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Validation of a Novel Method to Quantify Local Axilla Sweating: SweatSENSE

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Validation of a novel method to quantify local axilla sweating, SweatSENSE

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ABSTRACT

The aim of this study was to validate the ability of the novel SweatSENSE technique to measure local axilla sweating. The local axilla sweating responses to a range of physical activities were measured in 30 healthy females (28 ± 5 yr, 163 ± 7 cm; 62 ± 9 kg). Participants completed low-to moderate-intensity treadmill walking, stepping, and cycling in a 3-h protocol. Left axilla sweating was intermittently recorded using the novel SweatSENSE method, in which non-hydrochromic sweat-responsive paper sensors with PCDA polymer were placed in the axilla vault for 5 s. The sensors were analysed for the proportional colour change as an index of instantaneous local sweating. Percentage total sweat coverage (%TC) of the patches was determined. Ipsilateral axilla sweating was continuously recorded using capacitance hygrometry (CH). Intraclass correlation coefficient (ICC) analyses was used to examine the agreement between the CH and SweatSENSE %TC data for each participant. Heart rate, core and skin temperatures, ratings of perceived exertion (RPE) and thermal discomfort were also recorded. Heart rate (100 ± 25 beats.min^{-1}, $P < 0.05$) and T_{core} increased during the protocol (37.82 ± 0.23 °C, $P < 0.05$). Thermal discomfort increased from 'neutral' to 'warm' and RPE increased to 'somewhat hard' during the protocol (both $P < 0.05$). Local axilla sweating (CH and the SweatSENSE method) increased during each physical activity bout and progressively throughout the protocol (both $P < 0.05$). Twenty one out of thirty participants demonstrated significant ICC between axilla SweatSENSE and capacitance hygrometry sweating data [average (95 % confidence intervals] ICC; 0.483 (0.191–0.713)) indicating a moderate agreement between SweatSENSE and capacitance hygrometry, suggesting a moderate level of validity of the SweatSENSE method.

1. Introduction

The regulation of body temperature is a homeostatic feedback control system that ensures temperature is maintained within a narrow range (Cramer et al., 2022), which is critical for optimal health and wellbeing. Exposure to exercise and or thermal stressors via hot and/or humid environmental conditions can cause excessive elevations in body temperature (Havenith, 2005). The body's thermoregulatory system consists of regulatory pathways and effector organs that respond to increases in body heat storage and increase heat loss mechanisms in order to defend body temperature (Cramer et al., 2022). Avenues of heat loss are therefore vital for the body to facilitate heat dissipation to the environment. Mechanisms involved in heat dissipation involve neurally-mediated elevations in skin blood flow to transfer heat from the body's core to the shell and increases in sweating to evaporate heat from the skin's surface. Sweating is the predominant pathway for losing heat via evaporation during environmental heat stress and exercise (Kenny et al., 2018).

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The action of sweating involves the secretion of a dilute electrolyte solution from a sweat gland which consists of a bulbous secretory coil leading to a duct (Baker, 2019; Shibasaki et al., 2006). Human sweat glands are generally divided into 3 types: eccrine, apocrine and apoeccrine glands. Eccrine sweat glands are distributed over nearly the entire body's skin surface and secrete serous fluid directly onto the skin surface, whereas apocrine sweat glands are present in certain anatomic locations always associated with hair follicles, e.g., the scalp, axillae and groin, and open directly into the upper portion of hair follicles secreting a rather viscous fluid (Sato et al., 1987, 1989). Apocrine glands are also larger and shorter than eccrine glands. Acetylcholine is the primary neurotransmitter released from cholinergic sudomotor nerves that binds to muscarinic receptors on sweat glands (Shibasaki et al., 2006). Sweating can also be induced via adrenergic stimulation, particularly at apocrine glands (Sato et al., 1989). Apoeccrine glands display somewhat intermediate morphologic and functional features of both eccrine and apocrine glands (Shibasaki et al., 2006); e.g., they are larger than eccrine glands but smaller than apocrine glands and they open directly onto the skin surface (Sato et al., 1987, 1989).

Sweat from apocrine glands causes stains and malodour (Kanlayavattanakul and Lourith, 2011), which can suppress social interaction by diminishing self-confidence and accelerating damage to the wearer's clothes. The fluid released from apocrine glands is odourless until it combines with bacteria on the skin. Antiperspirant products are popular methods to blunt local increases in axilla sweating and subsequent malodour. Antiperspirants are based on the use of metal salts such as aluminium and zinc, which can block the excretory ducts of sweat glands obstructing the sweat fluid from arising onto the skin surface (Teerasumran et al., 2023) and inhibiting the growth of malodourous bacteria (Kanlayavattanakul and Lourith, 2011).

