1. Overview

UK-based, qualified adult nurses working in UK hospital settings will be recruited to partake in a repeated-measures cross-over design, consisting of five separate 3-hour experimental sessions simulating clinical work, and taking place within a climatic chamber at Southampton General Hospital (UK).

Sessions will differ by ambient temperature and **cooling intervention** as follow: 1) control (CTR; 18°C, 50%RH); 2) moderate heat (Mod-HEAT; 26°C, 50%RH); 3) moderate heat with fan (Mod-HEAT+FAN; 26°C, 50%RH); 3) intense heat (Int-HEAT; 34°C, 50%RH); 2) intense heat with fan (Int-HEAT+FAN; 34°C, 50%RH). Sessions will be performed in a counterbalanced order and will be separated by a minimum of 48h. The order of experimental sessions will be randomised for each participant using a computer-generated allocation schedule. Session order will be balanced across participants as far as possible to minimise order and learning effects.

The choice of ambient temperature conditions was driven by clinically meaningful considerations and practice within the UK. Ambient temperature for the CTR session was derived based on the design conditions set in the "NHS Health Technical Memorandum 03-01 Specialised ventilation for healthcare premises Part A", whereby general wards are expected to be maintained at 18°C. Ambient temperature for the Mod-HEAT session was derived based on guidance set by the "UKHSA Heat-Health Alert action card for health and social care providers", which states that rooms and cool areas should be maintained below 26°C, thereby considering this temperature as a first heat threshold. Ambient temperature for the Int-HEAT session was derived from overheating incident reports collected at two NHS hospitals in the south of England, which confirmed clinical areas to have reached indoor temperatures of up to 34°C during the 2022 UK heatwave. FAN conditions were selected based on the use of a pedestal fan generating an air speed of 3.5m/s.

2. Participants

Participants will consist of UK-based, qualified adult nurses working in UK hospital settings, and will be recruited according to the criteria presented in Table 1. Those criteria were designed to provide a sample whose characteristics will be reflective of the majority of current nurses within the UK workforce, i.e. typically a woman, with an average age of 44y, practicing adult nursing, and with an ethnicity ratio of 4:1 between white British and other ethnic minorities (e.g. Black, African, Caribbean, or Asian British/non-British workers).

Table 1. Participant inclusion and exclusion criteria.

Inclusion	Exclusion
Capable of providing informed consent	Female participant is pregnant
Willing and able to attend all visits	Family history of cardiovascular disease
Healthy female volunteers	Suffering from neurological conditions
Aged 30-60 years	Suffering from skin conditions (e.g. eczema)
BMI < 30	Presence of conditions altering thermoregulation and blood flow (e.g. Raynaud's disease)

Qualified adult nurse with minimum 5 years working experience in a UK hospital setting	Smoker or vaper
White British and other ethnic minorities	Allergic to adhesives
	History of gastrointestinal obstruction, dysphagia, swallowing difficulties

3. Experimental Procedures

Once screened and recruited, participants will be invited to complete five experimental sessions at Southampton General Hospital (UK) on separate days.

Participants will ingest a telemetric temperature capsule (e-Celsius Performance pill, BodyCAP, France) approximately 3–4 h before each experimental session for continuous core temperature measurement. Upon arrival, height (Seca 213 Stadiometer, Birmingham, UK), body mass (KERN 150K2DL, Balingen, Germany; accurate to 0.005 kg), and demographic information will be recorded during the initial visit. For the assessment of whole-body sweat loss (WBSL), dry nude body mass will be measured before each trial behind a privacy curtain, and participants will be instructed to refrain from drinking until the post-trial body mass measurement has been completed. For all experimental visits, participants will be instrumented with a heart rate monitor (POLAR H10, POLAR Electro, Kempele, Finland) and four wireless skin temperature sensors (iButtons, Maxim, San Jose, USA; 0.2Hz) positioned on the calf, thigh, chest, and shoulder such that mean skin temperature can be calculated with established equations.

Following instrumentation, participants will enter the climatic chamber and undergo an initial assessment of fatigue and vigilance. Subjective fatigue will be assessed using the Occupational Fatigue Exhaustion Recovery (OFER) Scale, whilst objective vigilance will be assessed using the Brief Psychomotor Vigilance Task (PVT-B). Participants will also perform a baseline assessment (i.e. pre-fatigue) of cardiopulmonary resuscitation (CPR) on a manikin, and they will not be informed of the required duration, replicating the uncertainty of real-world emergencies. They will be instructed to continue until stopped by a researcher; however, to ensure consistent physical requirements across participants, each CPR bout will be standardised to 2 min. CPR performance will be quantified using software integrated within a resuscitation manikin (Resusci Anne QCPR, Laerdal Medical, Kent, UK).

