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Physiological and perceptual responses of wearing a dryrobe for rewarming after passive cold-water immersion in men

Dale B Read ,[1,2] Tess R Flood ,[1] Amy E Harwood ,[1] Thomas Dos'Santos,[1] Jonathon J S Weakley,[3,4] Gethin H Evans[5]

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[1]Department of Sport and Exercise Sciences, Institute of Sport, Manchester Metropolitan University, Manchester, UK
[2]Carnegie Applied Rugby Research (CARR) Centre, Carnegie School of Sport, Leeds Beckett University, Leeds, UK
[3]Sports Performance, Recovery, Injury and New Technologies (SPRINT) Research Centre, Australian Catholic University, Brisbane, Queensland, Australia
[4]School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, Queensland, Australia
[5]Department of Life Sciences, Manchester Metropolitan University, Manchester, UK

Correspondence to
Dr Dale B Read; d.read@mmu.ac.uk

ABSTRACT

Objectives To investigate the physiological and perceptual responses to wearing a dryrobe for rewarming after passive cold-water immersion (CWI).

Methods 15 unhabituated healthy Caucasian men (age: 28.9 (5.4) years) attended the laboratory on three occasions and performed passive CWI (14°C) for 30 min followed by 15 min of rewarming wearing either a dryrobe, towel or foil blanket while positioned in front of fans replicating a 10 mph wind. Physiological (deep body temperature, skin temperature and heart rate) and perceptual (thermal sensation and thermal comfort) variables were measured.

Results At 15 min post-immersion, deep body temperature was higher in the dryrobe condition (mean: 37.09 (SD: 0.49)°C) compared with the foil blanket (36.98 (0.64)°C) and towel (36.99 (0.49)°C) (p<0.001). On average across the 15 min post-immersion period, the dryrobe increased skin temperature to the greatest degree (18.9 (1.0)°C, +2.4°C), compared with the foil blanket (18.1 (1.2)°C, +1.8°C, p=0.034) and the towel (16.6 (1.2)°C, +1.3°C, p<0.001). Average heart rate across the 15 min post-immersion period was lower when wearing the dryrobe (dryrobe: 74 (10) b.min^{-1}, foil blanket: 78 (6) b.min^{-1} and towel: 82 (14) b.min^{-1} (p=0.015). Thermal sensation and thermal comfort were higher at all post-immersion time points in the dryrobe compared with the foil blanket and towel.

Conclusions During the rewarming period following CWI, physiological and perceptual responses are improved when wearing clothing that combines an insulative layer with a vapour barrier, such as the dryrobe compared with a towel or foil blanket. This might have future implications for safety recommendations during rewarming.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Participation in cold-water immersion (CWI) such as outdoor swimming and ice baths has increased in popularity.
⇒ The recommendations for rewarming following CWI, that include changing into warm/dry clothing, are generally accepted.
⇒ Simulated studies show that after wearing wet clothes, rewarming is improved when the clothing consists of a combination of an insulative and vapour barrier layer.

WHAT THIS STUDY ADDS

⇒ The study demonstrates that following CWI, physiological and perceptual responses are improved in the rewarming period when wearing a garment that is a combination of an insulative and vapour barrier layer such as the dryrobe compared with a towel or foil blanket.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Rewarming policymakers are encouraged to recommend wearing clothing that combines an insulative layer with a vapour barrier, such as the dryrobe following CWI.

INTRODUCTION

Participation in cold-water immersion (CWI) such as outdoor swimming and ice baths has increased in popularity over the last few years.[1] These activities result in exposure to cold water in addition to the potential of low air temperatures and high winds when undertaken in seas, rivers or lakes. Due to this increase in participation, safety during immersion and the post-immersion period known as rewarming remains vital. The physiological responses to initial and prolonged CWI such as cold shock response and hypothermia are well documented.[2 3] However, less research has been conducted on rewarming following CWI.

After CWI, a phenomenon known as afterdrop can occur, where there is a continued drop in deep body temperature during the rewarming phase.[4] The afterdrop is thought to occur from cold blood returning to the core from the periphery of the body and is a serious complication of CWI and in extreme cases can lead to ventricular fibrillation. Current recommendations for rewarming include consuming a hot drink, relocating to a warmer environment and changing into warm/dry clothing.[5] However, despite the potentially dangerous impact of CWI and the rising popularity of open water swimming and other water-based sports,[1 6] little to no research has examined different types of clothing after CWI and the impact on physiological and perceptual responses.

