Assessment of Wet Bulb Globe Temperature (WBGT) heat stress limits for application in the air domain

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Agenda

- Background – ***Why we did the work***
  - ‘Heat Stress’ - The problem
  - Military context & control measures (Joint Service Publication, JSP 375)
  - Military air domain context & need for work
- Aims
- Method – ***What and how we did the work***
  - Laboratory trial with participant volunteers
  - Supplementary modelling predictions
- Results – ***What we found***
- Discussion & Conclusions – ***What are the potential implications / military benefit?***

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Acknowledgements

- **UK MoD / Dstl**
  - Funded this work as part of the Aircrew Systems Research programme
- **Institute of Naval Medicine (INM) / Dr Simon Delves**
  - Stakeholder support and provision of information underpinning the WBGT limits in JSP 375
- **Military stakeholder group (e.g. RAF CAM)**
  - Participated in initial workshops to substantiate the need and agree potential exploitation

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Heat Stress

Impaired performance

Heat illness

Heat stress

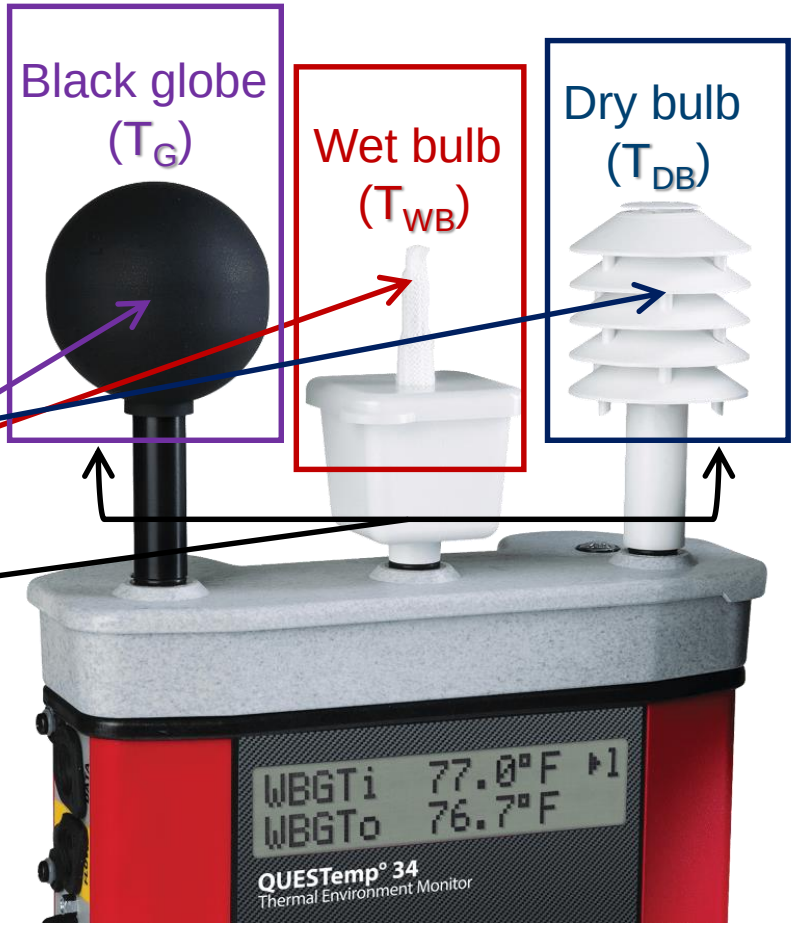
WBGT Limits to protect against an excessive rise in core temperature in all individuals!

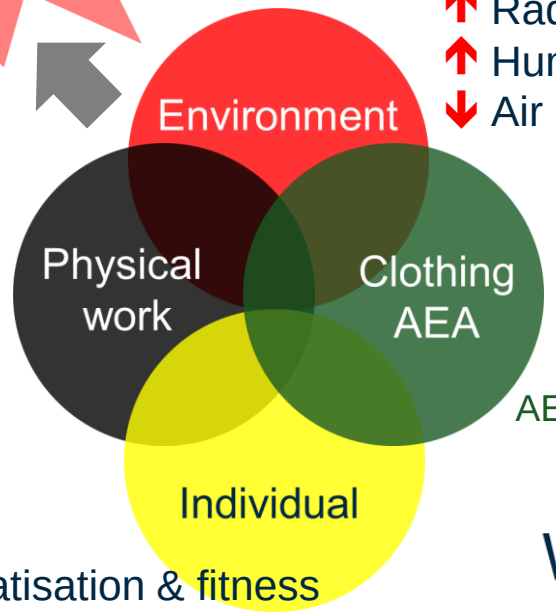
39.2 ºC

Mean = 38 ºC

Wet Bulb Globe Temperature (WBGT)

