Development of the Rowing Heat Stress Scale (RHSS) tool

Date

November 2023

Version

Beta version 1.2 (revised)

Developers

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This document details the changes that have been made to the policy from beta version 1.1 to 1.2. For reference, the original report supplied to Rowing NSW in December of 2021 is continued at the end of this summary.

Disclaimer

There are risks inherent in using the RHSS and the user accepts responsibility for the use of the rating. The RHSS is designed to reduce the risk of a heat-related adverse event during competition. It cannot guarantee that an athlete will not develop heat-related illness since there are factors which might pre-dispose an athlete to heat illness that cannot be included in the modelling. The scale is designed to assist management, coaches, and athletes to make informed decisions about the risk of heat illness during competition rather than functioning as a binding decision-making tool.

It is important to note that the tool is based upon assumptions that apply to regatta competitions and therefore has less relevance to training contexts.

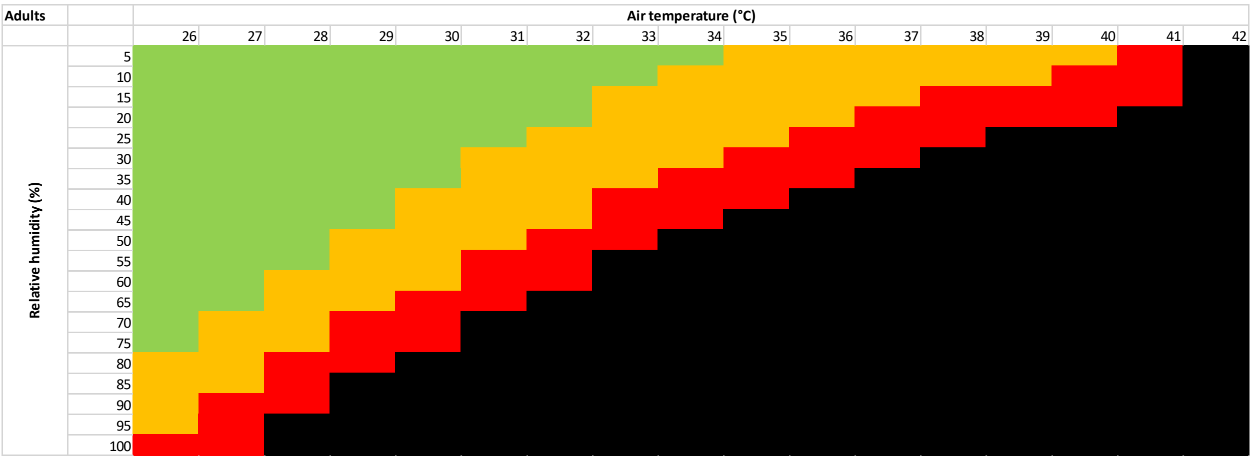
Summary of changes

1. Removed the option to input the level of cloud cover into the calculator due to the potential inconsistencies between raters. The effect of cloud has now been dynamically built-in to the model based upon the assumption that the effect of the sun upon athletes will be greater during days of higher air temperature compared to lower air temperature.
2. The assumed race distance has been changed to 1 km for youth and older adults based upon advice provided by Rowing NSW in March 2023.
3. The assumed time spent on the lake (either warming-up or rowing to the start line) prior to the race has been reduced from 30 to 15 min, as per advice provided by Rowing NSW in March 2023.
4. The assumed rehydration of athletes in-between races has been amended from 50 % to 75 % (note: 100 % is equal to complete rehydration) based upon advice by Rowing NSW in March 2023 and other observations from similar athletes.
5. Greater emphasis was placed in the modelling upon the inability to attain acceptably high sweat rates during extremely hot days.
6. Subtle changes to the model were made to factors relating to clothing heat exchange properties and allowable levels of heat storage.
7. Clarified that the youth risk chart is related to those under the age of 17 (not 18) due to the need to truly separate the adult scale from the youth scale.

