Scientific rationale for changing lower water temperature limits for triathlon racing to 12 °C with wetsuits and 16 °C without

Jane Saycell, Mitch Lomax, Heather Massey, Mike Tipton

Extreme Environments Laboratory, Department of Sport and Exercise Science, University of Portsmouth, UK

Correspondence to:

Jane Saycell
Department of Sport and Exercise Science,
University of Portsmouth,
Spinnaker Building,
Cambridge Rd
Portsmouth,
UK
+44 (0)23 9284 5163
jane.saycell@port.ac.uk

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ABSTRACT

Objectives To provide a scientific rationale for lower water temperature and wetsuit rules for elite and sub-elite triathletes.

Methods 11 lean, competitive triathletes completed a 20-minute flume swim, technical transition including bike control and psychomotor testing, and a cycle across five different wetsuit and water temperature conditions: with wetsuit, 10 °C, 12 °C and 14 °C; without wetsuit (skins), 14 °C and 16 °C. Deep body (rectal) temperature (T_{re}), psychomotor performance and the ability to complete a technical bike course after the swim were measured, as well as swimming and cycling performance.

Results In skins conditions, only 4 out of 11 athletes could complete the condition in 14 °C water, with two becoming hypothermic ($T_{re} < 35$ °C) after a 20-minute swim. All 11 athletes completed the condition in 16 °C. T_{re} fell further following 14 °C (mean 1.12 °C) than 16 °C (mean 0.59 °C) skins swim ($p = 0.01$). In wetsuit conditions, cold shock prevented most athletes (4 out of 7) completing the swim in 10 °C. In 12 °C and 14 °C almost all athletes completed the condition (17 out of 18). There was no difference in temperature or performance variables between conditions following wetsuit swims at 12 °C and 14 °C.

Conclusion The minimum recommended water temperature for racing is 12 °C in wetsuits and 16 °C without wetsuits. ITU rules for racing were changed accordingly (January 2017).

What are the new findings?

- Based on rectal temperature and performance in skills test, lean triathletes could not compete safely in 14°C water without wetsuits;
- With wetsuits, lean triathletes could not compete safely in 10°C water;
- Most athletes can compete safely in 12 °C water with wetsuits;
- Athletes most vulnerable to hypothermia are leanest, regardless of fitness.

How might it impact on practice in future?

- Wetsuits made compulsory for international triathlon racing below 16 °C;
- Limited racing allowed in 12 °C water;
- Awareness of vulnerable athletes to improve safety of events.

INTRODUCTION

Triathlon racing is governed by the International Triathlon Union (ITU) which maintains rules on water temperatures for racing, and the use of wetsuits (Supplementary Tables 1 and 2).[1] Prior to this study, elite racing was permitted in water above 13 °C, with wetsuits mandatory below 14 °C, optional between 14 °C and 20 °C and forbidden above this, however, to our knowledge, there was no scientific data underpinning these rules.

The swim element of triathlon poses the greatest risk to athlete safety,[2] and water temperature rules which balance this concern with the need to run events are critical. Previous studies have indicated that cold shock on entering the water may result in increased heart rate and hyperventilation, affecting an athlete's ability to control breathing during the swim and posing an increased risk of adverse cardiac events, stroke and drowning.[2,3,4,5] A further safety concern is the ability to maintain swimming ability: deterioration in swimming performance due to peripheral muscle cooling has been found before rectal temperature falls to 35˚C, with shorter strokes, higher stroke rate, increased swim angle and reduced efficiency all precursors to swim failure.[4] Studies have indicated a large variation in the ability of participants to maintain deep body temperature; from those who are able to maintain it while swimming in water at 10 ˚C,[5] to those who cannot at 18 ˚C,[4,6] but none have studied a specific group of fit, experienced, competitive open water triathletes. This group of athletes has a combination of low body fat and high heat production potential, and so the present study aims to investigate the responses to cold water of such a group.

Triathletes complete a transition to start cycling immediately after leaving the water. The ability to control a bike in technical situations and close to other cyclists is therefore important for race safety and performance. Muscle fatigue and reduced grip strength have been observed after cold swimming,[2,4] and it is possible that this has a detrimental effect on the ability to safely control a bike and use brake levers after leaving the water.

