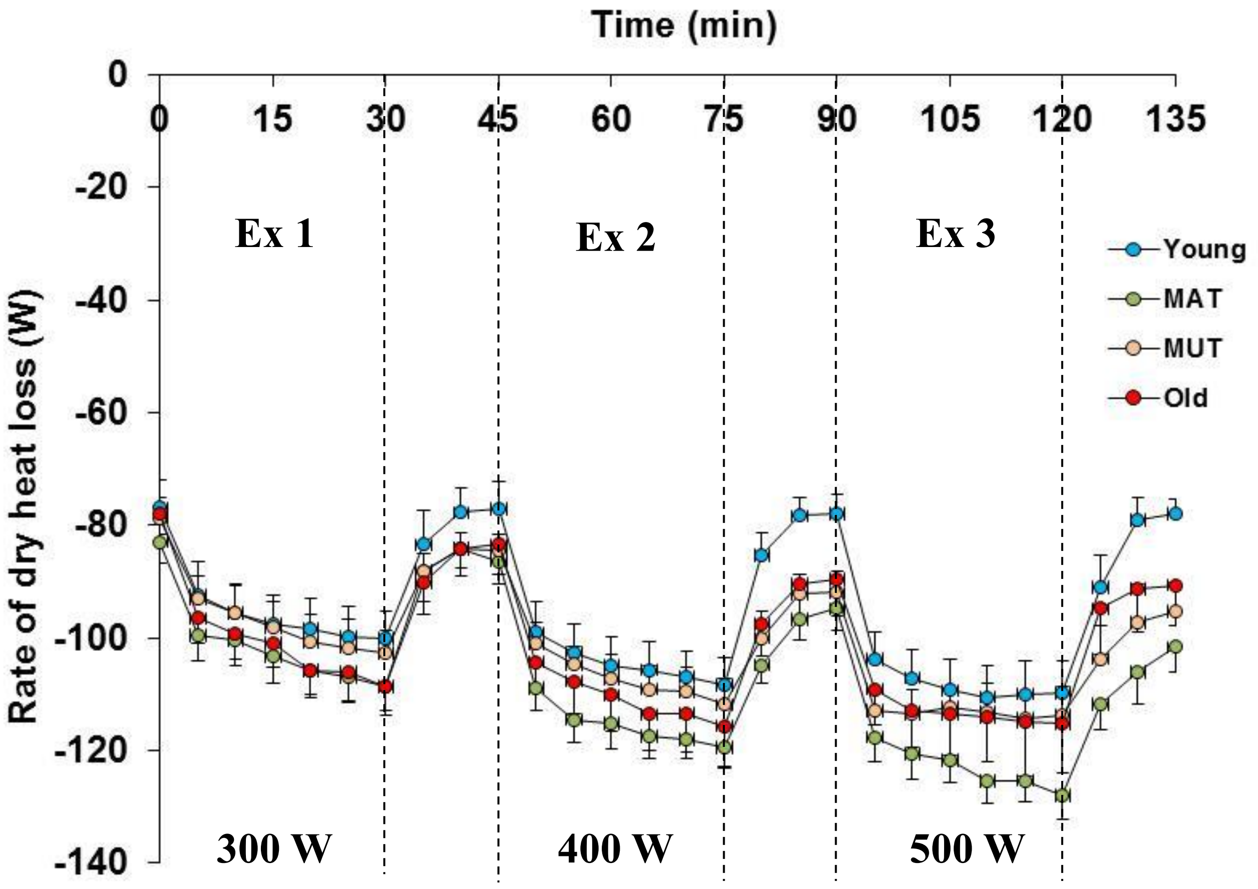
Young – MUT = 10.7%

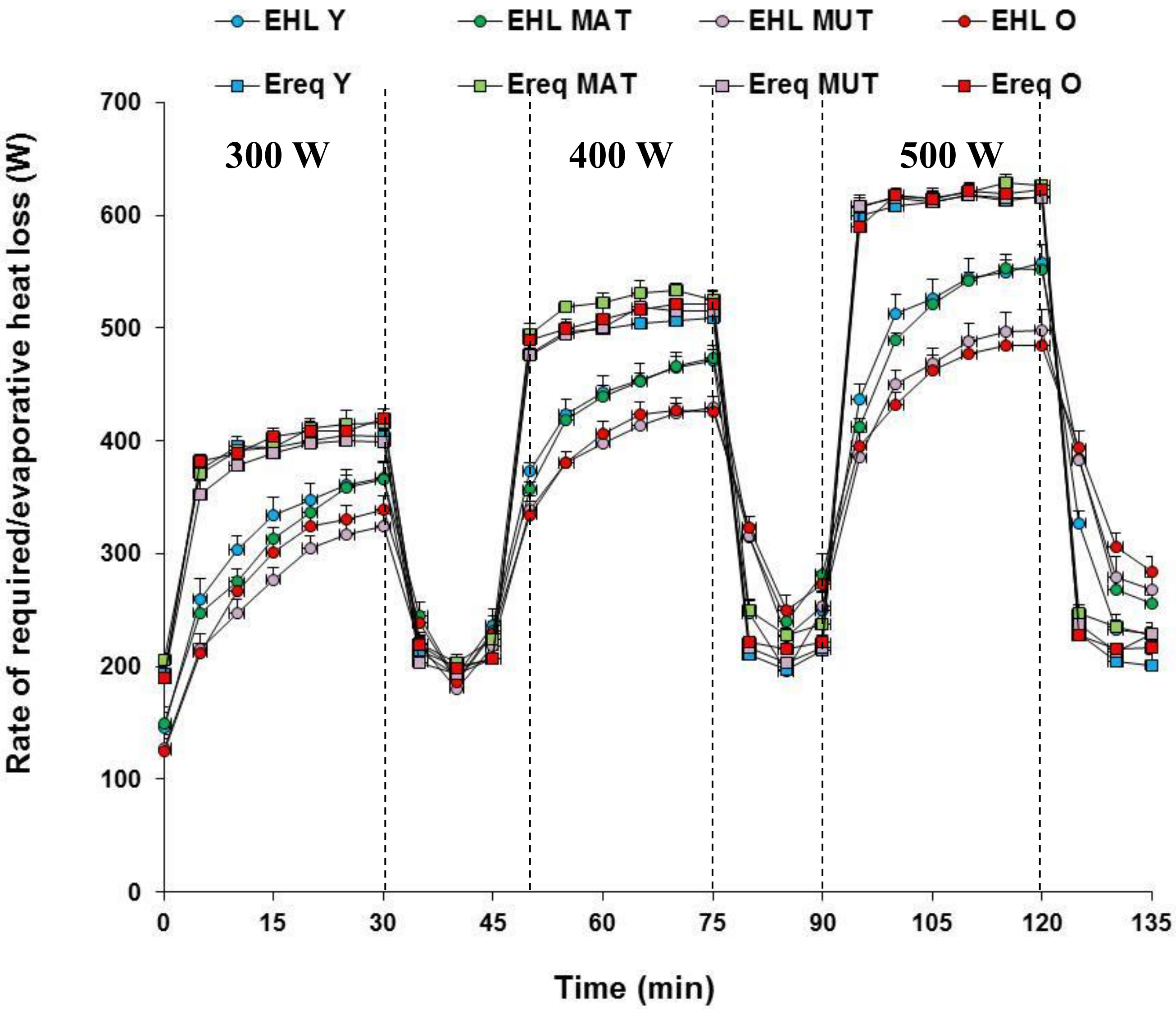
Young – Old = 13.2%

MAT – MUT = 9.7%

MAT – Old = 12.2%

When evaluating heat loss responses you must factor in both the metabolic and dry heat load





Ex 1 (300 W)

Young – MUT = 11.8%
Young – Old = 7.8%

MAT – MUT = 11.5%
MAT – Old = 7.5%

Ex2 (400 W)

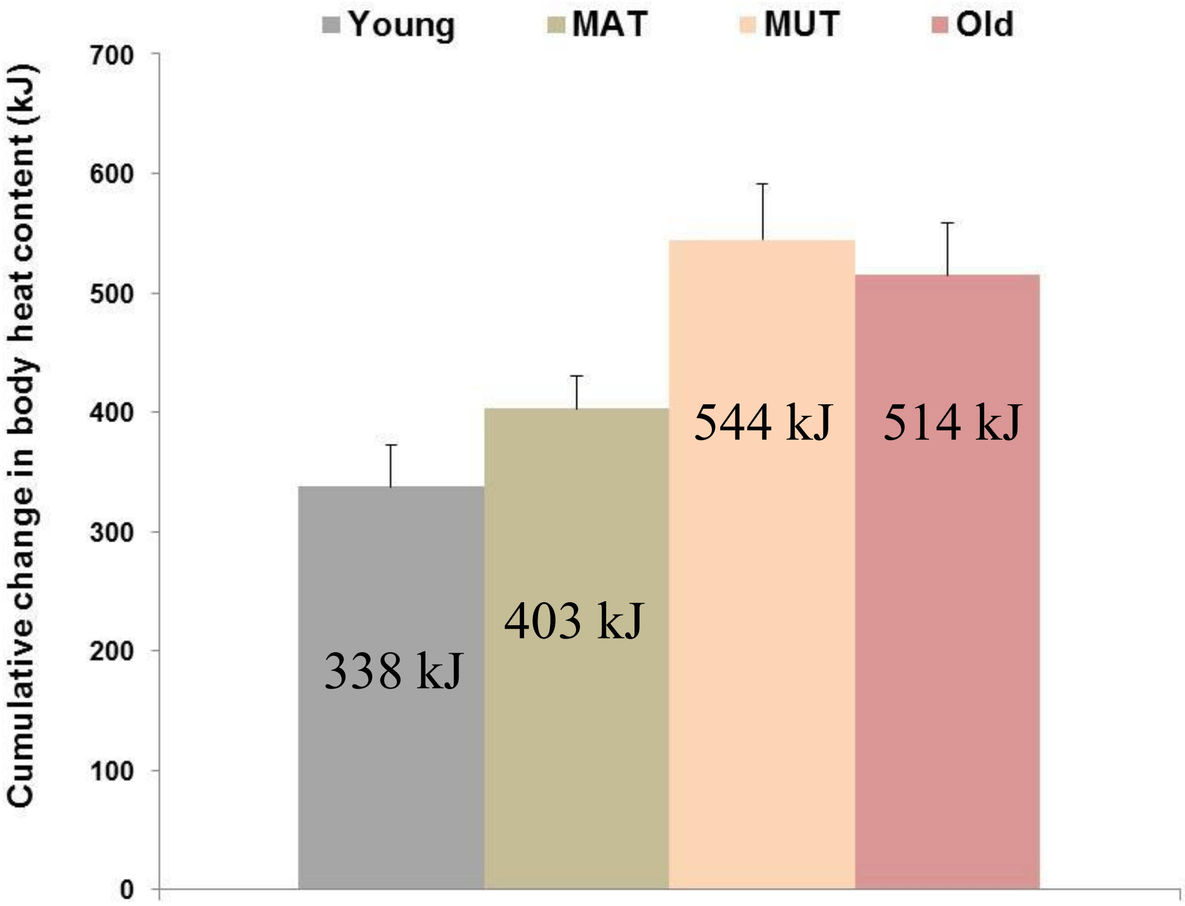
Young – MUT = 8.9%
Young – Old = 9.8%

MAT – MUT = 9.4%
MAT – Old = 10.2%

Ex3 (500 W)

Young – MUT = 10.7%
Young – Old = 13.2%

MAT – MUT = 9.7%
MAT – Old = 12.2%



Where do you rank?

Young – MAT = 19.3%
Young – MUT = 61.2%
Young – Old = 52.5%

MAT – MUT = 35.1%
MAT – Old = 27.8%

MUT – Old = 5.4%

Exercise training can improve cardiovascular health and fitness in older adults but can it improve the body's physiological capacity to dissipate heat?