- ↑ Air temperature
- ↑ Radiant temperature
- ↑ Humidity
- ↓ Air speed





- ↑ Metabolic rate (Watts)
- ↑ Duration

- ↑ Thermal resistance
- ↑ Evaporative resistance

AEA, Aircrew equipment Assembly

Lack of acclimatisation & fitness
Dehydration, health factors, …..

$$WBGT\ (ºC) = (0.2 \times T_G) + (0.7 \times T_{WB}) + (0.1 \times T_{DB})$$

Corrected for 

JSP 375 Chapter 41 – Prevention of Heat Illness (Oct'20)

- WBGT limits part of the heat stress risk assessment
- Limits are for all military services & domains
- **BUT** are they valid and can they be applied to protect aircrew?

8 x Tables – 4 Clothing cats. x 2 Acclimatisation states

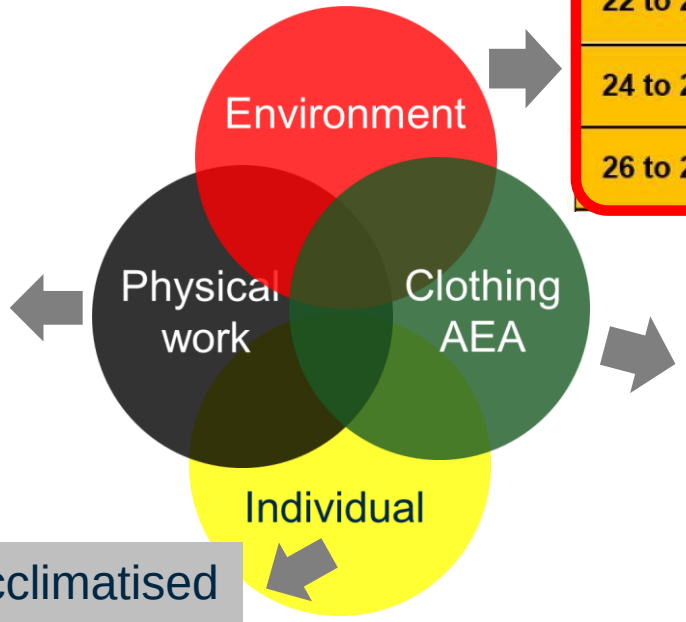
MTP + BA

WBGT (°C)	Maximum Exercise Duration (Minutes)			
	Easy Work	Moderate Work	Hard Work	Very Hard Work
20 to 21.9	240	110 OR 20 work 40 rest	80 OR 20 work 40 rest	60 OR 10 work 50 rest
22 to 23.9	195			
24 to 25.9	180 OR 40 work 20 rest	95 OR 20 work 40	70 OR 10 work	50 OR 10 work 50 rest
26 to 27.9	150 OR 40 work 20 rest	85 OR 20 40 rest	50 rest	45 OR 10 work 50 rest

Safe working time limits as a function of WBGT

Based on modelling

Work categories:
- Easy
- Moderate
- Hard
- Very hard



- ± Heat acclimatised
- Assumes hydrated

Clothing categories:
- Physical Training (PT) kit
- MTP clothing / SSE
- MTP + Body armour (BA)
- CBRN PPE

Based on Land Forces

MTP, Multi Terrain Pattern
SSE, Single Service Equivalent
CBRN, Chemical Biological Radiological or Nuclear
PPE, Personal Protective Equipment

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Can JSP 375 WBGT Limits be applied to the Air Domain?

Physical work

Work categories:

[Metabolic rate – Watts, W]

- Easy [< 250]

Basic operation of an aircraft

- Moderate [250–425]

Moderate operation of aircraft

- Hard [425–600]

Demanding operation of an aircraft (e.g. high G)

■ Data from or derived from Delves [01.02.148; 03 Mar'21]

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Clothing AEA

Based on Land Forces

Clothing categories

[Evap. resistance – $m^2 \cdot Pa \cdot W^{-1}$]:

- PT kit
- MTP clothing
- MTP + BA [~20]
- CBRN PPE [~80]

Environment

Inside or outside the aircraft?

[~80-100 $m^2 \cdot Pa \cdot W^{-1}$]

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[~40 $m^2 \cdot Pa \cdot W^{-1}$]

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Military need, aim and approach

Military need

- JSP 375 provides official MoD heat stress prevention guidance that is relevant to aircrew, but;
  - Are they valid for all aircrew / platforms and can they be easily applied in air operations?