This study aimed to ascertain safe lower water temperature limits, with and without wetsuits, for elite and high-level 'age group' triathletes. The ultimate objective was to provide the ITU with evidence-based recommendations on any changes required to existing limits.

It was hypothesized that the existing lower limits were appropriate for the safe conduct of elite triathlon racing.

METHODS

Participants

12 participants (10 male and 2 female) were recruited to the study. Contact authors for more information about recruitment procedures. All gave written, informed consent, were physically fit and healthy, lean (body fat 12% or less for men, 16% or less for women as calculated from sum of 7 skinfolds,[9,10]), aged 15 or over, well-trained triathletes who compete in ITU-sanctioned events, competing either as youth elites or internationally as age-group athletes representing their countries. Detailed characteristics are presented in Table 1.

Table 1. Characteristics of study participants (ordered by skinfold thickness, least to most)

ID	Sex	Age (years)	Height (m)	Mass (kg)	Sum of 7 skinfolds (mm)
1	male	17	1.80	71.40	32.50
2	male	33	1.75	63.00	36.30
3	male	18	1.77	67.09	38.65
4	male	55	1.71	59.00	39.00
5	male	36	1.80	72.23	40.35
6	male	15	1.72	63.83	40.95
7	male	15	1.77	60.90	44.20
8	male	16	1.75	62.40	47.00
9	male	61	1.74	73.60	60.50
10	female	28	1.65	56.71	71.55
11	female	41	1.64	62.27	72.75
12	male	30	1.86	86.60	78.05
Mean (SD)		30 (15)	1.75 (0.06)	66.59 (7.90)	50.15 (15.38)

Patient Involvement

The research question and outcome measures were discussed with participants prior to the study, and their experience and preferences were taken into account. This influenced the protocol design, particularly the use of own equipment and clothing, and data that was available to participants during the procedures. Participants were given their own data after the study, as well as the overall results and final reports.

Procedures

Participants performed a 20-minute swim (the approximate time for the swim in an elite Olympic-distance triathlon) in a temperature-controlled flume, followed by a cycle on a stationary bike (participant's preferred bike connected to Computrainer, Racermate, U.S.A.). All activities were completed in a climatically-controlled laboratory. Activities were self-paced, and athletes were asked to swim and cycle at race-pace for an Olympic distance event (40 km or until T_{re} had returned to pre-swim baseline values).

Clothing

Athletes wore their own technical trisuits throughout the study. During the swim phase of the study, athletes wore their own standard swimming hat and goggles. In wetsuit conditions they also wore their own triathlon-specific, well-fitting, full-length wetsuits. For the cycling phase, they wore their own triathlon-specific bike shoes and used their own bike. On each test visit, participants were asked to arrive well-rested and refreshed as though for a race.

Environment

There were five clothing and water temperature conditions: with wetsuits, 10 °C, 12 °C and 14 °C; without wetsuits (skins swims), 14 °C and 16 °C. Abbreviations used: 10WS, 12WS, 14WS, 14SS, 16SS respectively. Participants completed these (order randomized for each participant) at the same time of day on different days, at least 24 hours apart. The lowest water temperature for skins swimming was 14 °C, the existing minimum temperature for skins racing. Pilot studies indicated that this might be too low for skins racing, but not for wetsuit racing, and so a higher-temperature skins condition was included and lower-temperature wetsuit conditions. Ambient temperature was maintained at 12 °C and windspeed for the cycle at 15-20 $km.h^{-1}$, provided by a 3.8 KW fan (Flakt Woods, Germany). While cycling, the movement of air increases heat loss through convection and evaporation. Fans were used to simulate this air movement: an air velocity of 15 $km{\cdot}h^{-1}$ is adequate to remove the boundary layer of air surrounding the skin, so that an increase in wind speed above this level will not increase the rate of cooling.[7]

Skills tests:

Psychomotor, strength and bike control skills were tested before and after the swim in each condition with a battery of tests: a "technical cycle course", a 4-choice reaction test (CRT) (Deary-Liewald Reaction Test)[8] and a maximum grip strength test (one attempt with each hand, using a hand-held dynamometer, Takei, Japan).