Methods that accurately assess local axilla sweating in-field are therefore critical in order to provide important consumer-relevant insights into the efficacy of anti-perspirant products and or the amount of axilla sweating produced during periods of physical activity and or heat exposure. Methods that are typically used to quantify axilla sweating are scarce though due to the anatomical structure of the axilla vault. A current method that has been used is the patch absorbent technique or gravimetric technique (Maxeiner et al., 2009). Other methods that have been used to assess local sweating on other areas of the body, e.g., forearms and chest, include the starch iodine patch technique and the ventilated capsule capacitance hygrometry technique (Buchmann et al., 2019; Baker, 2017). These methods have certain limitations, such as requiring extended application of the patch on the skin and/or the securing of equipment to the skin which could interfere with the movement of the shoulder or arm. For the detection and quantification of axilla sweating in-life, a simple method is required in order to easily access the axilla vault and not obstruct the natural movement of the arms about the shoulders.

The SweatSENSE technique is a validated, recently-reported low-cost method developed to assess local axilla sweating (Hand et al., 2024). SweatSENSE is a colourimetric, sweat-responsive, polydiacetylene-based chemosensor on a paper substrate that undergoes a selective blue to pink/red colourimetric change when in contact with acids and alcoholic compounds found in sweat. SweatSENSE is non-hydrochromic, in that it does not respond to water, and provides an instantaneous point measure of localised sweat rate. SweatSENSE is prepared via inkjet printing, resulting in a 5 × 5 cm patch. These sensors are applied to body test sites such as the underarm and the back for 5 s before being removed, and the colour change in response to sweat can be immediately observed upon removal of the sensor from the test site. Once removed, this reaction is fixed and irreversible.

Through assessing the proportional coverage (% Total Coverage) of the SweatSENSE sensor's area that changes colour, SweatSENSE has the ability to quantitatively demonstrate an individual's sweating behaviour instantaneously at various different body sites during real-life scenarios and activities, in real time and without the need for expensive, highly-specialised equipment. This, along with its ease of production, enables SweatSENSE to offer a scalable solution to quantitative in-field sweat monitoring. Owing to this, SweatSENSE can also be used to demonstrate and quantify the relative efficacies of antiperspirants during consumer-relevant daily activities and moments that matter, providing insights to consumers.

While SweatSENSE has been previously validated against the industry standard Hot Room method of sweat collection and antiperspirant efficacy assessment (Hand et al., 2024), it has not yet been validated against an established local sweating assessment technique during periods of physical activity that stimulate sweating. The aim of this study was to therefore validate the ability of the SweatSENSE technique to measure local axilla sweating responses against a standard continuous sweat monitoring method, capacitance hygrometry.

2. Methodology

2.1. Participant profile

Thirty healthy females were recruited for this study and their characteristics are described below in Table 1. Participants were informed of the methods verbally and in writing before providing written informed consent. The study conformed to the Declaration of Helsinki and was approved by the local research ethics committee (UREC Ref: 21/SPS/053).

2.2. Experimental design

Participants visited the laboratory once for the assessment of their local axilla sweating responses to an intermittent physical activity protocol for ~3 h (see Fig. 1). The visit typically took place between 09:00–12:00. Participants completed bouts of treadmill walking, carrying of weights, stepping and cycling. This protocol provided a range of different activities of varying levels and exertion in order to stimulate sweating. This range of activities were designed to emulate the variety of events consumers may experience throughout their daily life, such as household activities, work-related activities and lifestyle-driven activities. The panellists were free to adjust the exercise intensity to a level they deemed "light to moderate". Prior to the visit, participants were provided with a deodorant to wear in both axillae for 14 days, which did not contain any antiperspirant actives, to allow for a baseline measurement of unimpeded sweating during the trial. Additionally, participants were instructed to avoid exercise or consumption of alcohol for 24 h, or caffeine for 8 h prior to testing.

2.3. Instrumentation

Heart rate was monitored via a pulse oximeter (ANP100, Anapulse, Surrey, U.K.) placed on a finger and core body temperature was measured from an ingestible pill telemetry system taken ~5 h before data collection began (CoreTemp, HQInc; Palmetto, FL, US). Local skin temperature was recorded continuously at the calf, thigh, forearm and left axilla using thermocouples (DS1922L i-Button temperature loggers, Integrated Maxim, San Jose, CA, US) taped to the skin. Ratings of Perceived Exertion (RPE) during the physical activities were obtained

Table 1
Participant profile.