A previous study has shown that woollen blankets were less efficient at preventing heat loss than foil blankets; however, this was an in vitro study and therefore making extrapolation of the findings to humans is difficult.[7] Two previous studies have also investigated different clothing options to passively rewarm participants after placing them in wet clothing and concluded that the combination of an insulative layer with a vapour barrier is more effective at preventing heat loss and produces higher ratings of thermal comfort compared with single-layered options.[8 9] This suggests the clothing worn after CWI to improve rewarming should be a combination of an insulative and vapour barrier layer. However, both of these abovementioned studies placed participants in wet clothing but did not immerse them in cold water.[8 9] Therefore, to date, no study has yet specifically investigated the effect of different clothing options following CWI, in particular the comparison of single and dual-layered clothing.

A dryrobe is a commercially available garment that has been designed to support the rewarming phase following CWI.[10] The dryrobe has a synthetic lambswool lining and a nylon waterproof outer shell.[10] The garment was originally designed to improve on the existing option of a towel, and other alternatives such as the foil blanket which are used after races or during emergencies to rewarm humans. Theoretically, the dryrobe garment could provide a viable solution to improve rewarming post-CWI in humans; however, the efficacy of the garment in this situation has yet to be investigated.

Therefore, this study aimed to assess whether there were any differences in physiological (ie, deep body temperature, skin temperature or heart rate) or perceptual (ie, thermal sensation or thermal comfort) responses to wearing a dryrobe compared with a towel or foil blanket following 30 min passive CWI (14°C). It was hypothesised that the dryrobe would be the most effective option to improve physiological and perceptual variables during the rewarming phase.

METHODS

Participants

Using an effect size of 3.7 based on the difference in skin temperature at 15 min (25.6 (0.8)°C vs 28.5 (0.8)°C) wearing evaporative clothing and low evaporative clothing following CWI,[11] an alpha of 0.05 and a power of 0.80, a power calculation for a repeated-measures analysis of variance (ANOVA) was performed using G*Power software (V.3.1.9.7, University Kiel, Germany).[12] Accordingly, 15 unhabituated healthy Caucasian male participants were recruited (convenience sample) and gave written informed consent prior to commencing the study (age: 28.9 (5.4) years; height: 177.9 (5.2) cm; body mass: 83.8 (7.4) kg; estimated body fat percentage: 16.2 (4.1) %). Participants were excluded if they had; any heart conditions, asthma or lung disorders, high blood pressure (>140/90 mm Hg), any major gastrointestinal operations or dermatological conditions.

Design

A counterbalanced repeated-measures experimental design was used, whereby participants attended the laboratory on three occasions to complete 30 min passive head-out CWI followed by passive rewarming with one of three different clothing conditions. Participants were randomly assigned to the three clothing conditions using a counterbalanced Latin square design (1) dryrobe (long-sleeve dryrobe Advance, dryrobe, Barnstaple, UK, outer shell—100% recycled nylon, lining—lambswool 100% polyester, dryrobe size was assigned based on manufacturer guidance for size); (2) towel (500 gsm, Brentfords, England, 100% cotton—dimensions L:90× H:150 cm); (3) foil blanket (Reliance Medical, Stoke-on-Trent, UK—dimensions L:127× H:180 cm). Visits were separated by a minimum of 24 hours and were conducted at the same time of the day (±1 hour),[13 14] with participants asked to avoid strenuous exercise and alcohol in the preceding 24 hours and caffeine on the day of each visit. The dietary intake was standardised by asking participants to keep a dietary intake log for 24 hours prior to their first visit and then were asked to replicate this dietary intake for their subsequent visits.

Instrumentation

On the first visit to the laboratory (Institute of Sport, Manchester, UK), height (Seca 213, Seca, Hamburg, Germany) and body mass (Seca 807 Aura, Seca, Hamburg, Germany) were measured and body composition was estimated via bioelectrical impedance analysis at 50 kHz (Bodystat 1500, Bodystat, Douglas, Isle of Man).

Deep body temperature was measured using an ingestible telemetric pill (e-Celsius performance pills, BodyCap, Caen, France, SEM=0.039°C.)[15] The pill was ingested >5 hours before each trial and where trials were completed on consecutive days, it was checked using the receiver that the first pill had been passed before a second trial commenced. Before each trial could commence, a stable and comparable deep body temperature was achieved (±0.3°C) and if this was not achieved initially participants waited until deep body temperature was within the range before commencing the data collection.[14] Skin temperature was measured using iButtons (DS1922L Thermochron iButton, iButton, Newbury, UK, SEM=0.121°C)[16] attached at four sites: midpoint of the right triceps brachii lateral head (arm), midpoint of the right pectoralis major (chest), right rectus femoris (quadricep) and right gastrocnemius lateral head (calf). Mean skin temperature was calculated using the following equation: (mean skin temperature=0.3·arm+0.3·chest+0.2·quadricep+0.2·calf).[17] Heart rate was measured using a chest strap monitor (Polar H10, Polar Electro Oy, Kempele, Finland, SEM=0.07 b.min^{-1}).[18] All physiological data were measured at 1 min intervals throughout.