The test of bike control involved a short cycling course, marked out with tape on a non-slip floor (Supplementary Figure 1). Triathletes were asked to complete the course as quickly as possible without making any "errors" (front wheel over the line or putting a foot down). Each attempt was filmed (GoPro, Hero 4, U.S.A.) and time taken and errors were recorded.

Familiarisation with all test procedures and equipment was carried out on a separate day prior to the start of the data collection; participants repeated each test until variation was minimal. Specifically, mean bike course error rate ranged from 5.83% to 8.24% and mean CRT error ranged from 2.78% to 4.44%. The group coefficient of variation for bike course time was 2.28%, and 4.77% for CRT response time.

Measurements:

Deep body (rectal) temperature (T_{re}) was measured continuously by a rectal thermistor (Grant Instruments [Cambridge] Ltd, UK) self-inserted 15 cm beyond the anal sphincter, and recorded for the duration of the test at minute intervals (Squirrel data logger, Grant Instruments [Cambridge]). Heart rate was recorded using a telemetry system (MetaSwim, Cortex, Germany) tucked into the top of the trisuit.

Before the start of the swim, at the end of the swim, five minutes into the cycle and every 10 minutes thereafter, expired air measurements (ventilation and oxygen consumption) were measured using the MetaSwim system.

Power, distance and speed of cycling were recorded on a laptop, connected to the Computrainer; these data were available to participants.

Protocol:

After completing the baseline test battery participants entered the water. They remained upright for three minutes to allow breathing and heart-rate to recover before the flume was started at their preferred initial speed. Cold shock typically lasts for less than three minutes,[9] and heart rate was observed to level off within this time. Participants swam for 20 minutes, and could change speed at any time by signalling to researchers. Speed was measured by a current meter (Braystroke Model 001 Open Channel Flow meter, Valeport, UK), positioned 10 cm from the surface immediately in front of the swimmer's outstretched hand, and distance swum calculated from duration at each speed. After the swim, participants exited the water and removed their wetsuit (if using), hat and goggles before again completing the test battery ("post swim"). They mounted the stationary bike and cycled until T_{re} had returned to its pre-swim value, or for the equivalent of 40 km if this did not happen.

Participants were withdrawn if T_{re} fell to 35 °C before cycling (laboratory safety criteria), or if they felt unable to complete the bike course. If they were unable to grip handlebars or needed support to complete the bike course, they were deemed to be 'unsafe' and this was noted, although participants were not withdrawn.

The protocol is shown in Supplementary Figure 2.

Data analyses

Descriptive analyses:

Four objective, descriptive criteria were applied to participants in each condition to determine whether the swim was safe. All criteria were passed for an athlete to complete safely:

1. Completed swim without refusal or swim failure (defined as touching the floor of the flume)
2. T_{re} remained above 35 °C before starting the cycle
3. Completed bike course safely
4. Rewarmed during cycle.

Calculated variables:

Oxygen consumption was used to calculate metabolic heat production (MHP), according to the formula:

Heat Production= Mechanical Efficiency x Energy Input

Where Energy Input (E_i) was calculated from expired air measurements based on the Weir Method, [14] and Mechanical Efficiency (as a fraction) was calculated using the efficiency values of Toussaint, Knops, De Groot, & Hollander .[11]

Body surface area (BSA) was estimated according to the formula:

BSA (m^2) = 0.007184 x $\text{Mass}^{0.425}$ (kg) x $\text{Height}^{0.725}$ (m).[12]

MHP/BSA was calculated during swim and bike to give an indication of heat production vs heat loss through convection.

Statistical analyses:

Data were used to compare performance between wetsuit conditions and between skins conditions. For statistical power, conditions were only analysed where at least 8 participants completed. P was set at equal to or less than 0.05 and calculated using IBM SPSS version 22.

Data were tested for normality using Shapiro-Wilk test. Paired t-tests (or non-parametric equivalents) were used to compare conditions for the following variables: change in T_{re} during the swim; further change in T_{re} after the swim (afterdrop); time taken on the bike before T_{re} begins to rise (afterdrop time); total time on the bike for T_{re} to return to pre-swim value; distance swum; mean power during first ten minutes of cycling; change in test scores before and after the swim (mean grip strength; CR response time; error percentage on CR; bike course time; error percentage on bike course). One-way ANOVA was used to compare MHP/BSA between conditions.