Total Panel Size (N)	30
Age (Years)	28 ± 5
Height (cm)	163 ± 7
Pre-nude Body Mass (kg)	62 ± 9
Ethnicity	n = 24 Caucasian, n = 3 East Asian, n = 1 Black African, n = 1 South Asian, n = 1 Hispanic

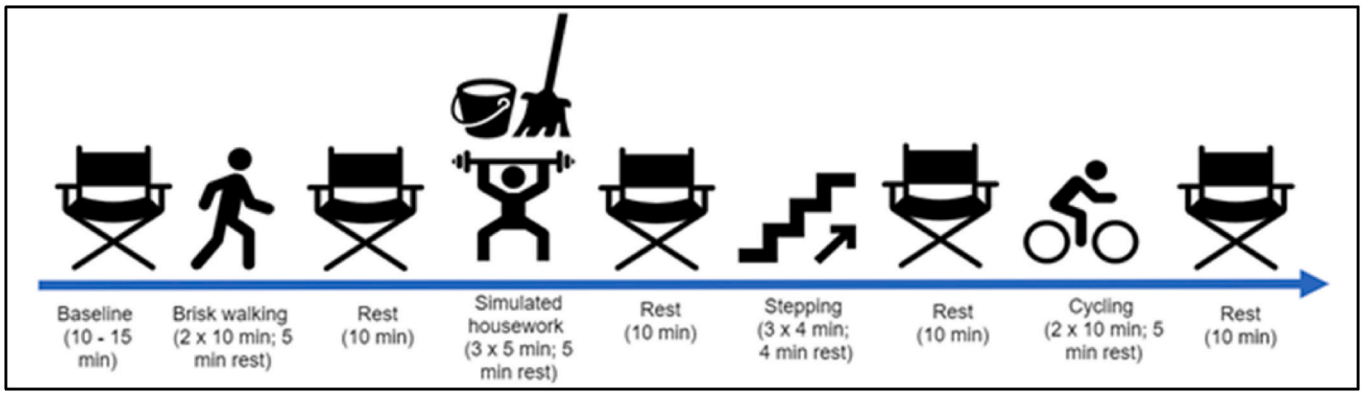

Fig. 1. Outline of the physical activity protocol completed by participants. The work to rest schedule for each activity is described under each one; e.g., participants completed two 10 min walking bouts with a 5 min rest in between; participants completed three 4 min stepping bouts with 4 min rest in between each one. Immediately after each physical activity bout and at the end of each rest period a SweatSENSE measurement was obtained.

using the Borg 6–20 scale. Ratings of Thermal Discomfort (TDR) during the rest periods and the physical activities were obtained using a 1–9 scale (1 = very cold, 5 = neutral, 9 = very hot) (Toner et al., 1986).

Local sweat rate was recorded continuously from the left axilla vault using capacitance hygrometry. A small capsule, with a surface area of 7 cm^2, was carefully, firmly and securely taped to the left axilla vault using topical skin glue and hypoallergenic tape to ensure it remained in place throughout the protocol. Dry nitrogen gas was blown through the capsule at a constant flow rate (300 ml min^{-1}) and any sweat produced was delivered via tubing to a humidity and temperature detector (HMT330, Vaisala, Helsinki, Finland) to index local sweating activity. Data were collected continuously using an online data acquisition software (LabChart v8, AD Instruments, Sydney), and were converted from the raw data measurement into local sweat rate ($mg.cm^2.min^{-1}$) in real time, using the capsule surface area, gas flow rate, and the humidity and temperature of the gas leaving the capsule as follows:

Local sweat rate($mg.cm^2.min^{-1}$) = Absolute humidity(mg)*gas flow rate($ml.min^{-1}$)/capsule surface area (cm^2).

Local sweat rate from both axillary vaults was also intermittently obtained using the SweatSENSE method, however only data collected from the left side was used for validation purposes, as this was the only underarm with data collected for both methods. The non-hydrochromic sweat-responsive sensors (see Fig. 2, below) with PCDA polymer printed on a paper substrate were placed in the left axilla vault (by the same investigator) using a bespoke applicator device at the end of each rest period as well as the end of each bout of physical activity for 5 s and then removed. The bespoke applicator device was developed to ensure consistency in both SweatSENSE sensor placement and application style, fixing the application pressure, time and contact area for each sensor in each participant. The paper-based samples were then digitally analysed using a bespoke mobile application, for the detection of the area of the pink/red colour change on the SweatSENSE paper (if sweating has occurred) as an index of local, instantaneous sweating activity. Percentage total coverage (%TC) of each sensor, i.e. the amount of the SweatSENSE sensor that exhibited a pink/red colour as a proportion of the total SweatSENSE sensor area, was determined using this bespoke software.

Participants also self-recorded their nude body mass pre- and post-trial to determine body mass loss and estimate whole body sweat rate. Water and food-consumed and urine passed throughout the trial was weighed and accounted for during whole body sweat rate calculations.