Thermal sensation (1–7 Likert scale) and thermal comfort (1–4 Likert scale) were measured using standardised scales throughout the entire study at 5 min intervals.[19] The thermal sensation scale (1=cold, 2=cool, 3=slightly cool, 4=neutral, 5=slightly warm, 6=warm, 7=hot) was shown to the participants, and they were asked 'How does the temperature of your body feel?'.[19] The thermal comfort scale (1=very uncomfortable, 2=uncomfortable, 3=slightly uncomfortable, 4=comfortable) was shown to the participants, and they were asked 'How comfortable do you feel with the temperature of your body?'.[19] All participants were familiarised with the scales prior to their use at each visit.

Protocol

Pre-immersion

Participants changed into knee-length swimming jammers and a dryrobe before entering the environmental chamber where 10 min of baseline data was collected. The environmental chamber (Sport Edge, UK) ensured the conditions (air temperature: 12°C and relative humidity: 35%) remained consistent throughout and replicated typical conditions individuals might experience during outdoor CWI in the UK.

Immersion

Following pre-immersion data collection, the participants were given 1 min to remove the dryrobe and enter the ice bath (iCool MiPod, iCoolsport, Burleigh Heads, Australia) which contained still water of 14°C, which represents typical sea water temperature in the UK.[20] The ice bath had the following dimensions (L:1.5× W:0.8× H:1.2 m) and contained an inbuilt seat so the participants were immersed in the water up to the level of their clavicle for 30 min. Hands were immersed throughout, and no gloves were worn. Participants were free to withdraw themselves from the water at any point and a deep body temperature of 35°C was used as the threshold for removing participants to ensure safety.[13 21]

Post-immersion

Following 30 min of immersion participants exited the water and were given 1 min to towel off any excess water. They were then provided with either a dryrobe, towel or foil blanket to wear while seated for 15 min. Wearing of the three options was standardised, with the dryrobe zipped up with the hood down, the towel wrapped around the upper body and the foil blanket also wrapped around the upper body but due to the length, the foil blanket also covered some of the lower body. The towel covered two of the iButtons (ie, arm and chest), while the dryrobe and the foil blanket also covered the quadricep iButtons. To simulate conditions, participants were positioned in front of two 45 cm diameter circular electric fans (Belaco, Doncaster, UK) that provided an air flow and replicated a wind speed of 10 mph, as measured via an anemometer (BT100, BTMETER, Zhuhai, China) for 15 min. One fan was directed at the participant's lower body and the second at the upper body from 1.5 m away.

Statistical analyses

Unless stated, all data are presented as mean (SD). All data were analysed using SPSS V.27 (IBM, Armonk, USA), with an alpha level of 0.05 set for statistical significance. Physiological and perceptual data were checked for normality using the Shapiro-Wilk test and confirmed all data were parametric. An one-way repeated measures ANOVA was run to compare consistency measures across the trials. Separate two-way repeated measures ANOVAs were used to test condition (dryrobe, towel, foil blanket) and time for pre-immersion, immersion and post-immersion in 5 min intervals. Assumptions of sphericity were checked using Mauchly's test and adjusted if