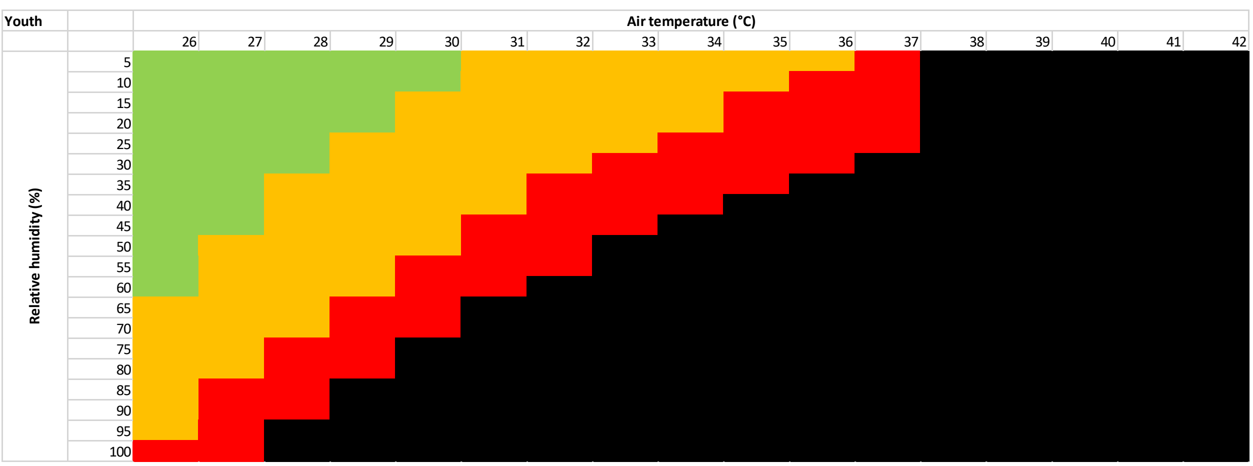
Example use of the revised RHSS

The below figures illustrate the air temperature and relative humidity tradeoff for each risk band for all three revised age category scales.

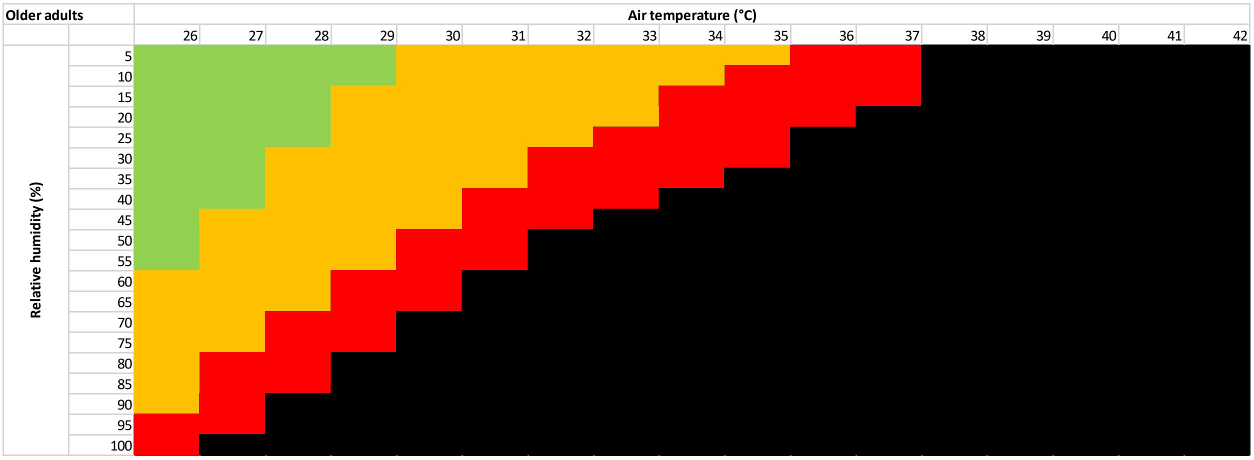
Adults:



Youth:



Older adults:



The breadth of the revised scales can also be illustrated using two examples during historical summer afternoon conditions. It is important to note that the tables below represents the risk at 3pm, which is usually the most severe time of the day, and does not indicate the risk rating that would be reported during an earlier (or later) time of the day. Since the scale provides real-time risk rating, the recommended action is only relevant for this specific time-of-day, and therefore, even though an ‘extreme’ rating might be present at 3pm, this does not guarantee that the remainder of the day was deemed ‘extreme’.