Effect sizes were calculated, using Cohen's *d,* or Probability of Superiority (PS_{dep}) for non-parametric data, to assess the impact of the water temperature on each variable, for the difference between 12WS and 14WS and between 14SS and 16SS. For Cohen's *d* scores were valued as follows:[13] 0.2 = small effect; 0.6 = moderate effect; 1.2 = large effect; 2 = very large effect; 4 = extremely large effect. For PS_{dep} a score above 0.8 was considered to be a large effect.

RESULTS

One male (#4) withdrew from the study after his first visit, as participation was more demanding than he had anticipated.

Completing conditions

Table 2 shows the outcome of each condition completed by volunteers.

Table 2. Outcomes of simulated triathlon tests at different water temperatures with and without wetsuits. Participants are ordered by least to most skinfold thickness

	1	2	3	4	5	6	7	8	9	10	11	12	Total Completed Safely
16 ˚C SS	C	C	C	-	C	C	C	C	C	C	C	C	11/11
14 ˚C SS	C	W	U	W	C	U	R	U	U	-	C	C	4/11
14 ˚C WS	-	C	C	-	C	C	C	C	C	C	-	C	9/9
12 ˚C WS	C	W	C	-	-	C	C	C	C	C	C	C	9/10
10 ˚C WS	R	-	R	-	-	R	R	C	C	-	-	C	3/7

C = Completed condition; W = Withdrawn (due to T_{re} falling to 35 °C before cycling); U = Unsafe (completed condition but unsafe on cycle course); R = Refused to swim (due to cold response). SS = Skins Swim (non-wetsuit); WS = Wetsuit Swim.

Deep Body Temperature

Figures 1 and 2 show T_{re} for all participants who completed the swim element of each condition.

Statistical analyses

Table 3 shows the mean and standard deviation of measured variables during each condition. Table 4 shows the change in performance of the skills tests before and after the swim. There was no significant difference between wetsuit conditions for any variable. There was a significant difference between 14SS and 16SS for the change in T_{re} during the swim ($t = -3.36$; $p = 0.01$). Effect size was moderate between 12 °C and 14 °C wetsuit conditions for afterdrop time (0.8) and change in error rate on the bike course (0.86). Effect size was moderate between skins conditions for T_{re} change during the swim (0.88), size of afterdrop (0.81) and change in error rate on the bike course (0.89).

Metabolic heat production

There was no difference in metabolic heat production between conditions in either the final five minutes of the swim ($p = 0.96$), or the start of the cycling ($p = 0.43$) (Supplementary Table 3).

Table 3. Mean (SD) changes in rectal temperature, swim distance and bike power output during simulated triathlons in different water temperatures with and without a wetsuit

Wetsuit swims	**10WS**	**12WS**	**14WS**	**Effect size**[1]	**P**[2]
n	3	9	9		
Δ T_{re} during swim (°C)	-0.28 (0.80)	-0.4 (0.52)	-0.21 (0.48)	0.38[a]	0.14
Δ T_{re} after swim (°C)	-0.87 (1.18)	-0.24 (0.18)	-0.18 (0.15)	0.36[a]	1.00
Distance swum (m)	1560 (311.77)	1505 (291.97)	1633 (210.78)	0.50[a]	0.11
Afterdrop duration (minutes)	2.5 (3.53)	3.14 (2.85)	1.44 (1.01)	0.8[b]	0.43
Duration on bike before rewarmed (minutes)	30.50 (43.10)	16.14 (13.18)	10.56 (9.26)	0.49[a]	0.06
Mean power during first 10 minutes of bike (W)	221.17 (14.07)	206.40 (20.16)	216.35 (28.81)	0.40[a]	0.37

Skins swims	**14SS**	**16SS**	**Effect size**[1]	**p**
n	9	11		
Δ T_{re} during swim (°C)	-1.12 (0.71)	-0.59 (0.50)	0.88[d]	0.01*
Δ T_{re} after swim (°C)	-0.77 (0.41)	-0.49 (0.28)	0.81[d]	0.19
Distance swum (m)	1433 (187.17)	1447 (151.03)	0.08	0.92
Afterdrop duration (minutes)	10.62 (11.75)	5.18 (4.40)	0.64[d]	0.20
Duration on bike before rewarmed (minutes)	54.57 (49.25)	34.10 (19.55)	0.57[c]	0.18
Mean power during first 10 minutes of bike (W)	191.28 (35.48)	202.06 (20.87)	0.38[c]	0.29