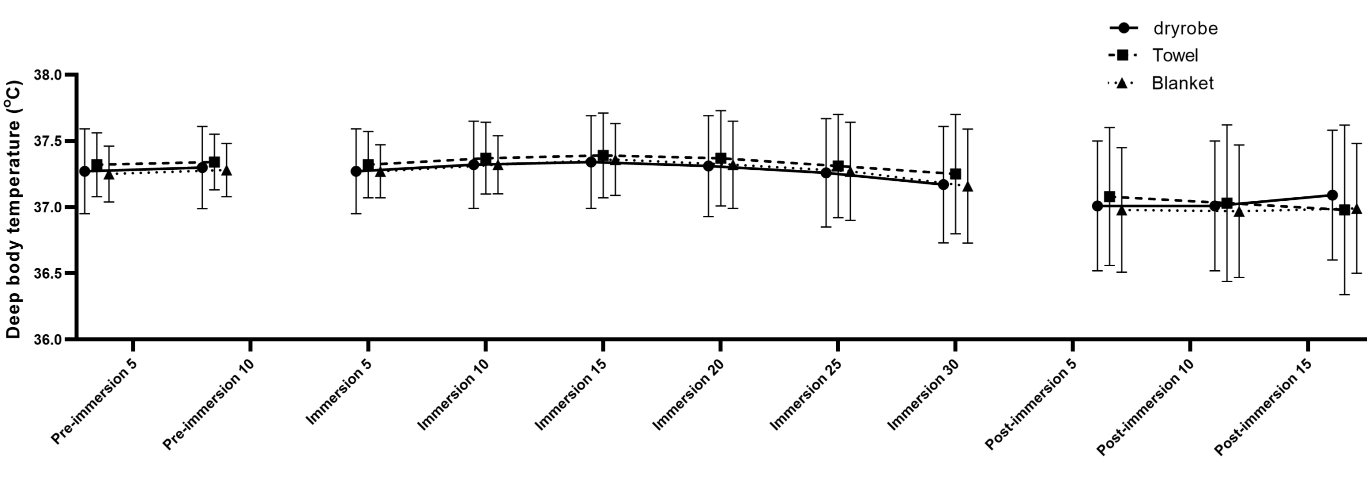

Figure 1 Deep body temperature (mean and SD error bars) during pre-immersion, immersion and post-immersion for all three conditions (ie, dryrobe, towel and foil blanket).

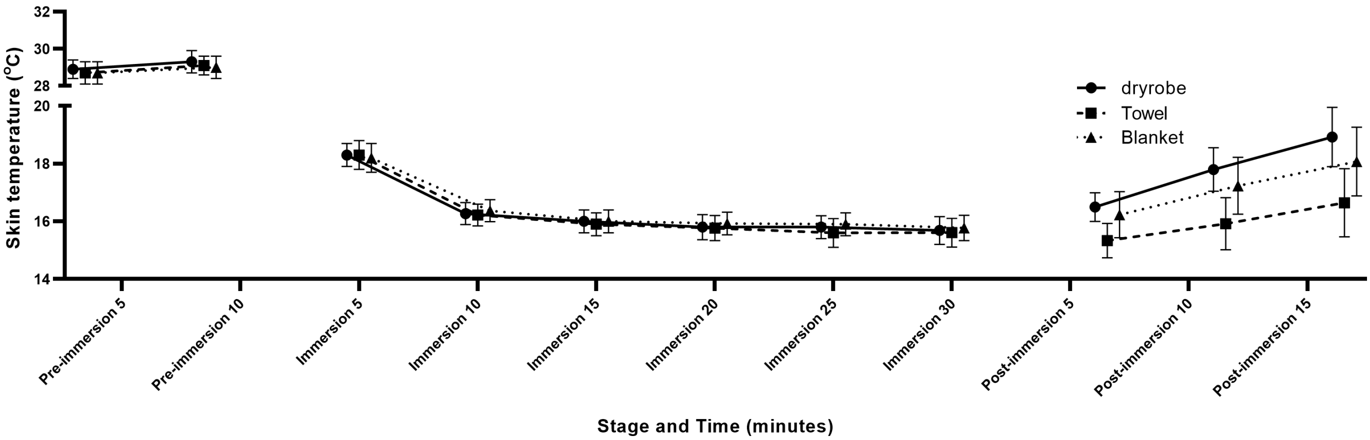

Figure 2 Skin temperature (mean and SD error bars) during pre-immersion, immersion and post-immersion for all three conditions (ie, dryrobe, towel and foil blanket).

sphericity was not assumed. Where significance was found in a main effect, pairwise comparisons were conducted. Partial eta squared (η_p^2) was used to denote the effect size of the ANOVA main effects.

RESULTS

Consistency measures

There was no effect of condition on air temperature (11.7 (0.6)°C, $F_{(2,26)}$=0.321, p=0.728, η_p^2=0.024) or relative humidity (37 (3)%, $F_{(2,26)}$=0.984, p=0.387, η_p^2=0.070) in the environmental chamber, nor water temperature of the ice bath (14.1 (0.2)°C, $F_{(2,26)}$=1.00, p=0.382, η_p^2=0.071).

Deep body temperature

Figure 1 shows deep body temperature throughout the study. Pre-immersion, deep body temperature increased across the 10 min by on average +0.02 (0.03)°C, ($F_{(1,14)}$=10.641, p=0.006, η_p^2=0.432) but was not different between conditions ($F_{(2,28)}$=0.999, p=0.381, η_p^2=0.067). During immersion, deep body temperature fell on average −0.09 (0.23)°C across the 30 min ($F_{(1.1,16.2)}$=6.407, p=0.19, η_p^2=0.314), but was not different between conditions ($F_{(2,28)}$=0.859, p=0.434, η_p^2=0.58). An afterdrop was seen at 5 min post-immersion of −0.16 (0.11)°C in the dryrobe, −0.16 (0.14)°C in the towel and −0.18