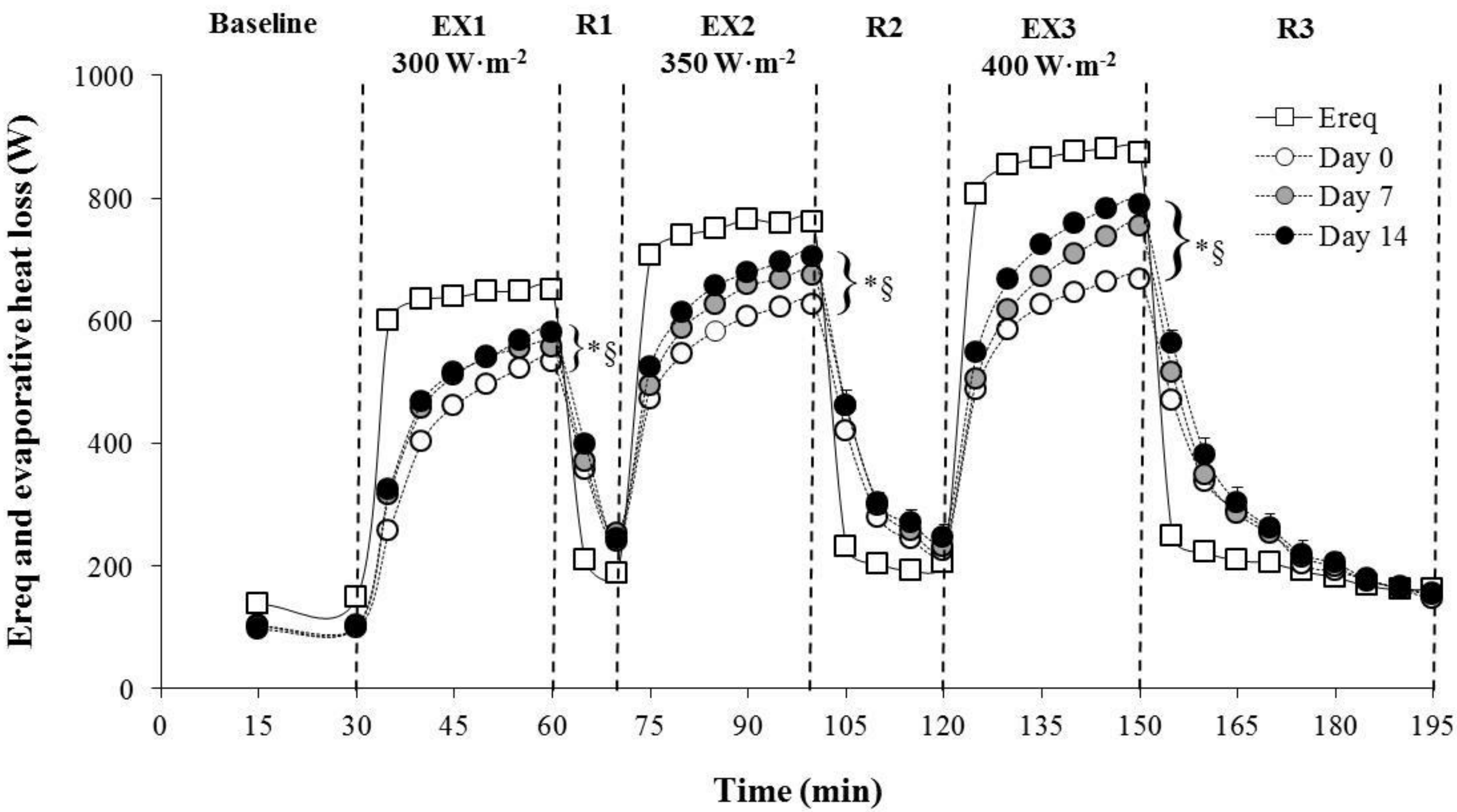


Figure 1. Mean (±SE) changes in evaporative heat loss relative to the required evaporation for heat balance (E_{req}) during exercise performed at rates of metabolic heat production equal to 300, 350, and 400 W·m^{-2} during the induction of heat acclimation. (*) Significantly different than day 0. (§) Significantly different than day 7. Both p≤0.05. Med Sci Sports Exerc, *under review*.

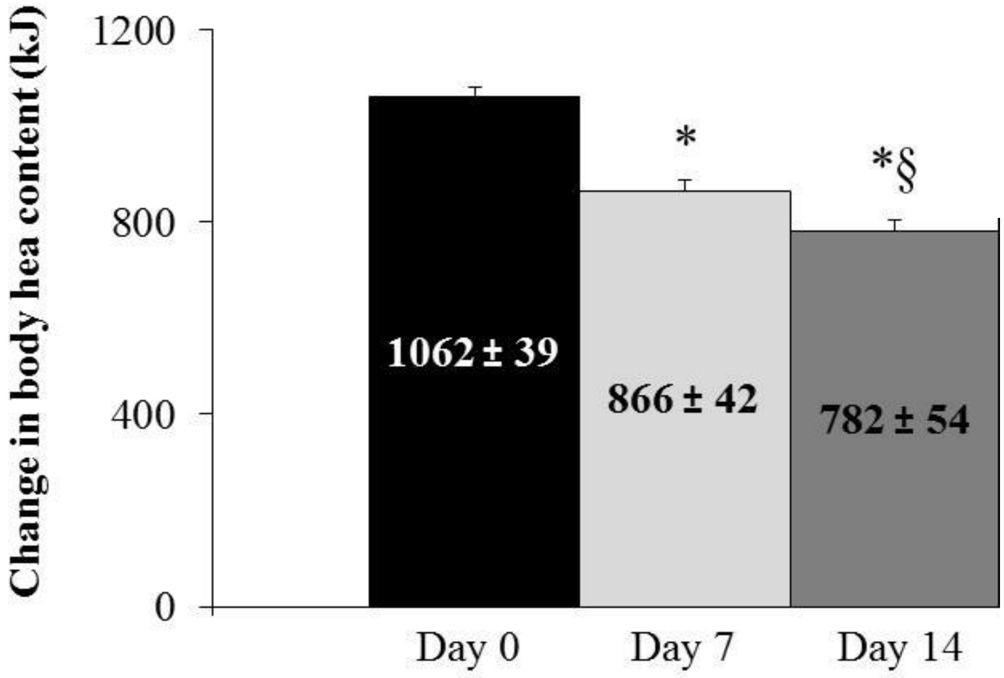


Figure 2. The cumulative change in body heat content measured across the three exercise periods. (*) Significantly different than day 0; (§) Significantly different than day 7. All p≤0.05. Values are mean ± standard error. Med Sci Sports Exerc, *under review*.

Do Older Firefighters Show Long-Term Adaptations to Work in the Heat?