2.4. Data analysis

The averages and standard deviations for HR, core, and skin temperatures, RPE, TDR and body mass loss were calculated. Local absolute sweating data (30 s bins) at the time of each SweatSENSE patch collection were identified, and the local absolute sweating data and SweatSENSE %TC data were assessed for normal distribution. HR, core temperature, RPE, TDR, local absolute sweating and SweatSENSE %TC data were assessed over time using one-way repeated measures ANOVA. In order to determine the agreement between the local absolute sweating data via capacitance hygrometry and the corresponding SweatSENSE sensors, facilitating an evaluation of the accuracy of the SweatSENSE method, two-way mixed effects, consistency, intraclass correlation coefficients [ICC (3,1)] were used to examine the agreement between the local absolute sweating data and SweatSENSE %TC data for each individual panellist as well as the pooled data (McGraw and Wong, 1996). Because the units and scales of the 2 methods differed all data were standardised by converting both measures to z-scores within each method prior to calculating the ICC. Ninety-five % Confidence Intervals (CI) of the ICC estimates were also calculated. ICC values of less than 0.5,

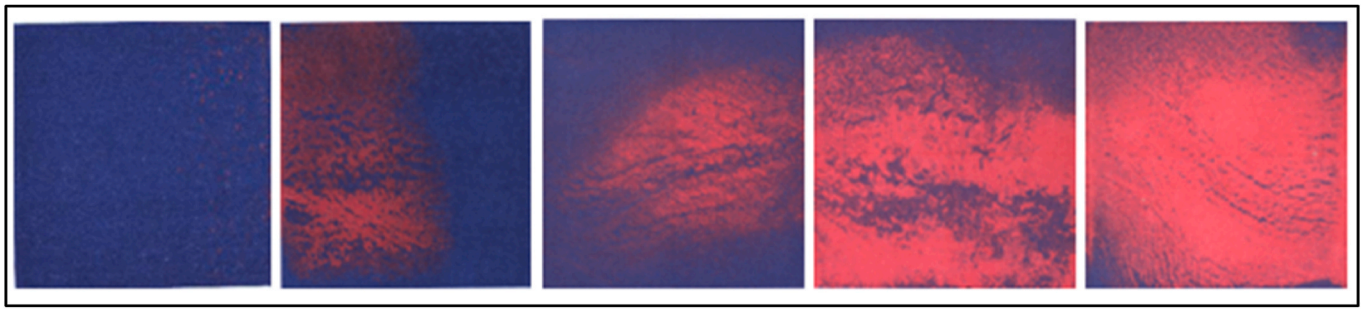

Fig. 2. Representative SweatSENSE sensors, demonstrating the colour response in the presence of sweat at different % Total Sweat Coverage levels, from left to right 0 %, 24 %, 31 %, 68 % and 89 %. SweatSENSE is a highly-sensitive, novel sweat-responsive non-hydrochromic polymeric PCDA paper-based sensor that measures localised sweating instantaneously. This is then analysed using a bespoke application to produce the % Total Sweat Coverage output.

between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 were used as indicative of poor, moderate, good, and excellent agreement, respectively (Koo and Li, 2016).

3. Results

3.1. Physiological responses

The data presented below are the average heart rate (N = 30), core temperature (n = 27) and ratings of perceived exertion (RPE) (N = 30) and thermal discomfort (N = 30) (see Fig. 3). Heart rate increased during the physical activity bouts and progressively throughout the protocol ($P < 0.05$; average; 100 ± 25 beats.min^{-1}). Core temperature increased during the protocol to 37.82 ± 0.23 °C ($P < 0.05$). The average change in core temperature was 0.38 ± 0.24 °C. Skin temperatures of the calf, thigh, forearm and back increased during the physical activity bouts and progressively throughout the protocol (see Fig. 4). Axilla skin temperature generally decreased during the protocol. Thermal discomfort increased from 'neutral' to 'warm' during the protocol ($P < 0.05$) and RPE increased from 'very light' to 'somewhat hard' during the protocol ($P < 0.05$). The average body mass loss was 0.5 ± 0.3 kg after the trial.

3.2. Agreement between SweatSENSE and capacitance hygrometry

Local axilla sweating (absolute sweating) as measured by capacitance hygrometry increased with each physical activity bout and progressively throughout the protocol ($P < 0.05$) (see Fig. 5). Similarly, local axilla sweating as determined by the SweatSENSE method also increased with each physical activity bout and progressively throughout the protocol ($P < 0.05$). Table 2 summarises the ICC analysis for each participant's axilla SweatSENSE and capacitance hygrometry sweating data. Twenty one out of thirty participants demonstrated significant ICC with an average (CI) ICC of 0.483 (0.191–0.713).