Aim and approach

- To assess JSP 375 WBGT limits through:
  - Laboratory simulations with volunteers, incorporating representative RW AEA, physical work loads and duration
  - Heat strain modelling, to extend the scope of the work regarding AEA (to include Winter-Sea) and flight duration

Platform relevance

Most relevant to aircrew operating in aircraft without air conditioning (i.e. RW and some FW platforms such as the Prefect)

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Methods

Individual

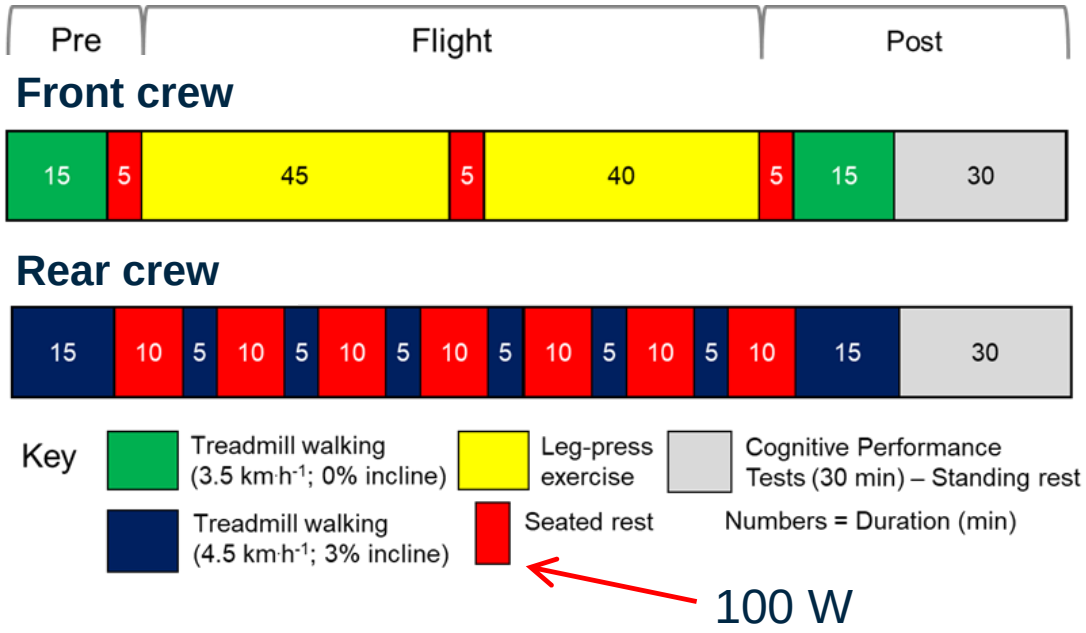
	Age (y)	Height (m)	Weight (kg)
Mean	28.1	1.81	83.5
1SD	7.6	0.07	12.6

- **Participants**: 10 civilian men:
- **Test conditions**: x 4
- **Physical activity profiles**

Physical work

  - 160 min ‘Trooping’ scenario
  - Target average metabolic rate 250 W (i.e. ‘Easy’) for Front and Rear simulations

	4 x Test conditions			
Role	Front crew		Rear crew	
WBGT	26	20	26	20
ID	Front 26	Front 20	Rear 26	Rear 20



A Leg-pressing

B Treadmill walking

C Cognitive tasks

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Methods (2)

Environment

- **Environments**:

Parameter	26 ºC	20 ºC
Air / dry bulb temperature (ºC)	33	22
Relative humidity (%)	40	76
Wet bulb temperature (ºC)	23	19
Globe temperature (ºC)	33	22
Air speed ($m \cdot s^{-1}$)	1	1

WBGTs

- **Clothing (RW Summer Ops AEA)**:
  - Rollneck vest and longjohns, and socks
  - One-piece coverall, leather Mk3 gloves & Mk1 boots
  - Body Armour Load Carriage System (BALCS) with hard / soft BA, and Mk4A4 helmet

Clothing AEA

BALCS

- **Outcome measures**:
  - Physiological – Gastro-intestinal (Core) & skin temperatures, heart rate, sweat rate, water balance & metabolic rate
  - Subjective – Ratings of thermal sensation and comfort, & perceived exertion (RPE)
  - Cognitive performance – Tasks to assess working memory, vigilance, psycho-motor skill & cognitive/motor processing