Heather E. Wright,[1] Joanie Larose,[1] Tom M. McLellan,[2] Scott Miller,[3] Pierre Boulay,[4] and Glen P. Kenny[1]

Journal of Occupational and Environmental Hygiene, 10: 705–715

TABLE I. Participant Characteristics

Group	Age (years)	Height (cm)	Mass (kg)	BSA (m^2)	Body Fat (%)	VO_{2peak} ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	VO_{2peak} ($L{\cdot}min^{-1}$)
Non-FF	51.7 (1.5)	172.5 (1.9)^A	81.1 (2.8)	1.94 (0.04)	24.4 (2.3)	39.4 (2.2)	3.2 (0.1)
FF	49.8 (1.1)	178.5 (1.6)	84.9 (1.8)	2.03 (0.03)	19.3 (1.8)	40.7 (1.8)	3.4 (0.1)

Values are means (SE). Body surface area (BSA), maximal aerobic power (VO_{2peak}), Non-Firefighter (Non-FF), Firefighter (FF). ^{A}Significantly different than FF.

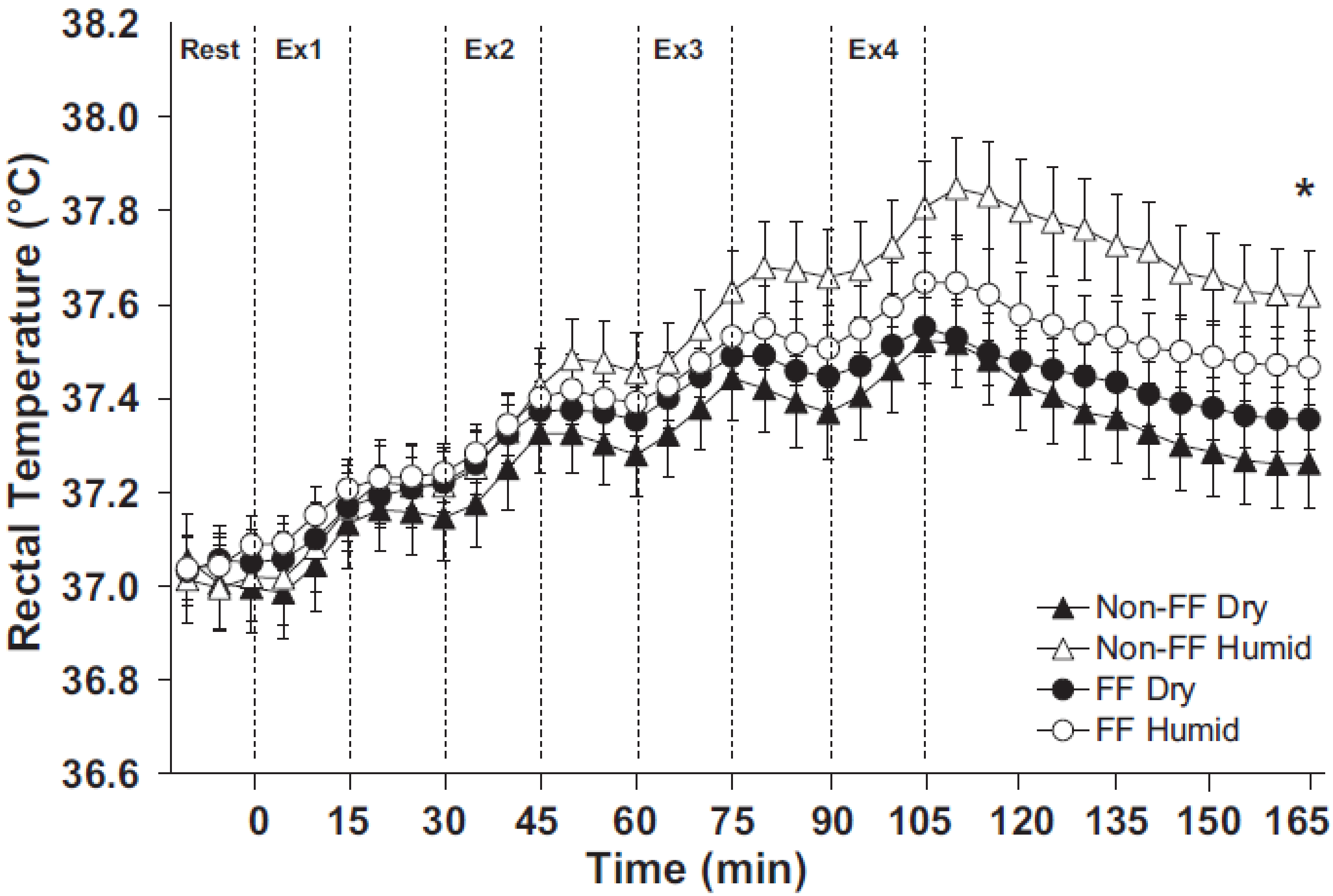


FIGURE 1. Rectal temperature responses during the intermittent exercise protocol under Warm/Dry (Dry) and Warm/Humid (Humid) conditions for the Non-firefighters (Non-FF) and Firefighters (FF). Dashed lines indicate the start and end of each exercise cycle. Values are mean ± SE. *Main effects of time and heat stress condition.