4. Discussion

The aim of this study was to validate the ability of the novel SweatSENSE technique to measure local axilla sweating. Thirty healthy females completed periods of low-moderate intensity treadmill walking, weight carrying, stepping, and cycling in a 3-h protocol. Local axilla sweating was intermittently recorded using a novel SweatSENSE method and continuously using capacitance hygrometry. ICC analyses was used to examine the agreement between the CH and SweatSENSE data. The main finding of the study was that there was a moderate agreement between SweatSENSE and capacitance hygrometry suggesting a moderate level of validity of the SweatSENSE method. These findings have implications for the assessment of axilla sweating during thermoregulatory research, as well as the assessment of products aimed at modifying axilla sweating.

Sweating is a critical avenue for losing heat during heat stress exposure (Kenny et al., 2018) via the release of a solution from the sweat glands that evaporates. Sweat glands of 3 different types are distributed over the body's skin surface, including apocrine sweat glands at the scalp, axillae and groin (Sato et al., 1987, 1989). Sweat from apocrine glands when combined with bacteria on the skin causes malodour and can stain clothing (Kanlayavattanakul and Lourith, 2011), which, along with the presence of large amounts of wetness and sweat patches, can negatively affect social interaction and cause damage to clothes. Antiperspirant products can block sweat arising onto the skin surface (Teerasumran et al., 2023) and thus the onset of malodour (Kanlayavattanakul and Lourith, 2011). The assessment of local axilla sweating is therefore important to provide quantitative information on the extent of axilla sweating during physical activity, and or heat exposure as well as the effectiveness of anti-perspirant products at abrogating axilla sweating. Very few methods of axilla sweating