*significant difference between 12WS and 14WS ($p \leq 0.05$). [1] Cohen's *d*. [2] Significance (2-tailed) of difference between 12WS and 14WS conditions. [a] small effect of water temperature between 12WS and 14WS conditions. [b] moderate effect of water temperature between 12WS and 14WS conditions. [c] small effect of water temperature between 14SS and 16SS conditions. [d] moderate effect of water temperature between 14SS and 16SS conditions. T_{re} = deep body (rectal) temperature.

Table 4. Mean (SD) change in scores for test battery before and after the swim in each condition

Wetsuit conditions	**10WS**	**12WS**	**14WS**	**Effect size** [1]	**P**[2]
n	3	9	9		
Δ Grip strength (kg)	-4.5 (1.63)	-4.85 (4.86)	-2.67 (4.68)	0.43	0.33
Δ Response time for CRT (ms)	-33.34 (26.41)	-57.00 (109.16)	-6.43 (23.56)	0.43	0.71
Δ Errors in CRT (%)	1.67 (1.18)	0.83 (3.12)	2.78 (3.12)	0.42	0.34
Δ Time to complete bike course (s)	-0.54 (0.52)	-1.10 (1.20)	-0.74 (0.73)	0.57	0.37
Δ Error on bike course (%)	11.02 (9.71)	12.77 (10.23)	2.63 (9.54)	0.86[a]	0.28

Skins conditions		**14SS**	**16SS**	**Effect size**[1]	**p**
n		9	11		
Δ Grip strength (kg)		-5.11 (3.1)	-6.64 (4.53)	0.33	0.06
Δ Response time for CRT (ms)		24.79 (26.79)	36.59 (46.98)	0.33	0.37
Δ Errors in CRT (%)		2.5 (3.73)	1.82 (4.53)	0.56	0.73
Δ Time to complete bike course (s)		-1.85 (1.77)	-2.12 (2.08)	0.44	0.86
Δ Error on bike course (%)		24.87 (24.02)	13.24 (26.73)	0.89[b]	0.11

[1] PS_{dep}. [2] significance (2-tailed) of difference between 12WS and 14WS conditions. [a] large effect of water temperature between 12WS and 14WS conditions. [b] large effect of water temperature between 14SS and 16SS conditions. CRT = Choice Reaction Test.

DISCUSSION

This study aimed to ascertain safe lower water temperature limits, with and without wetsuits, for elite and high-level ‘age group’ athletes. Currently and to our knowledge, it is the first study to quantify the deep body temperature, performance and psychomotor responses that occur in semi-elite and elite triathletes whilst swimming in cold water, and provided evidence for the revision of ITU rules.[2]

Four objective criteria were applied to each condition to determine whether the condition was safe for racing, as described in the Methods. All athletes successfully completed all criteria in 14WS and 16SS conditions, and 10 out of 11 in 12WS conditions. In contrast, most participants did not successfully complete criteria in 14SS and 10WS. These observations led to a recommendation that a lower limit be set of 12 °C for wetsuit racing and 16 °C for skins racing, and ITU rules were amended accordingly (Supplementary tables 1 and 2).[2] The hypothesis that existing lower water temperature rules were appropriate was therefore rejected.

Swimming capability

Completing the swim was problematic in the 10WS condition. 4 of 7 athletes refused to swim due to the cold shock response, complaining of breathing difficulties and headaches.

The reduction in functional swimming capability noted by Tipton et al.[4] was not observed in these shorter swims. Even with rapid heat loss, the triathletes maintained swim speed for the duration of each condition and there was no difference in swim performance between conditions. This may be due to the highly-trained nature of the athletes, and the consequent fact that they were able to work at high levels of heat production thereby better maintaining muscle temperature. The increased peripheral (muscle) blood flow required to support this activity would help (along with low body fat levels – see below) to explain the unusually rapid falls in deep body temperature.[16, 17] Further investigation in this area would be useful.