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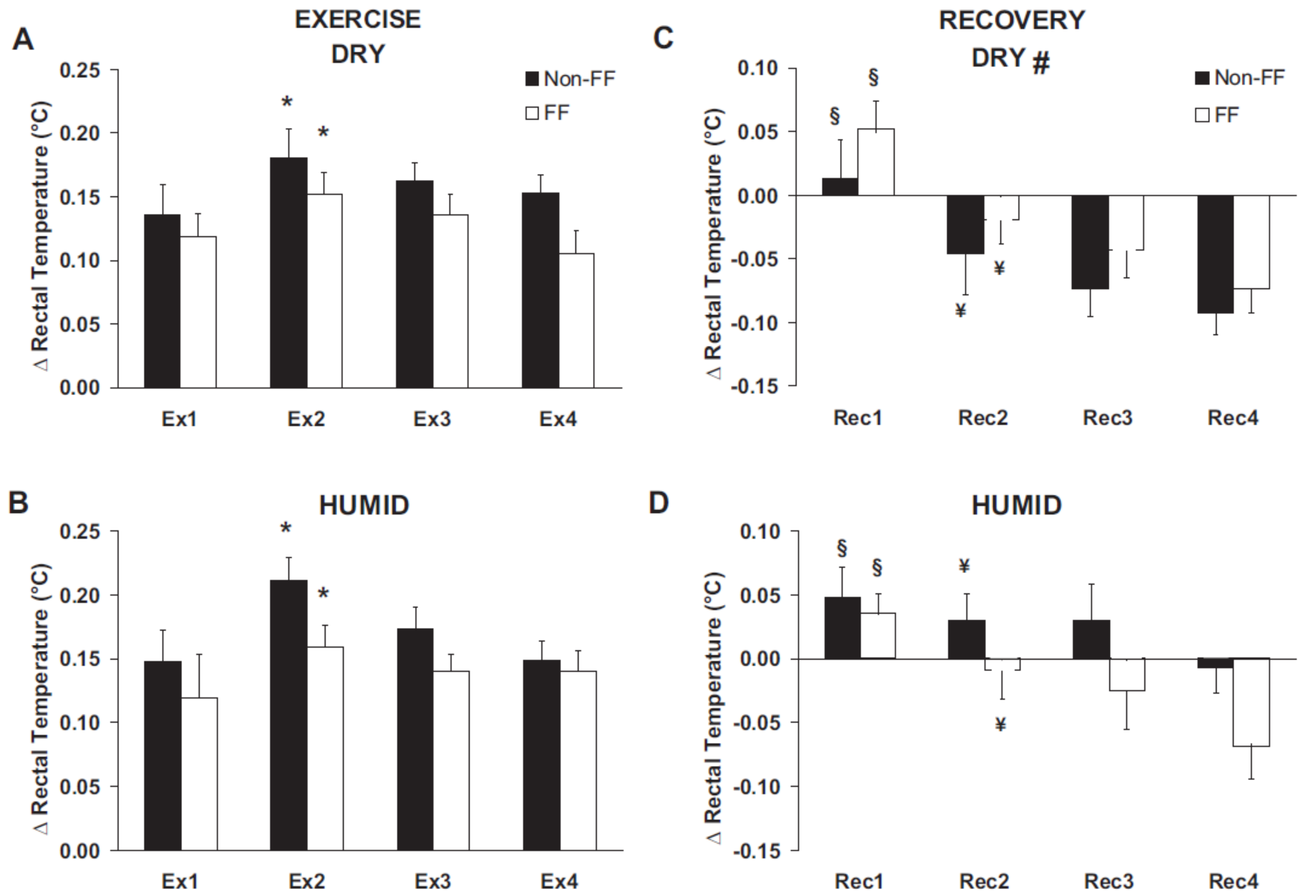

FIGURE 2. The change in rectal temperature during each exercise bout and recovery period during the intermittent exercise protocol under Warm/Dry (left upper panel, A, and right upper panel, C, respectively) and Warm/Humid (left lower panel, B, and right lower panel, D, respectively) conditions for the Non-Firefighters (Non-FF) and Firefighters (FF). Values are mean ± SE. *Significantly greater than ΔEx1, # Main effect of heat stress condition, § Significantly different than ΔRec2-4, and ¥ Significantly different than ΔRec4.

Journal of Occupational and Environmental Hygiene, 10: 705–715

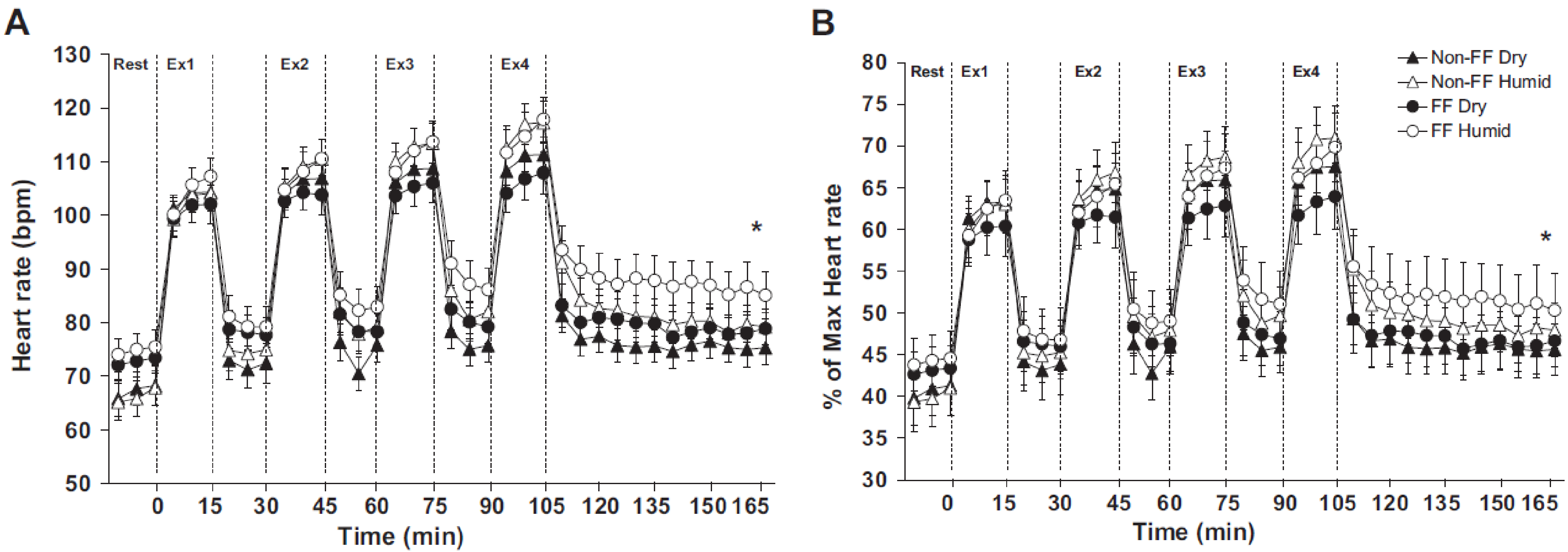

FIGURE 3. Heart rate (upper panel, A) and percent of maximum heart rate responses (lower panel, B) during the intermittent exercise protocol under Warm/Dry (Dry) and Warm/Humid (Humid) conditions for the Non-firefighters (Non-FF) and Firefighters (FF). Dashed lines indicate the start and end of each exercise cycle. Values are mean ± SE. *Main effects of time and heat stress condition.