January 2018

Table 1. Risk rating at 3pm during January 2018 according to BoM data collected from Penrith Lakes (station 067113).

Date	Air temp (°C)	Relative Humidity (%)	Adult risk	Youth risk	Older adult risk
1	30.7	40			
2	33.7	33			
3	24.7	55			
4	26.7	43			
5	33.8	24			
6	39.2	20			
7	45.1	9			
8	39.9	21			
9	29.3	62			
10	23.8	58			
11	26.5	53			
12	34.1	44			
13	31.9	38			
14	25.9	29			
15	27.8	28			
16	25.2	35			
17	28.2	24			
18	34.5	13			
19	40.4	12			
20	38.1	7			
21	39.2	12			
22	42.1	12			
23	28.8	56			
24	36.1	25			
25	31.4	43			
26	34.3	38			
27	32.6	45			
28	31.4	47			
29	34.4	30			
30	36	22			
31	22.4	48			

Taree 2023

Table 2. Risk rating at 3pm during January 2023 according to BoM data collected from Taree (station 060141).

Date	Day	3:00 PM				
		Temp	RH	Adults	Youth	Older adults
		°C	%	Risk	Risk	Risk
1	Su	24.8	61			
2	Mo	26.2	55			
3	Tu	26.9	55			
4	We	25.5	72			
5	Th	19	100			
6	Fr	24.9	45			
7	Sa	20.7	96			
8	Su	23.1	54			
9	Mo	25.4	56			
10	Tu	25.7	56			
11	We	25.6	57			
12	Th	25.6	61			
13	Fr	26.7	58			
14	Sa	25.7	58			
15	Su	27.4	58			
16	Mo	26.5	53			
17	Tu	24.7	70			
18	We	28.4	57			
19	Th	22.7	79			
20	Fr	21.7	66			
21	Sa	23.4	62			
22	Su	23	73			
23	Mo	24.6	78			
24	Tu	28.5	64			
25	We	27.3	72			
26	Th	31.2	62			
27	Fr	29.3	52			
28	Sa	29.7	70			
29	Su	31	63			
30	Mo	24.7	100			
31	Tu	27.6	61			

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Summary

A biophysical human heat balance approach was adopted to model the combined effect of environmental and personal factors upon the development of heat strain during rowing. The model factors air temperature, relative humidity, air velocity, mean radiant temperature, metabolic heat production (via activity), and clothing. Each heat balance component was quantified specifically for rowing to ultimately develop the Rowing Heat Stress Scale (RHSS). The scale is designed to protect individuals using a "worst-case" scenario philosophy, whereby a high-end athlete competes in 3 x 2km races over the course of a single day. Moreover, the risk of heat illness during a multi-event day is also derived from cumulative dehydration. The level of estimated dehydration is accounted in the modelling of risk. A risk model was made for adults, which was then adjusted for both older adult rowers (≥55 years old) and youth rowers (<18 years old)

Disclaimer

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Modelling

The descriptions detailed below outline the development of the base adult scale, which is followed by a description about how this modelling was adjusted for the older adult and youth scales.

Body characteristics

Body characteristics for the model were based upon the typical anthropometrical data reported by a range of scientific investigations on national-level elite rowers and reported in a review paper by Shephard (1). Body characteristics are based on an adult male, since this is the population that is likely to high elicit the highest metabolic heat production during competition.

Metabolic heat production

Metabolic heat production was calculated as per Cramer and Jay 2019 (2). The calculation was informed by direct and indirect measurements of rowing-specific metabolic rates (i.e. oxygen consumption [VO_2] for given rowing speeds) and work efficiency in Jackson and Secher (3), de Campos Mello et al. (4), Das et al. (5), Jetté et al. (6), Fukunaga et al. (7), and di Prampero et al. (8). Race speeds were calculated according to the typical performance of an elite 2-km crew (9). Average rowing speed (and hence, VO_2) during the warm-up was estimated given an assumed typical duration spent actively warming-up on the lake. This was deemed to be 30 mins and associated with an exercise intensity that is on average ~50% of race speed. Both the race and warm-up time were combined to constitute one event.