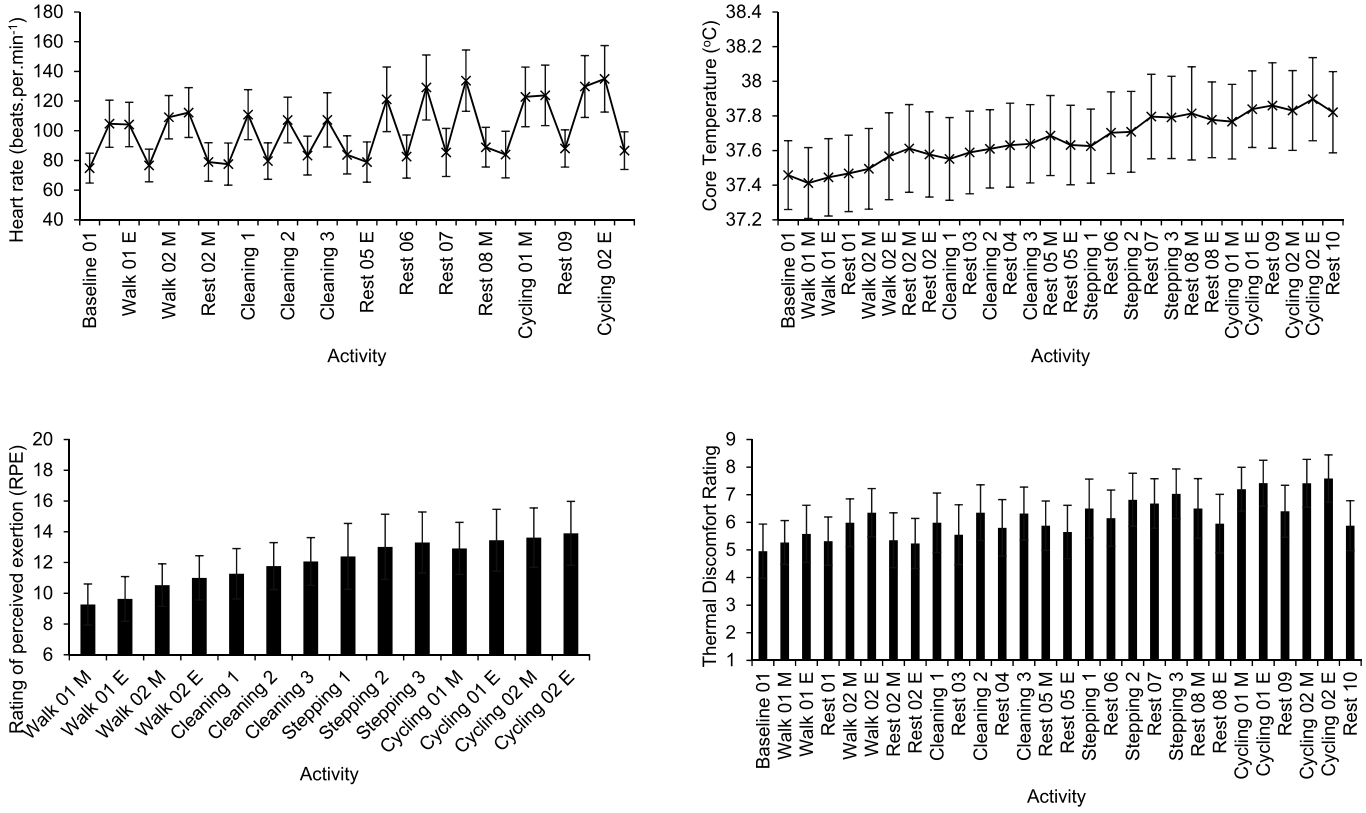

Fig. 3. Mean (±SD) heart rate, core temperature, rating of perceived exertion (RPE) and thermal discomfort rating responses to the physical activity protocol. Significant increases in all variables were evident during the protocol ($P < 0.05$).

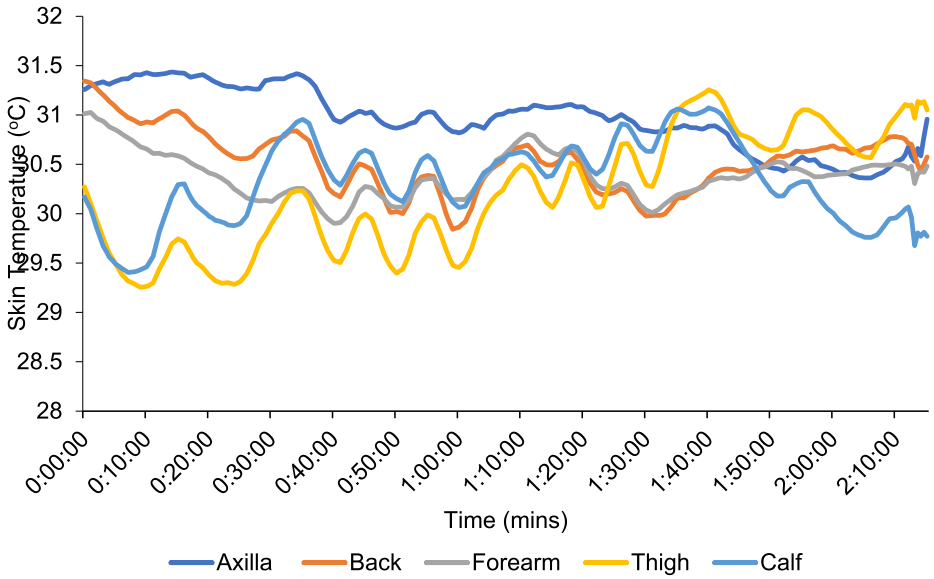

Fig. 4. Mean (±SD) responses of local skin temperatures during the physical activity protocol. Error bars removed to aid with graph clarity.

assessment are currently available, likely due to the anatomical structure of the axilla vault that makes the application of such methods difficult. Patch absorbent or gravimetric techniques have been used in some studies (Maxeiner et al., 2009) but this method requires prolonged application of the patch in the axilla vault. The ventilated capsule capacitance hygrometry technique is a well-used and gold standard method to assess local sweating (Buchmann et al., 2019; Baker, 2017) but the attachment of the capsule in the axilla vault is difficult and can interfere with the movement of the shoulder/arm and a constant supply of a dry gas through the capsule is also required as well as the connection to a humidity detector. In the present study we examined the validity of the recently developed method to assess local axilla sweating; the SweatSENSE technique.

The results of the present study showed significant ICC between axilla SweatSENSE and capacitance hygrometry sweating data in twenty one out of thirty participants (average ICC of 0.483), which suggests a moderate level of validity of the SweatSENSE method. Within those 21 participants 11 displayed moderate agreement and 6 displayed good agreement (the remaining 4 deemed as poor agreement). Lack of significant agreement in the remaining 9 participants (as well as those deemed poor agreement) may be due to individual point differences in sweating (as SweatSENSE is an instantaneous measure and so results when compared to the continuous capacitance hygrometry method could be skewed). This could also have been due to a small number of instances where the capacitance hygrometry capsule's seal to the underarm sampling site was compromised resulting in an air leakage, and to several instances where the capsule was temporarily detached from the underarm site entirely due to participant movement. In both cases, the capsule was quickly reattached and sealed to minimise disruption to the protocol and to data acquisition, however this temporary disruption may have introduced some inaccuracies which later influenced the data. Finally, while both the capacitance hygrometry capsule and SweatSENSE were within the axillary vault of the underarm, they were not in exactly the same position. When SweatSENSE was applied at the measurement points specified in the protocol, this was immediately adjacent to the capsule. It is possible the heterogeneous sweating within the axillary vault, even between such closely-related sites, may have introduced some variability between the results obtained using the two methods. It should be noted the ICC observed in twenty one of the thirty panellists is particularly compelling in light of the differing nature of the two measurement techniques, with capacitance hygrometry offering a continuous, flow-based measure of sweat rate while SweatSENSE provides a fixed, single-point, instantaneous portrait a participant's sweating at a select moment in time and is not weight- or flow-based.