Ratings

Expired air

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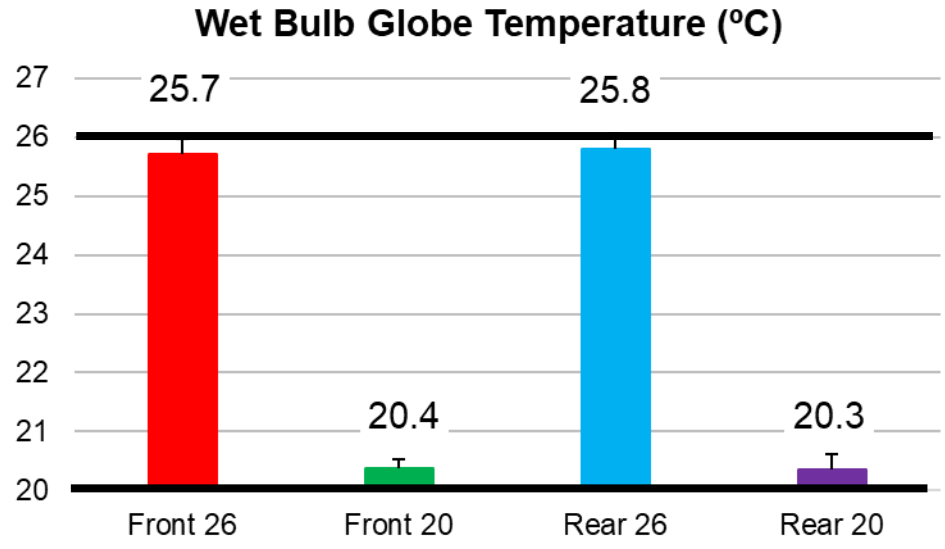
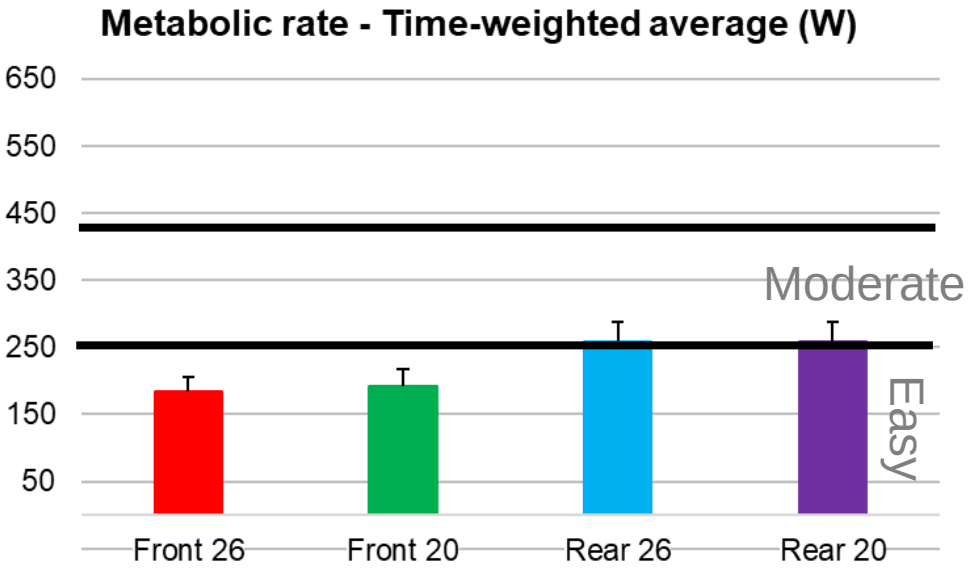
Results

- **Completion**: All 4 x 160 min Tests completed
- **Thermal environments**: Achieved
- **Metabolic demand of simulations**
  - Time-weighted average (TWA) greater in Rear vs Front, but both within the ‘Easy’ category
- **Sweat rates & water balance**
  - Average sweat rate 0.3 and 0.5 $kg \cdot h^{-1}$ in Front 26 and Rear 26, respectively
    - Well below occupational limit of 1 $kg \cdot h^{-1}$
  - Negligible dehydration in Rear 26 only
- **Mean skin temperature & heat sensation**
  - Environmental effects only
- **Cognitive performance**
  - No Environment or Role effects