Dry heat exchange

Radiative heat transfer was determined according to the coefficient provided by Cramer and Jay (2). Mean radiant temperature was calculated according to Cramer and Jay (2) after accounting for the black globe temperature (factors effect of cloud cover) and prevailing air velocity (wind speed). Air velocity is built into the model because the value provided by the Bureau of Meteorology (BoM) station is unlikely to fairly represent actual on-water conditions. This is due to both the standardised measuring methodology that BoM uses and the geographical differences that influence on-water vs on-land wind speed.

Convective heat transfer was determined using an air coefficient based upon movement velocity (10). The dry heat transfer resistance of clothing was estimated using known values of clothing ensembles according to ISO9920 (11). Estimated skin temperature was clamped at a near-maximum value, given the assumption that athletes will be both fully exposed to the sun and warm air, and performing repeated high-intensity exercise. Heat exchange via respiration (convective and evaporative) was calculated as per Cramer and Jay (2).

Evaporative heat loss

Evaporative heat loss was determined via a coefficient factor and well-established calculations provided by Cramer and Jay (2). The evaporative resistance of clothing was estimated based upon know values of sporting ensembles (2). Estimated sweat rate was determined according to Cramer and Jay (2) and estimated net percentage body mass loss following a single race (and associated warm-up) was determined by assuming that an individual will replenish 50% of fluid losses following a race. The dehydration risk factor that is applied to the modelling is ultimately designed to enforce a more conservative approach to recovery (i.e. more rest and active cooling strategies), especially when an athlete approaches a threshold of net percentage body mass loss of 2%. This is a known threshold that meaningfully influences cardiovascular and thermal strain, which manifests in a reduced performance and thermoregulatory capacity (12–14).

Determining risk

Ultimately, the modelling determines the level of physiological compensability for the activity being performed under the prevailing environmental conditions by comparing the evaporative requirements to maintain bodily heat balance during the specific activity (E_{req}) to the maximum evaporative capacity in the ambient environment (E_{max}). E_{req} represents the amount of evaporation needed to stop overheating, and if E_{req} is greater than E_{max}, the individual will continually get hotter. This base level of risk is accompanied by a dehydration factor, which accounts for the cumulative effects of high sweat rates throughout a multi-event day. The compensability rating and estimated dehydration are combined in a scale to provide a level of global risk and accompanied by recommended guidelines.

How the scale differs between adults, older adults, and youth athletes

The recommended age for the youth scale is <18 years old, and the recommended age for the older adult scale is ≥55 years old. The adult scale is suitable for all ages in-between. The typical body size associated with the modelling of risk for youth and older adult athletes is smaller than the adult modelling. The body size for the youth scale was adjusted as per upper-percentile normative growth values reported by the National Center for Chronic Disease Prevention and Health Promotion (assuming a natural selection effect of larger individuals competing in rowing). The body size for older adults was adjusted as per reported values in Masters rowers (15,16). The rowing speed of junior rowers is modelled as per typical race speed values for a 14 year old (9) and VO_2 is estimated as per normative VO_{2max} values for upper percentile 14 year olds (17,18) and observed VO_{2max} values in junior rowers (19). The critical environmental thresholds for each risk zone in the youth scale are more conservative (i.e. more protective), reflecting the long-time viewpoint that junior athletes are more susceptible to heat illness (20). Similarly, the critical environmental thresholds for each risk zone in the older adult scale are more conservative (i.e. more protective), due to the associated physiological declines and potential for underlying health conditions that may expose the aging individual to a greater risk of heat illness (21). Maximum skin temperature was slightly reduced in the older adult modelling due to the associated changes in skin blood flow dynamics with aging (21).

The product

The RHSS is a single tab Microsoft Excel-based tool which requires the user to input the air temperature (°C), relative humidity (%), and cloud cover (cloudy, partly cloudy, or mostly sunny).