Journal of Occupational and Environmental Hygiene, 10: 705–715

TABLE III. Hydration Indices

				Urine Specific Gravity		[PP] ($g \cdot 100\ mL^{-1}$)		OSMO ($mOsm \cdot kg^{-1}$)	
Group	Condition	Mass Δ (kg)	% Mass Δ	PRE	POST	PRE	POST	PRE	POST
Non-FF	Dry	−1.19 (0.04)	1.49 (0.08)	1.019 (0.002)	1.023 (0.002)^{A}	7.6 (0.1)^{C}	8.1 (0.1)^{ABC}	291 (1)	295 (1)^{AB}
	Humid	−1.30 (0.06)	1.62 (0.11)	1.018 (0.002)	1.022 (0.002)^{A}	7.6 (0.1)^{C}	8.2 (0.1)^{AC}	289 (2)	296 (2)^{A}
FF	Dry	−1.39 (0.05)	1.62 (0.06)	1.015 (0.003)^{1}	1.020 (0.002)^{1A}	8.0 (0.1)	8.4 (0.1)^{AB}	292 (2)	295 (1)^{AB}
	Humid	−1.38 (0.14)	1.59 (0.15)	1.016 (0.002)	1.021 (0.002)^{A}	8.0 (0.1)	8.5 (0.1)^{A}	289 (2)	293 (2)^{A}

Values are means (SE). Non-Firefighters (Non-FF) and Firefighters (FF). Change (Δ), plasma protein concentration ([PP]), serum osmolality (OSMO). $^{1}n = 11$, ^{A}Main effect of time, ^{B}PRE-POST change significantly different than Warm/Humid, ^{C}Significantly different than FF.

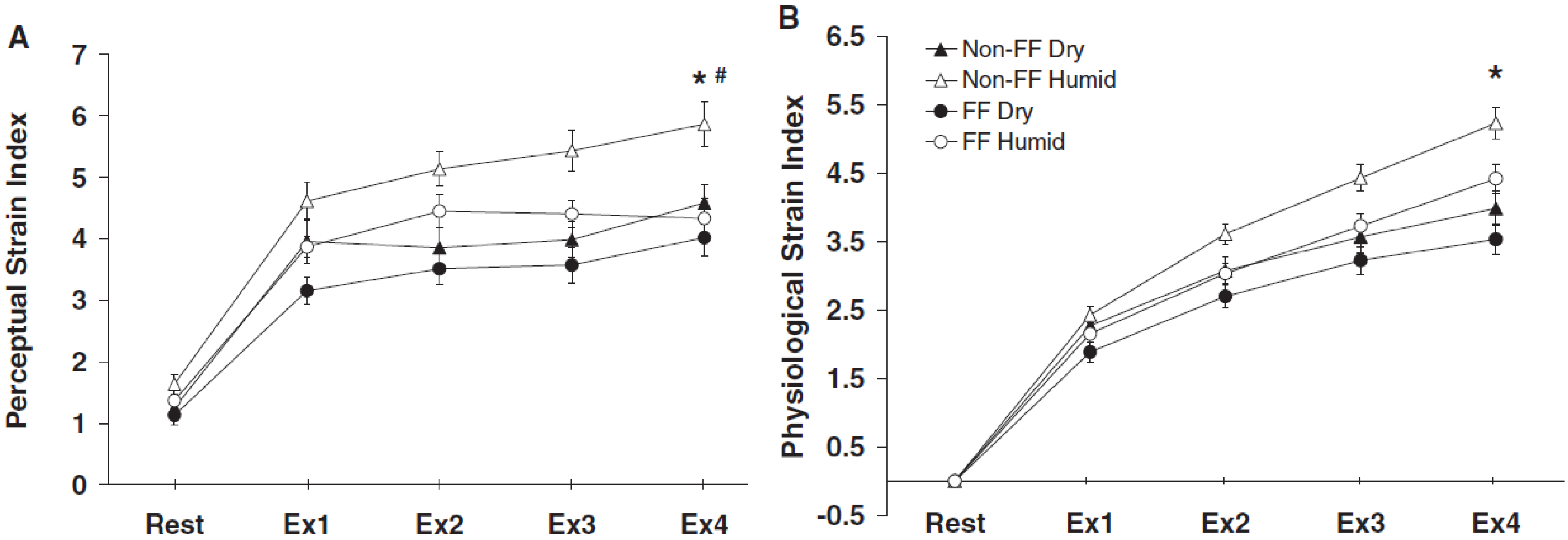

FIGURE 4. Perceptual Strain Index (PeSI; upper panel, A) and Physiological Strain Index (PhSI; lower panel, B) during intermittent exercise under Warm/Dry (Dry) and Warm/Humid (Humid) conditions for the Non-firefighters (Non-FF) and Firefighters (FF). Values are mean ± SE. *Main effects of time and heat stress condition and # Main effect of group.

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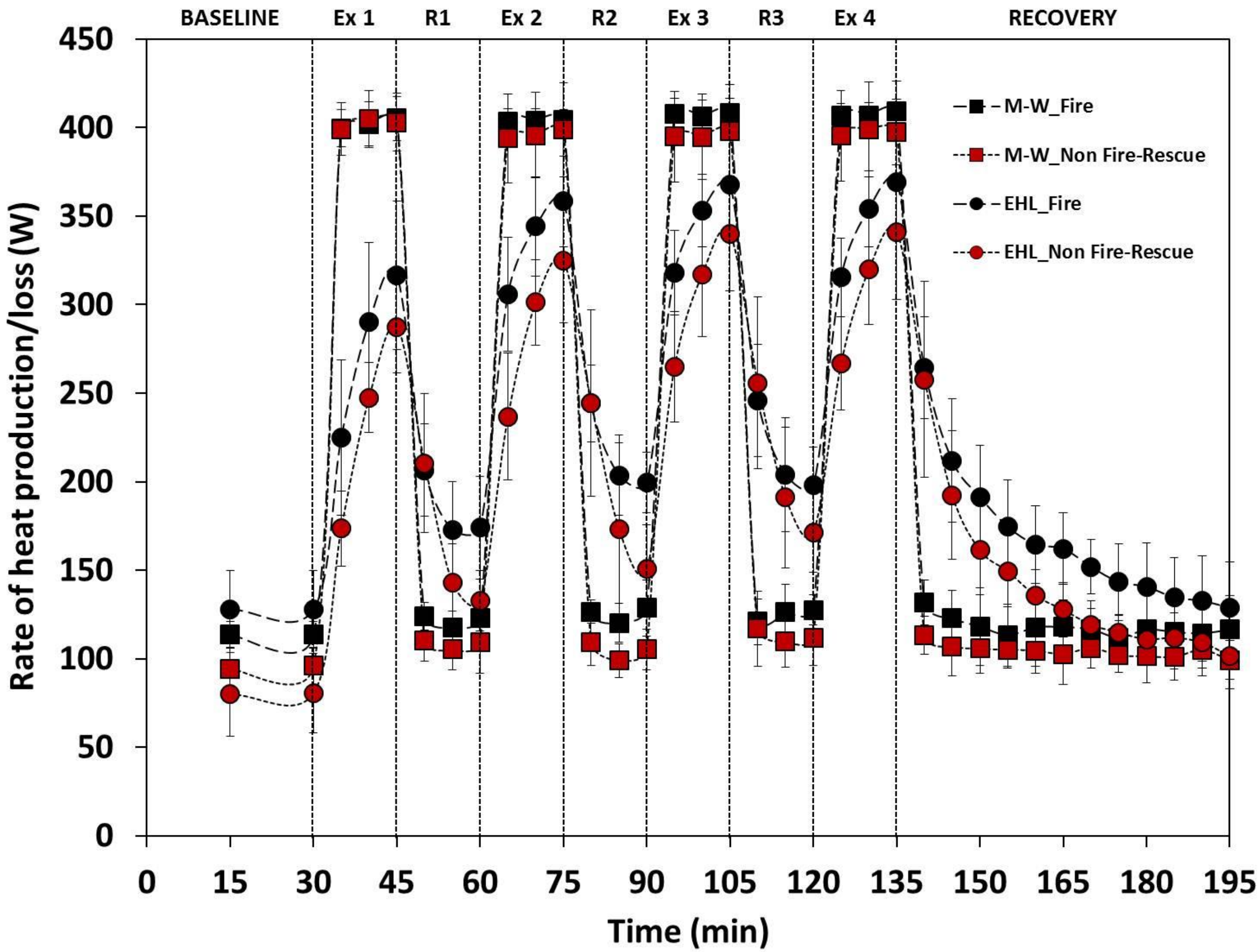
Aging and heat adaptation