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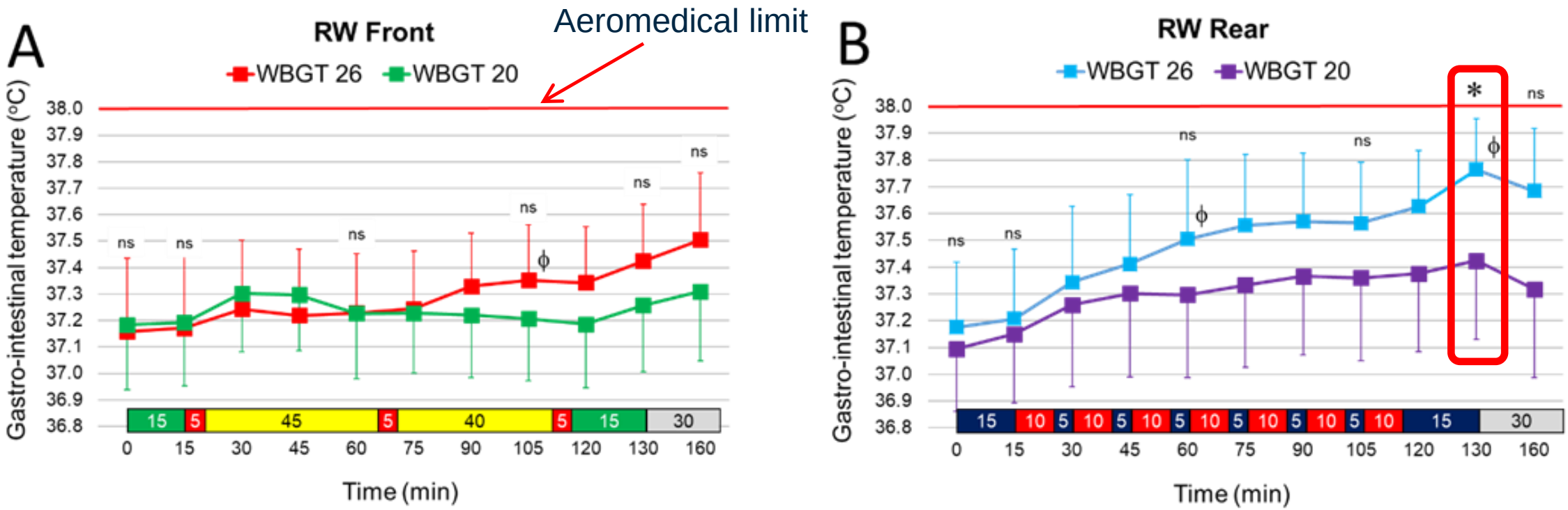
Results: Core (Gastro-intestinal) temperature



- **Risk**: Mean GI temperature well below the 38 ºC limit
  - In each WBGT 26 ºC condition, only 1 x participant reached 38 ºC
- **Environment effect**: Only in the Rear crew simulation was a higher GI temperature identified
- **Role effect**: At a WBGT of 26 ºC, GI temperature was higher in Rear vs Front (60 & 130 min)