Maintaining deep body temperature

Clinical hypothermia is defined as a deep body temperature below 35 °C.[14] Existing literature indicates that maintaining deep body temperature in cold water is a significant challenge due to the high heat capacity and thermal conductivity of water,[5,20,21] and that those who are lean are likely to cool more rapidly due to lower insulation from subcutaneous fat.[15] The current study supports this, with athletes most vulnerable to cooling being those with the least sub-cutaneous fat (sum of seven skinfolds around 40 mm or less): the leanest participants in the study showed a rapid rate of fall of T_{re}, with two triathletes reaching a T_{re} of 35 °C following 20 minutes of swimming in 14SS, in spite of a high work rate and therefore high metabolic heat production (Figures 1 and 2).

The impact of wearing a wetsuit on rate of deep body cooling was large. On average, the fall in T_{re} was over five times greater during the 14SS condition than the 14WS condition (Table 3).

Skills and safe completion of bike course

Muscle fatigue and reduced grip strength have been observed after cold swimming.[4] This is important for triathletes, who start cycling (and need to safely control bikes and operate brakes) immediately after leaving the water. This criterion was only problematic in the 14SS condition, where half (4 out of 8) of those who completed the swim without hypothermia were unable to grip handlebars due to cold/numb fingers.

Statistical analysis of skills tests (Table 4) indicated that time taken to complete the bike course was not affected by the swim condition, but error rate was, with a large effect size; almost all athletes showing a greater increase in error after the 14SS than the 16SS swim, and after the 12WS than the 14WS swim.

CRT response time was only higher following skins swims. This may correspond with lower neuromuscular temperatures in arms and hands, resulting in slower movement times, rather than a slowing of the decision-making process.[23] This is relevant to cycling as slowing response times (due to peripheral or central mechanisms) may increase the risk of accident. Errors in CRT were very low, before and after the swim for every condition and there was no significant difference between conditions.

Rewarming during cycle

Only one participant failed to rewarm during the cycle, in the 14SS condition. Further T_{re} cooling after completing the swim was observed, with the coldest T_{re} mostly during the cycling (Figures 1 and 2 and Table 3). Additional cooling after leaving cold water has been observed previously.[17–20, 23]. This is likely caused by a conductive process: peripheral tissues being colder than deep muscles. The effect may be more pronounced during exercise due to increased muscle blood flow.[21,22] The lack of significant difference in the size and time of afterdrop between WS and SS may reflect the small sample size (power for wetsuit swims = 0.52; for skins swims = 0.32).

Wetsuits reduced the time taken to rewarm on the bike (Table 3). Trappe et al.[24] found that use of a wetsuit in the swim reduced the afterdrop during a subsequent cycle. These findings are consistent with a conductive mechanism for the afterdrop,[23,24] indicating slower rates of fall of T_{re} on immersion in wet suits, and smaller gradient from skin to deep body temperature.[18] The current study extends the work of Trappe et al.[19] to lower water temperatures and performance athletes.

Limitations/further study

The small sample size (initially 12) was a consequence of the demands of the study. The statistical power of the results is therefore limited. Further, although all participants were lean, and 'vulnerable' to cooling, there was individual variability (Table 1). More females would be preferred, however vulnerability was related to physiological characteristics regardless of sex.[32] Further research with a larger pool of athletes would be recommended to confirm the recommendations and more aptly guide the ITU.

Athletes were self-paced and there was no control over individual heat production or water velocity, both of which will affect cooling rates. A study which controlled pace would give more information about factors involved in cooling.

There was no control over quality or thickness of wetsuits. A further study to quantify the impact of wetsuit thickness at different water temperatures would be useful.

Safety criteria were objective, but it is arbitrary what percentage of athletes should constitute pass/fail for any condition. In practice, detailed results were considered in limiting distances for racing in 12 °C [2].

CONCLUSION/RECOMMENDATIONS

The results of the present study are particularly relevant to elite triathletes, in part due to their combination of low body fat and high heat production potential. Without wetsuits, 14 °C was too cold for racing due to the rapid fall in T_{re} and inability to safely control a bike. 10 °C was too cold for wetsuit racing due to cold shock responses.