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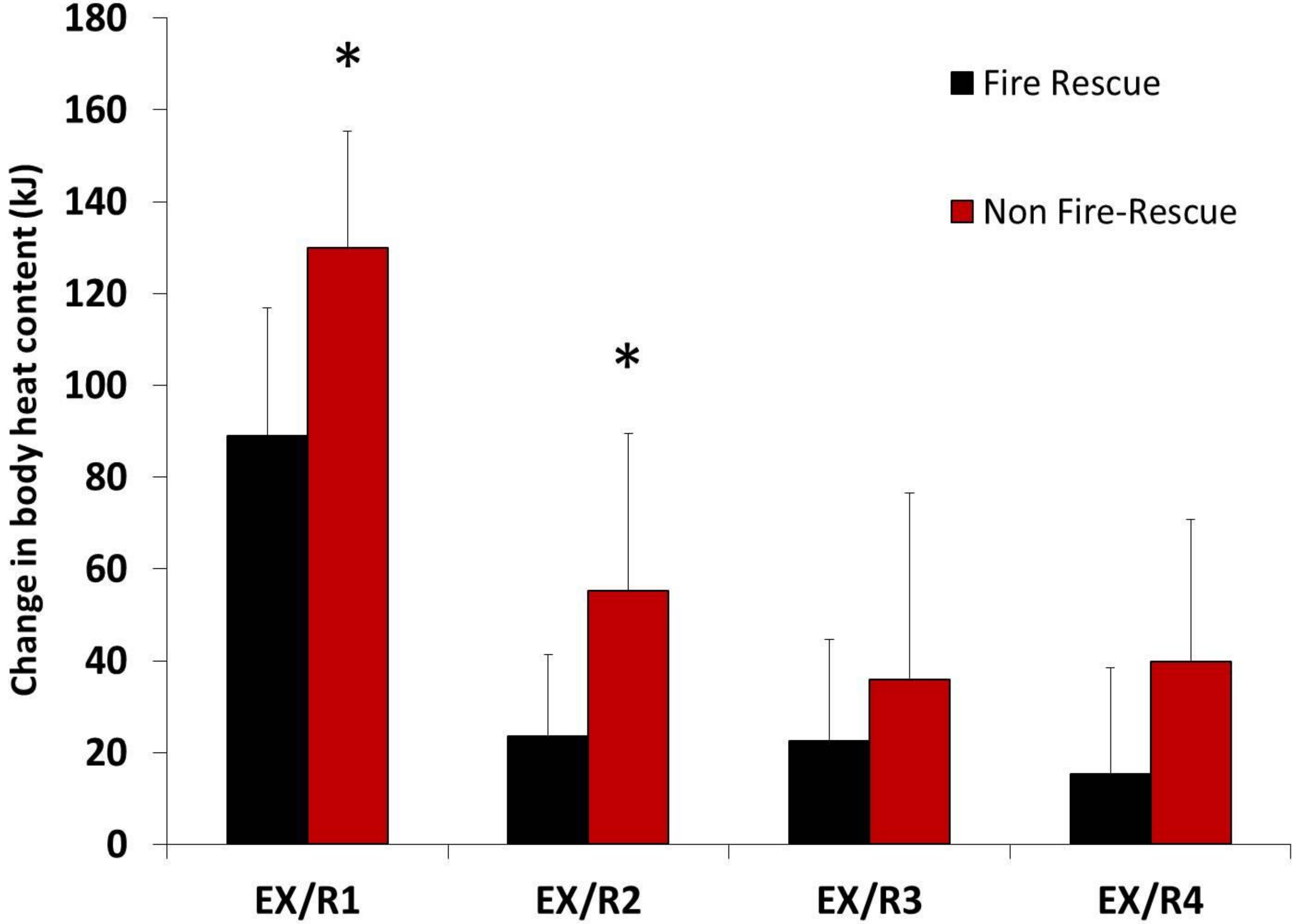
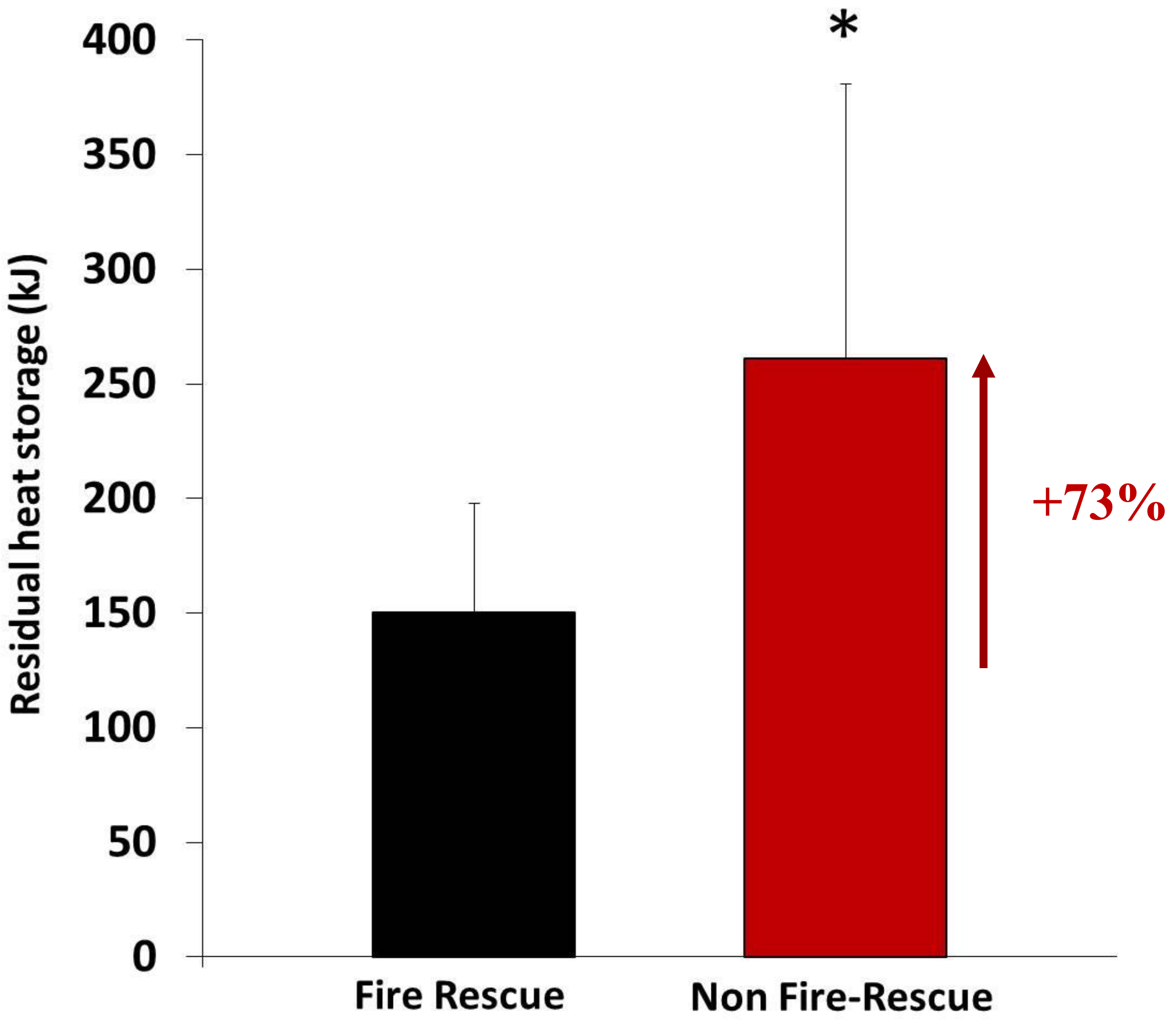