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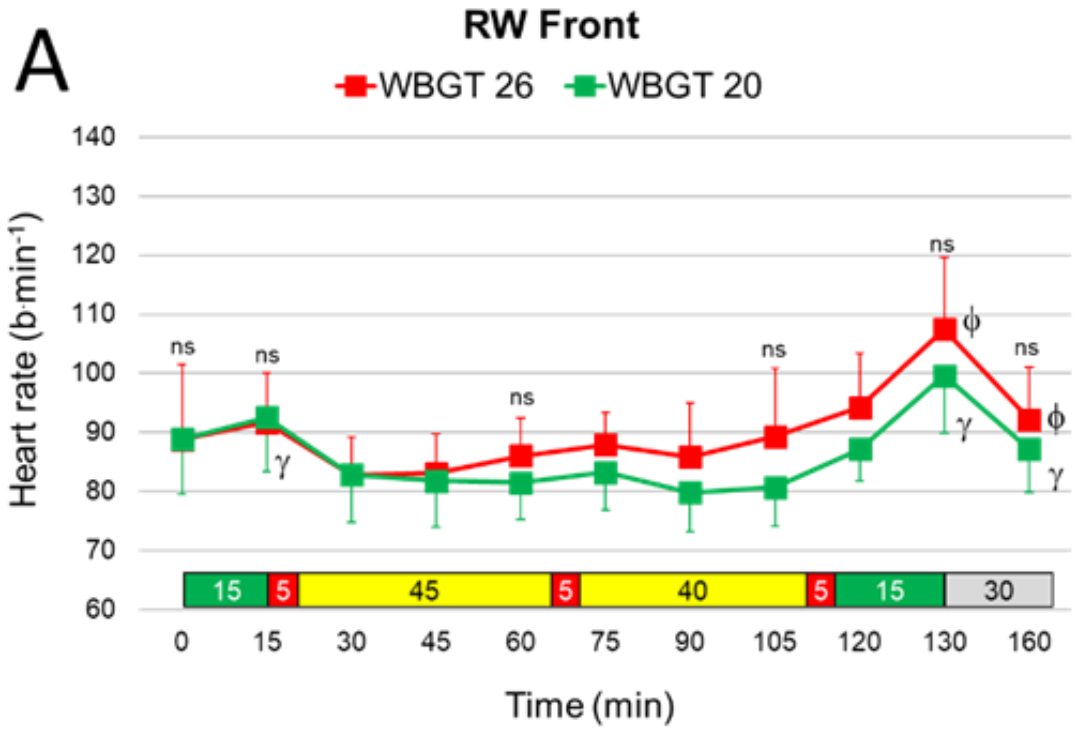
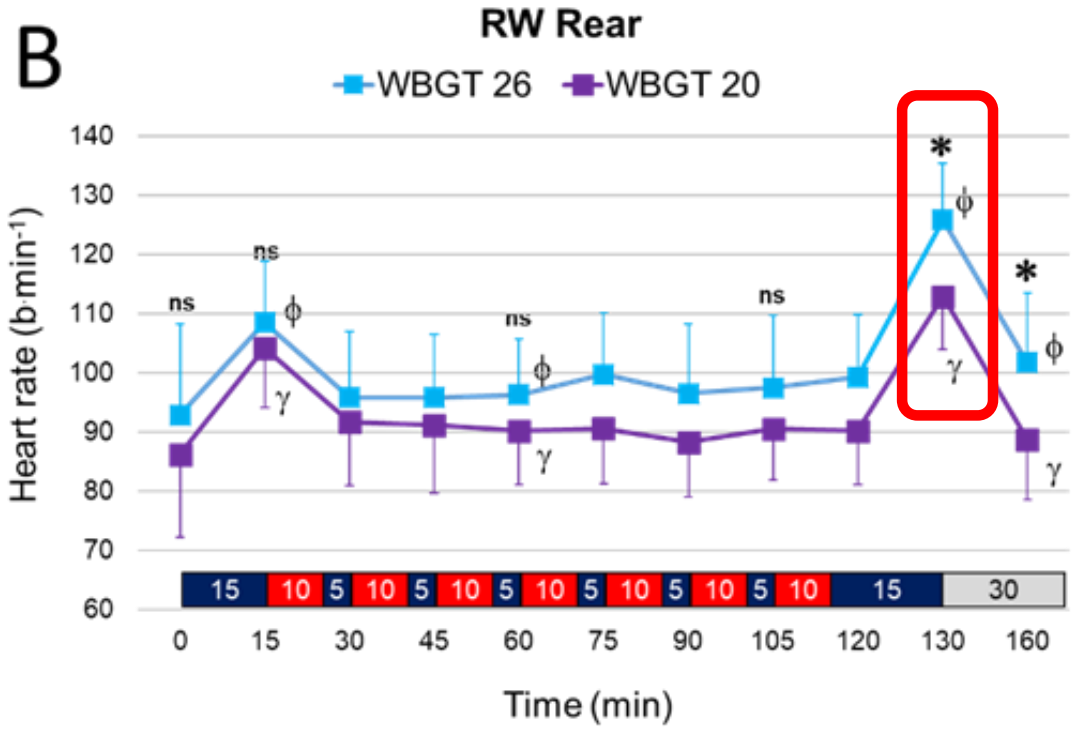
Results: Heart rate





- **Risk**: Mean heart rate well below occupational limit (~152 b·min^{-1})
- **Environment effect**: Only in the Rear crew simulation was a higher heart rate identified
- **Role effect**: At a WBGT of 26 ºC, heart rate was higher in Rear vs Front (15, 60 & 130 min)