These values should be placed in the calculator every 30-min (this is the refresh time of the nearest BoM weather station), or more frequently if updated weather station observations are available. It is important that these values represent current environment combinations, not a combination of the predicted peak daily temperature and peak relative humidity. This is because relative humidity is a function of air temperature, so the peak daily relative humidity rarely occurs at the same time as the daily peak air temperature.

The scale provides a single colour and description-coded rating (‘low, ‘moderate’, or ‘high’). The scale contains small transitional zones between categories, acknowledging that there is some error and inconsistency with the measuring of environmental parameters. It is important to note that there are individual differences between athletes that might influence their tolerance to heat stress and susceptibility to extreme heat strain that cannot be captured by the modelling. Each primary risk category (low, moderate, high) has recommended actions that are outlined in the accompanying policy document. The empirical evidence supporting the cooling and recovery approaches are outlined below. When the risk code is blank, it is likely that an unrealistic combination of air temperature and relative humidity has been input. In this instance, check the input values are correct for the current prevailing environmental conditions.

There is no ‘fixed’ air temperature that is associated with the risk zones

The modelling uses a holistic approach to determining risk, acknowledging that environmental stress is caused by the combined effect of air temperature, humidity, air velocity, and solar radiation. Therefore, there is no fixed air temperature that triggers different risk zones. For example, the *extreme* risk zone might be triggered on a day that air temperature could be ~5°C lower in comparison to a different day, if the prevailing humidity is much higher. Humidity determines the efficiency of sweat evaporation (22), which is the primary avenue for losing heat during exercise in the heat. A high humidity day will limit evaporative capacity (i.e. ability to lose heat and regulate core body temperature rises during exercise), and therefore will generally increase the level of risk. Moreover, it is absolute humidity that determines sweat efficiency, not relative humidity. Because the capacity of air to carry water vapour increases exponentially with air temperature, absolute humidity can be high despite a seemingly low relative humidity during the hottest time of the day. For example, absolute humidity is higher at 45°C with 25% relative humidity than at 30°C with 50% relative humidity. The risk calculator requires the user to input relative humidity as per available BoM data, but this is converted to absolute humidity (behind-the-scenes) in the model.

Example use of the SHSR

The breadth of the scales can be illustrated using two examples during historical summer afternoon conditions. It is important to note that the tables below represents the risk at 3pm, which is usually the most severe time of the day, and does not indicate the risk rating that would be reported during an earlier (or later) time of the day. Since the scale provides real-time risk rating, the recommended action is only relevant for this specific time-of-day, and therefore, even though an 'extreme' rating might be present at 3pm, this does not guarantee that the remainder of the day was deemed 'extreme'. Moreover, the cloud cover is only estimated via limited data.

January 2021

Table 1. Risk rating at 3pm during January 2021 according to BoM data collected from Penrith Lakes (station 067113).

Date	Air temp (°C)	Relative Humidity (%)	Estimated cloud cover	Adult risk	Youth risk	Older adult risk
1	20.1	68	2	Low	Low	Low
2	21.8	73	2	Low	Low	Low
3	25.6	71	2	Moderate	Moderate	Moderate
4	24.9	89	2	Moderate	Moderate	Moderate
5	28.9	55	3	Moderate	Moderate	Moderate
6	24.7	60	2	Low	Low	Low
7	21.1	77	2	Low	Low	Low
8	22.8	53	2	Low	Low	Low
9	25.1	48	2	Low	Low	Low
10	29.9	40	3	Moderate	High	High
11	30.3	36	3	Moderate	High	High
12	33	39	3	High	High	Extreme
13	31.2	37	3	High	High	High
14	36.9	26	3	High	Extreme	Extreme
15	32.5	48	2	High	High	High
16	28.8	16	3	Moderate	Moderate	Moderate
17	29.4	28	3	Moderate	Moderate	Moderate
18	31.7	32	3	Moderate-high	High	High
19	23	58	2	Low	Low	Low
20	22.5	57	2	Low	Low	Low
21	29.3	33	3	Moderate	Moderate	Moderate-high
22	36.8	28	3	High	Extreme	Extreme
23	37.3	31	3	Extreme	Extreme	Extreme
24	39.2	26	3	Extreme	Extreme	Extreme
25	39.1	17	3	High	High-extreme	Extreme
26	37.7	23	3	High	Extreme	Extreme
27	20.8	89	1	Low	Low	Low
28	22.1	66	2	Low	Low	Low
29	20.9	98	1	Low	Low	Low
30	26.9	81	2	Moderate-high	Moderate-high	High
31	23.7	81	2	Low-moderate	Low-moderate	Low-moderate