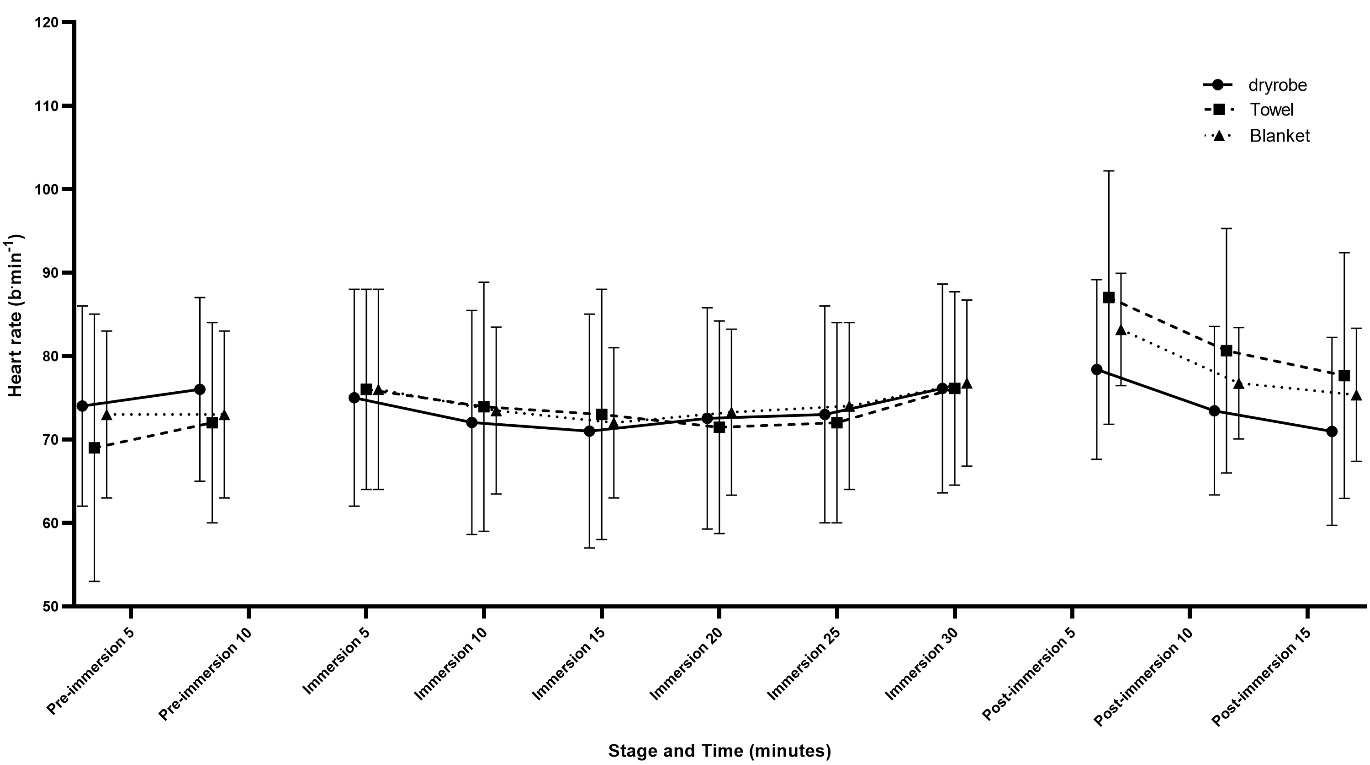

Figure 3 Heart rate (mean and SD error bars) during pre-immersion, immersion and post-immersion for all three conditions (ie, dryrobe, towel and foil blanket).

(0.13) °C in the foil blanket. An interaction effect was seen ($F_{(4,56)}$=9.247, p<0.001, η_p^2=0.398) with an increase in deep body temperature at 15 min in the dryrobe condition (37.09 (0.49) °C) compared with the foil blanket (36.98 (0.64) °C) and towel (36.99 (0.49) °C). Across the 15 min post-immersion, on average there was no difference in deep body temperature between the conditions (15 min average: dryrobe; 37.04 (0.49) °C, towel; 37.03 (0.58) °C, foil blanket; 36.98 (0.48) °C, $F_{(2,28)}$=0.495, p=0.615, η_p^2=0.34). There was also no difference in deep body temperature across the 15 min ($F_{(1.1,14.9)}$=0.296, p=0.609, η_p^2=0.21).