These findings indicate that the SweatSENSE method could be used to index axilla sweating during perturbations that elevate sweating such as exercise and or heat stress as well as to examine the effect of interventions to modulate axilla sweating, such as antiperspirant products. The ease with which SweatSENSE can sample body sites with challenging and varied topographies such as the axilla was also found to be a key benefit of this emerging technique, overcoming the limitations of existing methods discussed above. The strength of the average SweatSENSE:capacitance hygrometry sweating relationship was moderate, indicating some inaccuracy with the SweatSENSE method, the causes of which could include the sensor's detection method of the sweat, variation in the application technique of the sensor to the axilla vault and or the analyses process.

4.1. Limitations

There are several features of the study that warrant consideration. Only female participants were included during a protocol that elicited a relatively low increase in core temperature. Whether the study's findings would extend to a male population that have different anthropometrics and sweating responses to females or during larger elevations in core temperature and consequently bigger increases in sweating are not yet clear. Sweating responses were simultaneously assessed at the left axilla. It is not clear if bilateral differences in axilla sweating exist (or between dominant vs. non-dominant sides) or if the validity of the SweatSENSE device would differ between axilla sites which is important to consider when comparing bilateral product interventions. Furthermore, although the validity of the SweatSENSE method was examined in the present study, the reliability of a physiological measurement method is also key to understand the moment to moment and day to day variability of a method which has implications for repeated measures designs of participants and or products over time.

5. Conclusion

In conclusion, in this population of young females during a low-moderate intensity physical activity protocol that elicited a mild level of hyperthermia, significant ICC between the ipsilateral axilla SweatSENSE and capacitance hygrometry sweating responses were evident in twenty one out of thirty participants, as well as, on average, moderate