It was recommended to the International Triathlon Union that 12 °C wetsuit swims and 16 °C skins swims are the minimum realistic water temperatures for athletes, and rules should be changed accordingly. Following the report, ITU rules for racing in lower water temperatures were amended to allow racing from 12 °C with wetsuits mandatory up to 16 °C. Full details are shown in Supplementary Tables 1 and 2.[2]

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CONTRIBUTORS

All co-authors contributed to the study design and data collection. JS processed and analysed the data, and wrote the draft of the manuscript. All authors contributed to revising the draft of the manuscript.

COMPETING INTERESTS

None.

ETHICAL APPROVAL INFORMATION

The study was approved by The University of Portsmouth Science Faculty Research Ethics Committee (code 2014–087).

DATA SHARING

All unpublished data is available on request to the corresponding author.

REFERENCES

1. ITU rulebook 2014 [Internet]. [cited 2014 Feb 11]. Available from: http://www.triathlon.org/uploads/docs/itusport_competition-rules_15122013-highlighted1.pdf
2. USA triathlon. USA Triathlon Fatality Incidents Study. USA Triathlon. 2012;1–14. Available from: https://www.teamusa.org/USA-Triathlon/News/Articles-and-Releases/2012/October/25/102512-Medical-Panel-Report
3. Tipton MJ. The initial responses to cold-water immersion in man. *Clin Sci*. 1989;77:581–8. Available from: http://www.clinsci.org/content/ppclinsci/77/6/581.full.pdf

4. Barwood M, Burrows H, Cessford J, Fraser L, Goodall S, Griffiths S. Brain blood flow and hyperventilation on cold water immersion : can treading water help control these symptoms of cold shock ? *Extrem Physiol Med*. BioMed Central Ltd; 2015;4(Suppl 1):A40. Available from: http://www.extremephysiolmed.com/content/4/S1/A40

5. Stocks J, Taylor N, Tipton M, Greenleaf J. Human physiological responses to cold exposure. *Aviat Sp Environ Med*. 2004;75(5):444–57. Available from: http://apps.webofknowledge.com.libproxy.uoregon.edu/full_record.do?product=WOS&search_mode=GeneralSearch&qid=13&SID=1F6vOVWXQZg9XhaJZga&page=1&doc=7

6. Tipton M, Eglin C, Gennser M, Golden F. Immersion deaths and deterioration in swimming perform ance in cold wa ter. *Lancet*. 1999;354:626–9.

7. Rüst CA, Knechtle B, Rosemann T. Changes in body core and body surface temperatures during prolonged swimming in water of 10°C-a case report. *Extrem Physiol Med*. 2012 Jan;1(1):8. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3710093&tool=pmcentrez&rendertype=abstract

8. Tipton M, Bradford C. Moving in extreme environments: open water swimming in cold and warm water. *Extrem Physiol Med*. 2014;3(12):1–21.

9. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. *Med Sci Sports Exerc*. 1980 Jan;12(3):175–81. Available from: http://www.ncbi.nlm.nih.gov/pubmed/7402053

10. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr.* 1978 Nov;40(3):497–504. Available from: http://www.ncbi.nlm.nih.gov/pubmed/718832

11. Siple P, Passel C. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proceedings of the American Philosophical Society*. 1945. p. 177–99. Available from: http://www.jstor.org/discover/10.2307/985324?uid=3738032&uid=2134&uid=2&uid=70&uid=4&sid=21104259262961

12. Deary IJ, Liewald D, Nissan J. The Deary-Liewald reaction time task. *Behav Res Methods*. 2011 Mar;43(1):258–68. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21287123

13. Tipton MJ, Stubbs DA, Elliott DH. Human initial responses to immersion in cold water at three temperatures and after hyperventilation. *J Appl Physiol*. 1991 Jan;70(1):317–22. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2010387

14. Weir JBD V. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol*. 1949;109(5):1–9.

15. Toussaint HM, Knops W, De Groot G, Hollander AP. The mechanical efficiency of front crawl swimming. *Med Sci Sports Exerc*. 1990;22(3):402–8.

16. Du Bois D, Du Bois E. A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med*. 1916;17(6):863–71.

17. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3–12.

18. ITU Competition Rules. [cited 2017 May 18];8–12. Available from: http://www.triathlon.org/uploads/docs/itusport_competition-rules_2017.pdf

19. Castellani J, Young A, Ducharme M, Giesbrecht G, Glickman E, Sallis R, et al. American College of Sports Medicine position stand: prevention of cold injuries during exercise. *Med Sci Sports*

Exerc. 2006;38(11):2012–29.