Skin temperature

Figure 2 shows skin temperature throughout the study. Pre-immersion, skin temperature increased across the 10 min by on average +0.4 (0.2) °C ($F_{(1,14)}$= 71.780, p<0.01, η_p^2=0.837), but was not different between conditions ($F_{(2,28)}$=0.729, p=0.491, η_p^2=0.050). During immersion, skin temperature fell on average by −2.6 (0.4) °C across the 30 min ($F_{(1.5,21.2)}$=43.494, p<0.001, η_p^2=0.971), but was not different between conditions ($F_{(2,28)}$=0.372, p=0.693, η_p^2=0.26). Post-immersion, an interaction effect was seen with the dryrobe and foil blanket increasing skin temperature to a greater extent than the towel at all three time points (5 min; dryrobe +1.2 (0.7) °C, foil blanket +0.9 (1.0) °C, 10 min dryrobe +1.9 (0.9) °C, foil blanket +1.3 (1.3) °C, 15 min, dryrobe +2.3 (1.3) °C, foil blanket +1.4 (1.4) °C), $F_{(2.34,32.4)}$=14.829, p<0.001, η_p^2=0.514). Skin temperature increased across the 15 min in all conditions ($F_{(1.1,15.2)}$=157.240, p<0.001, η_p^2=0.918) and was different between conditions ($F_{(2,28)}$= 23.059, p<0.001, η_p^2=0.622). On average the dryrobe increased skin temperature to the greatest degree (18.9 (1.0) °C, +2.4°C), compared with the foil blanket (18.1 (1.2) °C, +1.8°C, p=0.034) and the towel (16.6 (1.2) °C, +1.3°C, p<0.001).

Heart rate

Figure 3 shows heart rate throughout the study. Pre-immersion, heart rate did not change across the 10 min ($F_{(1,14)}$=1.340, p=0.278, η_p^2=0.087) and was not different between conditions ($F_{(2,28)}$=2.674, p=0.124, η_p^2=0.160). During immersion, heart rate changed across time ($F_{(2.4,34.9)}$=5.950, p=0.004, η_p^2=0.298), but was not different between conditions ($F_{(2,28)}$=0.144, p=0.867, η_p^2=0.10). Post-immersion, no interaction effect was seen ($F_{(4,56)}$=0.579, p=0.679, η_p^2=0.40). Heart rate decreased across the 15 min in all conditions ($F_{(1.3,18.7)}$=25.805, p<0.001, η_p^2=0.648). There was a difference between conditions with the dryrobe decreasing heart rate to the greatest extent across the 15 min, compared with the foil blanket and towel (dryrobe average: 74 (10) b.min^{-1}, foil blanket average: 78 (6) b.min^{-1} and towel average: 82 (14) b.min^{-1}, $F_{(1.4,20.2)}$=5.991, p=0.015, η_p^2=0.300).

Thermal sensation

Figure 4 shows thermal sensation and thermal comfort throughout the study. Pre-immersion thermal sensation did not alter across the 10 min ($F_{(1,14)}$=0.135, p=0.719, η_p^2=0.010) and was not different between conditions ($F_{(2,28)}$=2.014, p=0.152, η_p^2=0.126). During immersion, thermal sensation decreased across time ($F_{(2.1,29.6)}$=7.651, p=0.002, η_p^2=0.353) but did not differ between conditions ($F_{(2,28)}$=0.130, p=0.878, η_p^2=0.009). Post-immersion, an interaction effect was seen with thermal sensation being higher at all post-immersion time points in the dryrobe compared with the foil blanket and towel ($F_{(23.4,33.3)}$=6.246, p=0.003, η_p^2=0.308). Thermal sensation increased across the 15 min ($F_{(1.2,16.7)}$=9.478, p=0.005, η_p^2=0.404), and differed between conditions ($F_{(1.3,19.4)}$=17.346, p<0.001, η_p^2=0.553).

Thermal comfort

Pre-immersion thermal comfort did not alter across the 10 min ($F_{(1,14)}$=1.000, p=0.381, η_p^2=0.067) and was not different between conditions ($F_{(2,28)}$=1.00, p=0.334, η_p^2=0.067). During immersion, thermal comfort decreased across time ($F_{(1.9,29.6)}$=11.864, p<0.001, η_p^2=0.459) but did not differ between conditions ($F_{(1.4,18.9)}$=1.374, p=0.267, η_p^2=0.089). Post-immersion, an interaction effect was seen with thermal comfort being higher at all post-immersion time points in the dryrobe compared with the foil blanket or towel ($F_{(2.94,40.9)}$=5.524, p=0.003, η_p^2=0.283). Thermal comfort increased across the 15 min ($F_{(1.3,18.2)}$=12.187, p<0.001, η_p^2=0.465), and differed between condition ($F_{(1.5,20.7)}$=32.774, p<0.001, η_p^2=0.701).

DISCUSSION

The aim of the present study was to investigate the physiological and perceptual responses to wearing a dryrobe, towel and foil blanket following CWI. The main findings of the study were that skin temperature was higher and heart rate was lower when wearing the dryrobe compared with wearing the towel and foil blanket post-immersion. Deep body temperature also increased at 15 min post-immersion in the dryrobe condition compared with the towel and foil blanket. Furthermore, thermal sensation and thermal comfort were rated higher in the dryrobe by the participants compared with the towel and foil blanket post-immersion. The data suggests that when rewarming following CWI, physiological and perceptual responses are improved when wearing a dryrobe, which might be due to the combination of the insulative layer with a vapour barrier.