(green)	Low
(green–yellow)	Low-moderate
(orange)	Moderate
(orange–red)	Moderate-high
(red)	High
(red–black)	High-extreme
(black)	Extreme

Estimated cloud cover	
1	Cloudy
2	Partly cloudy
3	Mostly sunny

**No historical data available so this was estimated based on prevailing conditions*

January 2018

The summer of 2017/18 was labelled the 'Angry Summer', characterized by repeated hot and humid conditions.

Table 2. Risk rating at 3pm during January 2018 according to BoM data collected from Penrith Lakes (station 067113).

Date	Air temp (°C)	Relative Humidity (%)	Estimated cloud cover	Adult risk	Youth risk	Older adult risk
1	30.7	40	3	High	High	High
2	33.7	33	3	High	High	High-extreme
3	24.7	55	1	Low	Low	Low
4	26.7	43	3	Moderate	Moderate	Moderate
5	33.8	24	3	High	High	High
6	39.2	20	3	High	Extreme	Extreme
7	45.1	9	3	Extreme	Extreme	Extreme
8	39.9	21	3	Extreme	Extreme	Extreme
9	29.3	62	1	Moderate	Moderate	Moderate
10	23.8	58	2	Low	Low	Low
11	26.5	53	2	Low-moderate	Moderate	Moderate
12	34.1	44	3	Extreme	Extreme	Extreme
13	31.9	38	3	High	High	High
14	25.9	29	3	Low-moderate	Moderate	Moderate
15	27.8	28	3	Moderate	Moderate	Moderate
16	25.2	35	3	Low-moderate	Moderate	Moderate
17	28.2	24	3	Moderate	Moderate	Moderate
18	34.5	13	3	Moderate	High	High
19	40.4	12	3	High	High-extreme	Extreme
20	38.1	7	3	Moderate-high	High	High
21	39.2	12	3	High	High	High
22	42.1	12	3	High	Extreme	Extreme
23	28.8	56	2	Moderate	Moderate	Moderate
24	36.1	25	3	High	High	Extreme
25	31.4	43	3	High	High	High
26	34.3	38	3	High	Extreme	Extreme
27	32.6	45	3	High	Extreme	Extreme
28	31.4	47	3	High	High	Extreme
29	34.4	30	3	High	High	High-extreme
30	36	22	3	High	High	High
31	22.4	48	2	Low	Low	Low

Green	Low
Green–yellow	Low-moderate
Orange-yellow	Moderate
Orange–red	Moderate-high
Red	High
Red–black	High-extreme
Black	Extreme

Estimated cloud cover	
1	Cloudy
2	Partly cloudy
3	Mostly sunny

**No historical data available so this was estimated based on prevailing conditions*

Evidence and reasoning for recommended risk mitigation strategies

Activity modification

Limiting time spent on the warm-up lake will reduce bodily heat storage since less physical activity can be undertaken and will also restrict the volume of bodily fluid loss via sweating, causing less systemic thermal and cardiovascular disturbance. Additional time between races enforces athletes to have greater time to cool-down via passive rest in the shade and applying active cooling strategies. The recommended duration (30 min) for passive rest in the *high* risk category is estimated to result in a reduced core temperature of up to ~1.0°C for heat-stressed athletes following a race. This is based upon previous research following exercise in the heat from Butts (23) that observed a reduction of core temperature during passive rest of 0.04°C/min and the work of Chalmers et al. (24) that showed that passive rest in the heat for 20-min reduced core temperature by ~0.6°C. Both these studies included heat stressed individuals. Therefore, the recommended duration (20 min) for passive rest in the *moderate* risk category is estimated to result in a reduced core temperature of up to ~0.5°C for heat-stressed athletes.