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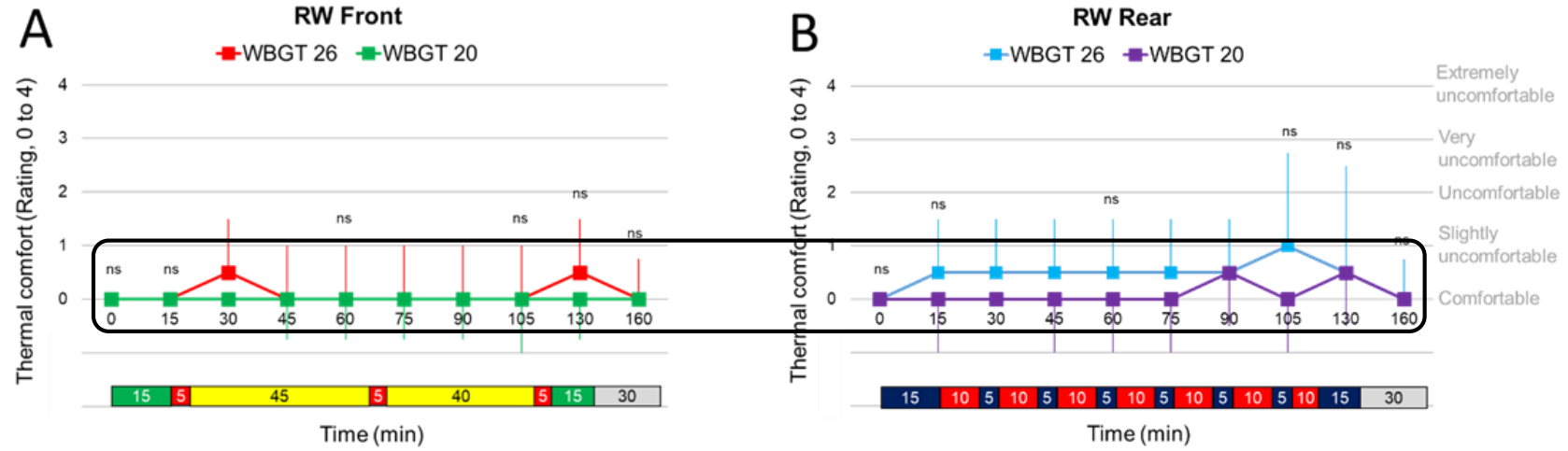
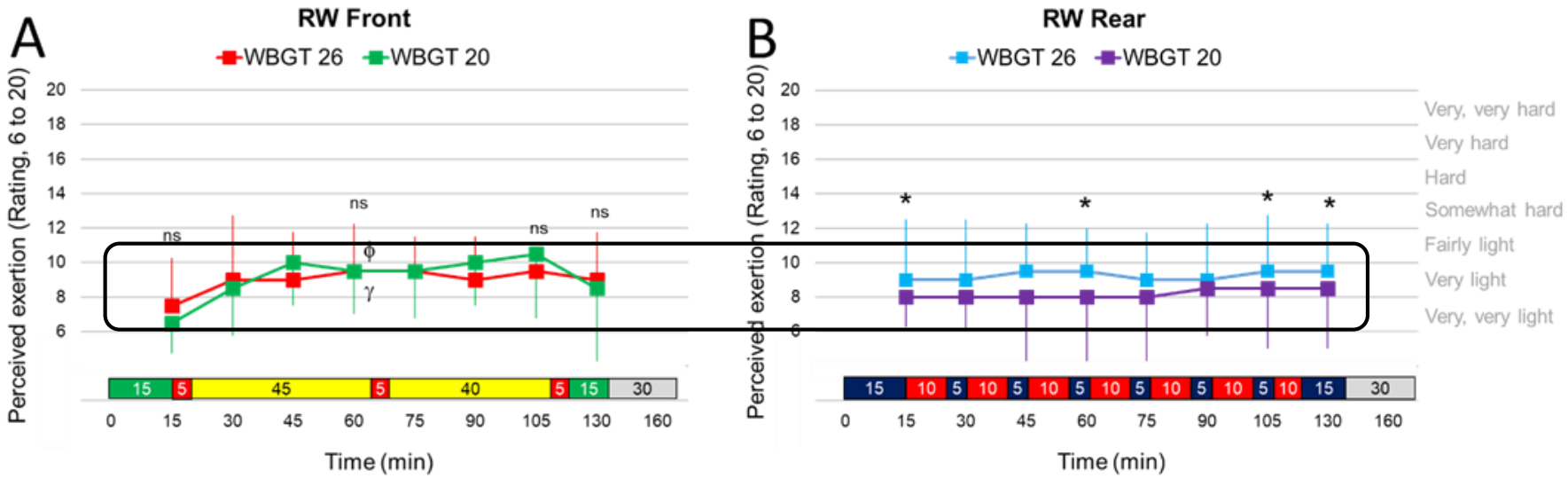
Results: Thermal comfort & perceived exertion (RPE)





- **Thermal comfort**: Minor discomfort; no environmental effect; slightly greater discomfort in Rear (60 min)
- **RPE**: Light exertion; environmental effect in Rear; slightly greater exertion in Rear (15 & 130 min)