20. McArdle WD, Magel JR, Spina RJ, Gergley TJ, Toner MM. Thermal adjustment to cold-water exposure in exercising men and women. *J Appl Physiol*. 1984;56(6).

21. Brannigan D, Rogers IR, Jacobs I, Montgomery A, Williams A, Khangure N. Hypothermia is a significant medical risk of mass participation long-distance open water swimming. *Wilderness Environ Med*. 2009 Jan;20(1):14–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19364182

22. Keatinge WR. The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. *J Physiol* . 1960 Aug;153:166–78. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1359738&tool=pmcentrez&rendertype=abstract

23. Enander A. Effects of moderate cold on performance of psychomotor and cognitive tasks. *Ergonomics*. 1987 Oct;30(10):1431–45. Available from: http://www.ncbi.nlm.nih.gov/pubmed/3428250

24. Giesbrecht GG, Bristow GK. A second postcooling afterdrop: more evidence for a convective mechanism. *J Appl Physiol*. 1992 Oct;73(4):1253–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1447067

25. Giesbrecht GG, Goheen MS, Johnston CE, Kenny GP, Bristow GK, Hayward JS. Inhibition of shivering increases core temperature afterdrop and attenuates rewarming in hypothermic humans. *J Appl Physiol*. 1997;83(5):1630–4. Available from: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9375331%5Cnhttp://www.ncbi.nlm.nih.gov/pubmed/9375331

26. Trappe TA, Pease DL, Trappe SW, Troup JP, Burke ER. Physiological responses to swimming while wearing a wet suit. Vol. 17, *International journal of sports medicine.* 1996.

27. Golden F, Hervey GR. The afterdrop and death after rescue from immersion in cold water. In: Adam JA, editor. *Hypothermia Ashore and Afloat*. Aberdeen University Press, Aberdeen; 1981.

28. Hong SI, Nadel ER. Thermogenic control during exercise in a cold environment. *J Appl Physiol*. 1979 Nov;47(5):1084–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/511710

29. Kruk B, Pekkarinen H, Harri M, Manninen K, Hanninen O. Thermoregulatory responses to exercise at low ambient temperature performed after precooling or preheating procedures. *Eur J Appl Physiol Occup Physiol*. 1990 Jan;59(6):416–20. Available from: http://link.springer.com/10.1007/BF02388622

30. Tomikawa M, Shimoyama Y, Nomura T. Factors related to the advantageous effects of wearing a wetsuit during swimming at different submaximal velocity in triathletes. *J Sci Med Sport*. 2008 Jul;11(4):417–23. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17387042

31. Trappe TA, Starling RD, Jozsi AC, Goodpaster BH, Trappe SW, Nomura T, et al. Thermal responses to swimming in three water temperatures: influence of a wet suit. *Med Sci Sports* Exerc. 1995;27(7):1014–21.

32. Solianik R, Skurvydas A, Vitkauskiene A, Brazaitis M. Gender-specific cold responses induce a similar body-cooling rate but different neuroendocrine and immune responses. *Cryobiology.* 2014; 69(2)

FIGURE LEGENDS

Figure 1. Rectal temperature changes for participants in wetsuit conditions. (A) 10WS, n=3; (B) 12WS, n=10; (C) 14WS, n=9.The break in the data is during the transition period, where thermistors were temporarily unplugged while participants completed the bike course. Volunteer numbers: black dash = 1; filled circle = 2; filled square = 3; filled triangle = 5; filled diamond = 6; open circle = 7; open square = 8; open triangle = 9; open diamond = 10; grey dash = 11; cross = 12.

Figure 2. Rectal temperature changes for all participants in skins conditions. (D) 14SS, n=10; (E) 16SS, n=11. The break in the data is during the transition period, where thermistors were temporarily unplugged to all for completion of bike course. Volunteer numbers: black dash = 1; filled circle = 2; filled square = 3; filled triangle = 5; black cross = 4; filled diamond = 6; open circle = 7; open square = 8; open triangle = 9; open diamond = 10; grey dash = 11; grey cross = 12.