180
160
140
120
100
80
60
40
20
0
Change in body heat content (kJ)
*
*
Fire Rescue
Non Fire-Rescue
EX/R1
EX/R2
EX/R3
EX/R4


*
+73%
Residual heat storage (kJ)
400
350
300
250
200
150
100
50
0
Fire Rescue
Non Fire-Rescue

Take home messages

- Age matters: both middle-aged and older workers are under-protected using current heat exposure guidelines.

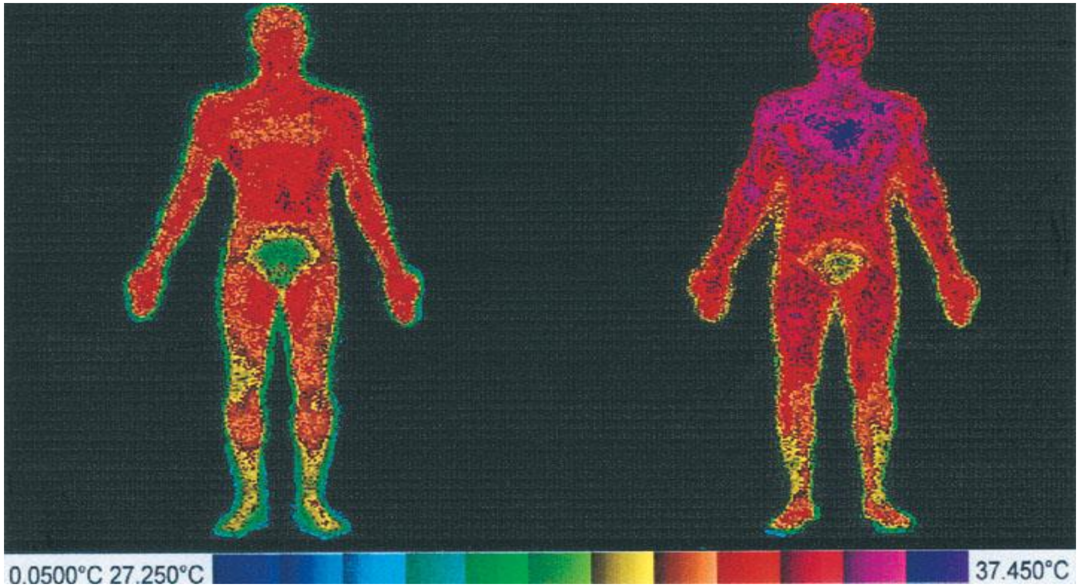
- Older workers who work in the heat are more heat-resilient. However, it is a two edge sword: they can tolerate greater levels of thermal strain and longer exposure times but the risk of a heat injury may rise.

- Keep your workers exposed to challenging work conditions on a regular basis – this helps maintain fitness and improves their physiological capacity to dissipate heat.

- Cooling strategies can be used to compensate for age-related reductions in the rate of heat dissipation (e.g., spot cooling, improved clothing designs, cooling vests, etc.).

- Monitor all workers and understand a workers end-point: young workers may sweat more but dehydrate more quickly. Older workers will sweat less but will store more heat. Depending on their level of fitness, older workers will fatigue more quickly.

Thank you for your attention!



Need more information? Don’t hesitate to contact me at:

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