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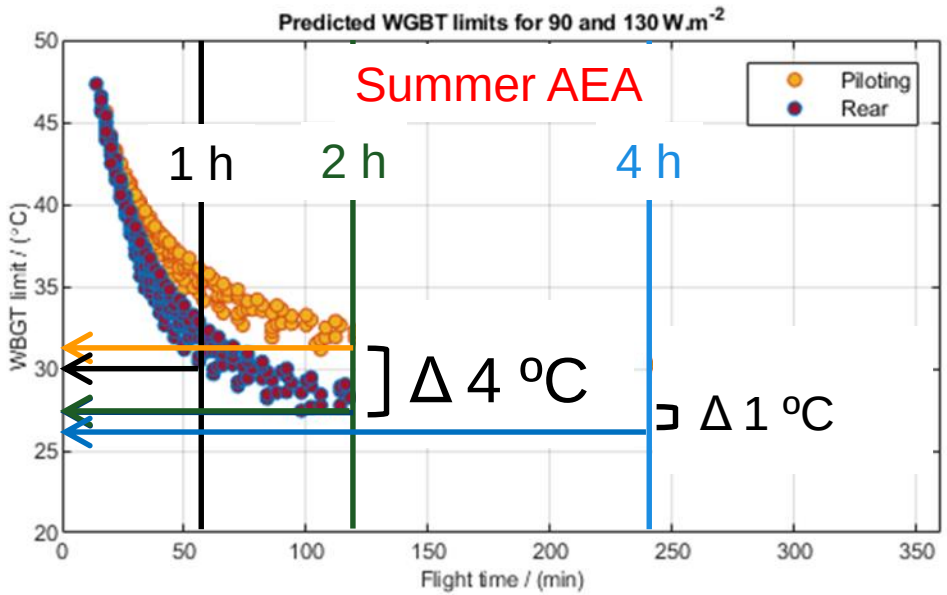
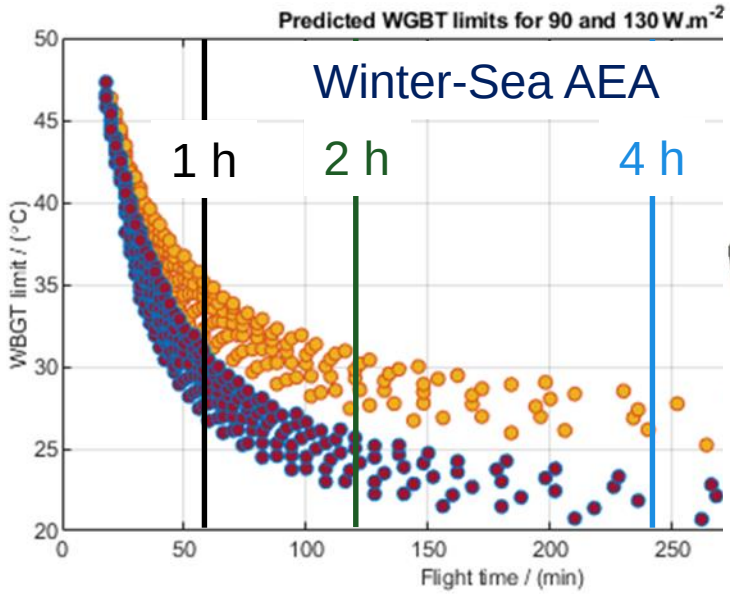
Results: Modelling predictions

- **Validation of model**
  - Good agreement between model & measured core temperature (TC), but predictions based on a higher TC
- **Predicted WBGT limits**
  - Large difference between Front & Rear
  - Small difference between 2 & 4 hour flights
  - Limits reduced 4-5 ºC in Winter-Sea vs Summer AEA

AEA

	Summer		Winter-Sea	
Flight time	Front	Rear	Front	Rear
1 hour	34	30	30	26
2 hour	31	27	27	22
4 hour	30	26	25	20





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Summary & Discussion

- The trial results indicate that a WBGT limit of 26 ºC is likely to induce a level of physiological strain in front and rear RW aircrew wearing Summer AEA that is well within recognised limits.
- The modelling results indicate that: the WBGT limits for the front crew are higher than for the rear crew; that the limits need only be reduced by about 1 ºC (Summer AEA) or 2 ºC (Winter-Sea AEA) when extending the flight time from 2 to 4 hours; and that wearing Winter-Sea AEA reduces the WBGT limits by about 5 ºC.
  - Given that it would not be practicable to use two different WBGT limits for RW operations with rear aircrew, heat stress risk should be based on the rear crew WBGT limit.
- Factors not quantified in this study that may influence heat stress include:
  - Female aircrew; solar load; different rear crew scenarios.
- Implementation of any WBGT limits are complicated by the fact that the thermal environments that aircrew are exposed to in the aircraft may differ from those outside at ground-level, and therefore WBGT limits should also accommodate this unknown risk.

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Conclusions

- Given these study findings and allowing for the unknown impact of other factors not considered (e.g. female aircrew), it is suggested that a WBGT limit of 26 ºC is suitable to protect all RW aircrew wearing Summer AEA during flights up to 2 hours in duration.
  - The proposed WBGT limit should be considered by the relevant RW duty holders as part of their heat stress/strain risk assessment when aircrew undertake hot weather operations
- It is likely that this WBGT limit will also be relevant for flights extended to 4 hours, and that the WBGT limit should be reduced by 5 ºC when Winter-Sea AEA is worn, but empirical evidence is required to support these limits.
- Further work is required to assess the suitability of applying the JSP 375 WBGT limits to the air domain as there are currently uncertainties, unquantified assumptions and practical difficulties in applying the limits to RW operations in the heat.

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