Active cooling strategies

Post-exercise cold fluid or ice slushie ingestion has been shown to have a beneficial cooling effect upon core temperature (25,26). Typical volumes of consumed cold fluid or ice slushie in research studies is ~400-600mL, and often spaced in smaller allotments (26). The application of ice or cold towels post-exercise has been shown to assist in reducing core temperature at a rate of ~0.06 – 0.11°C/min in heat stressed individuals (27). The effectiveness of fan cooling is largely dependent upon the prevailing environmental conditions. Broadly, if ambient temperature is <35°C, additional air movement is likely to provide a beneficial cooling effect (the magnitude of cooling will vary) since the air-skin temperature gradient facilitates convective heat loss away from the body. However, the body gains convective heat from the environment when the air-skin temperature gradient becomes reversed (i.e. ambient temperature is ~>35°C [and attainment of maximum skin temperature]). The effectiveness of fans to provide a net cooling benefit when ambient temperature is >35°C is also dependent on the prevailing humidity. A net cooling benefit is likely to be observed in hot-humid but not a very hot-dry environment (28). The cooling effect of fanning is reported to substantially improve when combined with dousing water on exposed skin (29). Conceptually, additional skin wetting stands to provide the more whole-body cooling benefit in hot-dry environmental conditions because skin wettedness (greater than physiological sweating alone) is temporarily improved within prevailing conditions that facilitate a high sweat efficiency (22,30). This functions to subsequently increase the rate of evaporative heat loss in the face of greater air movement (30). In comparison, skin wettedness is already likely to be far greater in humid conditions (potentially at maximum), therefore, adding fluid onto the skin is unlikely to provide an additional meaningful cooling benefit. Misting fans promote both additional airflow and skin wettedness, and have show to be particularly effective for cooling a heat-stressed individuals in a rugby context (31).

Hydration

Ensuring adequate hydration is important for reducing the risk of heat illness since substantial dehydration can impair thermoregulation capacity (32), but it should be emphasized that proper hydration cannot fully prevent cases of heat illness. High core temperatures (>39.5°C) have been observed in exercise research in the presence of only modest levels of dehydration (<1% of body mass loss) (33). Ultimately, striving to maintain net body mass losses (indicative of dehydration) below 2% is important since greater losses meaningfully influence cardiovascular and thermal strain, which manifests in a reduced performance and thermoregulatory capacity performance (12–14,34).

Statement about cold water immersion

Cold-water immersion has been omitted from the policy guidelines due to the likely lack of access for most teams. However, it is considered the gold-standard for both treating individuals with suspected cases of heat illness, or just simply cooling an athlete (13). Typically, water temperature is held between 2-26°C (27), however, very cold water <15°C is advocated by the National Athletic Trainers' Association (35) and <0-10°C has been shown to be more effective at cooling the body in comparison to 10-20°C (36). Post-event full-body water immersion reduces core body temperature of heat-stressed individuals at least twice as fast as passive recovery (36), and a rate of 0.15 – 0.24°C/min can be achieved according to the American College of Sports Medicine (13). Tarp cooling has been suggested as an accessible option in the field where tubs for full body immersion are not accessible (37). The method involves an athlete being placed on a water-proof sheet and three or more people holding up the edges to create a bowl-shape before cold water and/or ice is poured into the tarp and over the athlete whilst the water is agitated regularly (27). Tarp cooling studies have used water temperature that was either 2°C or 9°C and it has been shown to have a cooling rate of ~0.15°C/min (37,38).

Statement about pre-cooling prior to an event

Broadly, it is problematic to suggest the duration of effect from pre-cooling approaches since this is highly dependent on the type, length, exercise type, and potential adjustments in exercise-intensity following cooling. It is unreasonable to suggest that a pre-cooling routine which reduces core temperature by 0.5°C will simply result in a core temperature that is 0.5°C lower than expected at the end of the event. In fact, Jay and Morris (2018) (26) highlighted evidence to suggest that the rate of rise in core temperature may be greater in some cases (but not all) during the early stages of performance following a pre-cooling approach. Collective evidence from studies suggests that typical pre-cooling routines result in an average reduction in end-event absolute core temperature by ~0.2°C following a performance test in hot conditions (39). This tentatively suggests a reduction in the risk of heat illness.

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