Participants will then complete a standardised fatigue-induction protocol consisting of 30 min of low-intensity cycling on a semi-recumbent ergometer (~20 W; ~2 METs; 60 rpm). During cycling, participants will simultaneously perform a cognitive battery comprising three Key Stage 2 arithmetic tasks interspersed with a Stroop Colour and Word Test. This protocol has been designed to approximate light physical activity which equates to the average energy expenditure during a nursing shift (i.e. ~2 METs), while also incorporating cognitive tasks previously shown to induce mental fatigue and reduce reaction times. Immediately following the fatigue-induction protocol, participants will repeat the OFER and PVT-B assessments to quantify changes in fatigue and vigilance prior to commencing the nursing simulation.

At this point, participants will begin a simulated clinical shift lasting approximately 105 min. The climatic chamber will be configured to replicate a side-room hospital ward environment. Participants will receive a standardised handover consisting of six simulated patients and will subsequently complete a sequence of routine nursing activities. Tasks will include patient communication, vital-sign assessment and recording, medication management, recall of handover information, and infection-prevention procedures. A trained research team member will portray the 6 simulated patients using standardised scenarios. During the simulated ward round, participants will also complete two simulated cardiac arrest scenarios, occurring after the second and fourth patient encounters. In each scenario, participants will initiate CPR on a manikin for a duration unknown to them and will be instructed to continue until stopped by a researcher. To ensure consistent physical demands across participants and conditions, each CPR bout will be standardised to 2 min.

Clinical performance will be assessed throughout the simulation using a standardised observational assessment battery completed by a member of the research team (available in the supplementary material). Assessment domains will include communication, consent, hand hygiene, personal protective equipment use, vital-sign assessment, medication management, and CPR performance. These domains were selected to reflect core components of nursing practice that are routinely assessed within Objective Structured Clinical Examination (OSCE)-style approaches to nursing education and clinical skills assessment, including communication, procedural accuracy, medication safety, infection-prevention behaviours, and clinical decision-making.

Following the simulation, participants will repeat the OFER and PVT-B assessments, and dry nude body mass will be measured again for calculation of WBSL. Core temperature, skin temperature, heart rate, and environmental conditions will be monitored continuously throughout testing. Upon completion of all assessments, participants will exit the climatic chamber and remain under observation until physiological indicators confirm recovery from heat exposure.

4. Statistical Analysis

We selected 3 primary outcomes with robust, underlying empirical evidence on effect sizes, namely 1) changes in vigilance assessed via the PVT-B (i.e. a determinant of role-specific cognitive performance); 2) changes in CPR quality score (i.e. a determinant of role-specific physical performance); and changes in core temperature (i.e. a determinant of physiological state). These primary outcomes will be used to determine the effects of ambient temperature and cooling intervention on nurses' clinical and physiological performance.

Sample size calculations were performed using Gpower (Gpower 3.1) for a repeated-measures ANOVA assessing the within-subject effects of condition and time ($\alpha = 0.05$, power = 0.95, one group, ten repeated measurements representing five environmental conditions and two assessment time points, i.e. pre- and post-fatigue).

A conservative medium effect size (f = 0.30) was selected as the lower-bound estimate across the three primary outcome domains. This was based on published evidence demonstrating changes in 1) PVT-B scores among female shift workers (f = 0.39); 2) CPR performance under rescuer fatigue (f = 0.30); and 3) core temperature during simulated occupational tasks under heat stress (f = 0.30). Based on these assumptions, the required sample size was estimated to be 15 participants.

Primary outcome data will be assessed for normality of distribution (Shapiro-Wilk test) and analysed with a linear model with session (five levels: CON, Mod-HEAT, Mod-HEAT+FAN, Int-HEAT, Int-HEAT+FAN) and time (two assessment time points, i.e. pre- and post-fatigue) as fixed effects, and participant as a random effect for repeated measures. Pre-planned contrasts will compare the four sessions to CON, with Dunnett's method for multiple testing correction. Point estimates for each primary variable will be provided with 95% confidence interval (CI).

Secondary outcomes, i.e. changes in role-specific cognitive tasks (completion and accuracy of predefined clinical behaviours, including communication, consent, hand hygiene, vital-sign assessment and recording, medication management, recall of handover information, omission errors), fatigue (OFER Scale), mean skin temperature, heart rate and WBSL, will be analysed using the same linear mixed models and contrasts, with Dunnett's method for multiple testing correction.

Effect sizes will be reported using partial eta squared for parametric analyses and Kendall's W for non-parametric Friedman tests. Statistical significance will be accepted at $p < 0.05$.

Descriptive statistics will be reported as mean ± standard deviation, mean differences with 95% (CI), or median and interquartile range, depending on data distribution.