During pre-immersion (10 min) and CWI (30 min) the physiological and perceptual measures were similar between conditions (figures 1–4), and thus provides confidence in the results during the post-immersion period. At 5 min post-immersion, an afterdrop in deep body temperature (figure 1) of −0.16°C to −0.18°C was seen across the three conditions. On average across the 15 min post-immersion period, there was no difference in deep body temperature between conditions, although when examining the 15 min post-immersion time point in isolation, participants had started to rewarm in

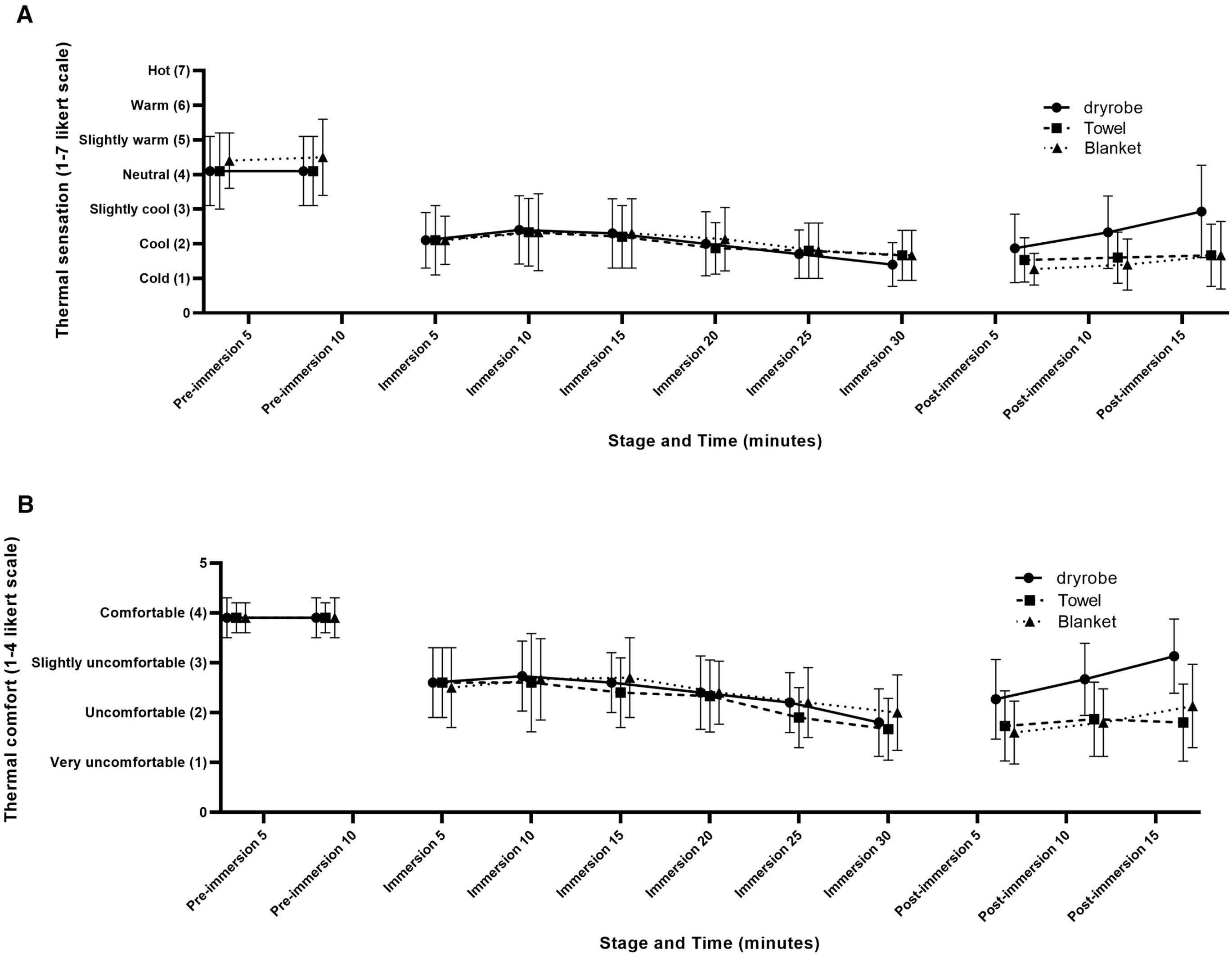

Figure 4 Thermal sensation (mean and SD error bars) (A) and thermal comfort (mean and SD error bars) (B) during pre-immersion, immersion and post-immersion for all three conditions (ie, dryrobe, towel and foil blanket).

comparison to the towel and foil blanket which had no change across the rewarming period. This shows promise that of the three clothing conditions, the dryrobe could be an impactful method of rewarming following CWI.

Skin temperature increased to the greatest extent when wearing the dryrobe during the post-immersion period (figure 2). The current results support previous research which shows that passive rewarming measures that combine an insulative layer with a vapour barrier are more efficient at preventing heat loss than single-layered rewarming measures.[7–9] The differences in skin temperature between the conditions seen in this study could be partially explained by their insulative value and skin surface coverage. In previous research assessing insulative values, a towel was found to have a greater insulative value than a foil blanket, although this insulative value was further reduced in windy conditions.[9] The greater amount of skin surface area coverage in the current study (dryrobe >foil blanket>towel) could have influenced the rewarming rate as greater skin coverage reduces exposure and increases skin temperature by reducing conductive, convective and radiative heat loss.[8 22]

Participants rated thermal sensation and comfort higher at 15 min post-immersion when wearing the dryrobe compared with the towel and the foil blanket (figure 4). These findings support previous literature suggesting that combining an insulative layer with a vapour barrier can improve thermal perceptions.[8 9] These findings also support the idea that thermal sensation in rewarming situations is driven by the activation of temperature receptors through skin temperature increases and hence that thermal sensation can be predicted from local skin temperature.[23] Overall, while wearing the dryrobe participants felt warmer and more comfortable potentially due to the greater insulative value and skin coverage.

Limitations

The study did have some limitations; first, the use of laboratory-based passive immersion for 30 min in still water as opposed to agitated water and active immersion, for example, swimming, might have produced different physiological and perceptual responses. The 15 min post-immersion period used in this study might have limited our understanding and application of rewarming during emergency rescues following CWI as a significant difference in deep body temperature only manifested at this period. Additionally, it should be noted the three clothing conditions did not have the same surface area coverage; however, the researchers opted for 'real-life' alternatives (ie, towel and foil blanket) to the dryrobe instead of standardising the surface area covered. It should also be acknowledged that the look or feel of wearing the dryrobe could have had a placebo effect on thermal sensation and comfort ratings. Lastly, this investigation chose to only assess men due to the changes in core body temperature that occur throughout the menstrual cycle and with hormonal contraceptive use. While this limits the findings to the wider population including women, assessing the impact the menstrual cycle and/or hormonal contraceptive has on rewarming was outside of the scope of this study. Despite these limitations, the current investigation provides a comparison of three passive clothing options for rewarming which found meaningful and impactful differences between conditions. Further investigation into rewarming clothing options including the dryrobe following a longer duration of CWI and rewarming strategies in both men and women are needed. These studies could help identify rewarming techniques following CWI and provide evidence for emergency settings where a larger drop in deep body temperature might be seen.

Research and policy implications

The findings demonstrate physiological and perceptual improvements during rewarming when wearing the dryrobe compared with the towel and foil blanket. Thus, rewarming policymakers are encouraged to recommend wearing clothing that combines an insulative layer with a vapour barrier, such as the dryrobe following CWI.

CONCLUSION

This study investigated the physiological and perceptual responses of wearing a dryrobe, towel and foil blanket after 30 min CWI (14°C). The study found that when wearing a dryrobe for 15 min following passive CWI; skin temperature was greater and heart rate was lower compared with other rewarming methods (towel, foil blanket). Deep body temperature also increased at 15 min post-immersion in the dryrobe condition compared with the towel and foil blanket. In addition, participants also felt warmer and more comfortable when wearing the dryrobe compared with the other rewarming options. These data suggest that a dryrobe could provide a potential method of passive rewarming for those who participate in CWI and provides greater benefits than a towel or foil blanket.

X Dale B Read @DaleRead4, Tess R Flood @tessflood, Amy E Harwood @AmyHarwood91, Thomas Dos'Santos @TomDosSantos91 and Jonathon J S Weakley @JonathonWeakle1

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Contributors Conceptualisation: DBR, AH, JW, GHE. Methodology: DBR, AH, JW, GHE. Formal analysis: TD, GHE. Investigation: DBR, AH, TF, TD. Writing—original draft preparation: DBR. Writing—review and editing: DBR, AH, TF, TD, JW, GHE. Visualisation: DBR, TF, JW. Project administration: DBR. Funding acquisition: DBR, GHE. DBR is the guarantor.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Ethics approval was granted by Manchester Metropolitan University Science and Engineering faculty ethics committee (38158) and was adhered to throughout. Participants gave informed consent to participate in the study before taking part.

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Data availability statement Data are available upon reasonable request.

ORCID iDs
Dale B Read http://orcid.org/0000-0001-6367-0261
Tess R Flood http://orcid.org/0000-0001-8897-0957
Amy E Harwood http://orcid.org/0000-0002-5745-2564

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