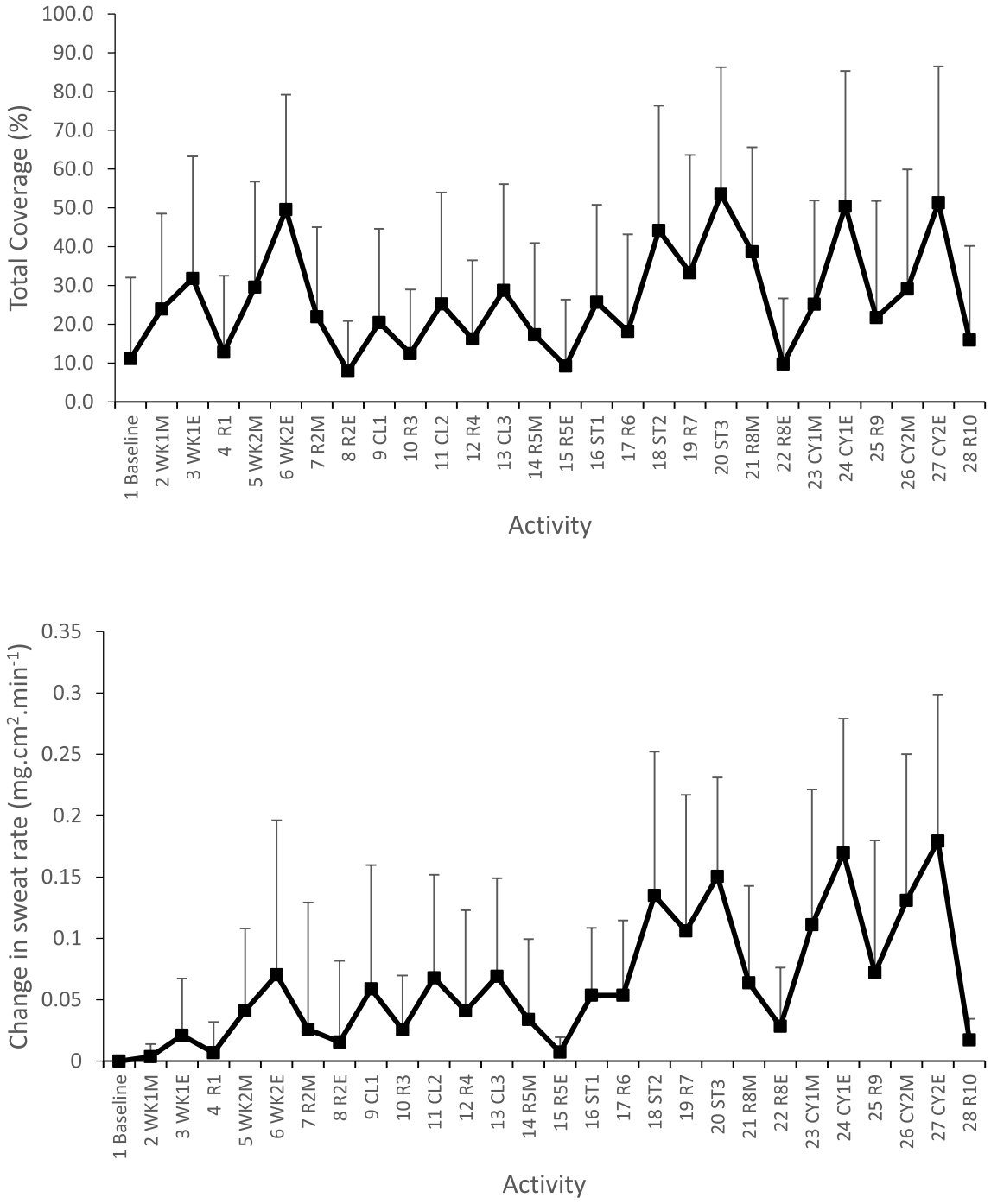

Fig. 5. Mean (±SD) local axilla sweating SweatSENSE responses to the physical activity protocol. Significant increases in local axilla sweating were evident during each physical activity bouts ($P < 0.05$) and local axilla sweating also significantly increased throughout the protocol (both $P < 0.05$).

agreement between the SweatSENSE and capacitance hygrometry methods of local sweating assessment suggesting a moderate level of validity in the SweatSENSE method. Validation of SweatSENSE against capacitance hygrometry confers confidence in the use of SweatSENSE as a real-time sweat detection tool that could be used in the lab or the field. Future studies should aim to strengthen the validity of the SweatSENSE method and use the SweatSENSE sweat detection and analysis technique to further understand sweating behaviour in response to a variety of stimuli and scenarios and measuring and comparing efficacy and performance of different antiperspirant products in consumer-relevant scenarios.

CRediT authorship contribution statement

Andrew McGill: Writing – review & editing, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Emmett Cullen Tinley:** Writing – review & editing, Methodology, Conceptualization. **Stephanie E. Edwards:** Writing – review & editing, Methodology, Conceptualization. **Andrew Jamieson:** Writing – review & editing, Methodology, Conceptualization. **Jane Ford:** Writing – review & editing, Methodology, Conceptualization. **Evie Winterton:** Writing – original draft. **Jacob Shardey:** Writing – original draft, Data curation. **Rachel A. Hand:** Writing – review & editing, Software, Resources, Methodology. **Spyridon**

Table 2
Axilla SweatSENSE Total Coverage (%) and Capacitance Hygrometry ICC (95 % Confidence Intervals) and P Values for all individual participants (N = 30). All axillae data pooled (N = 826) and the average of all individual ICCs as well as the ICC from the average SweatSENSE Total Coverage (%) and Capacitance Hygrometry data are also displayed. Bold indicates a significant ICC.

Panellist	Axilla capacitance hygrometry vs. SweatSENSE ICC (95 % CI) and P values
1	ICC = 0.074 (−0.350–0.472), P = 0.369
2	**ICC = 0.335 (-0.037–0.625), P = 0.038**
3	**ICC = 0.709 (0.462–0.854) P < 0.001**
4	**ICC = 0.588 (0.282–0.786), P < 0.001**
5	**ICC = 0.763 (0.520–0.892), P < 0.001**
6	**ICC = 0.770 (0.561–0.886), P < 0.001**
7	**ICC = 0.679 (0.415–0.837), P < 0.001**
8	**ICC = 0.452 (0.102–0.703), P = 0.007**
9	**ICC = 0.817 (0.638–0.912), P < 0.001**
10	**ICC = 0.399 (0.037–0.668), P = 0.016**
11	**ICC = 0.431 (0.076–0.689), P = 0.010**
12	ICC = 0.186 (−0.194–0.518), P = 0.167
13	**ICC = 0.583 (0.267–0.785), P < 0.001**
14	**ICC = 0.603 (0.302–0.794), P < 0.001**
15	**ICC = 0.762 (0.548–0.882), P < 0.001**
16	**ICC = 0.624 (0.235–0.840) P = 0.002**
17	ICC = 0.285 (−0.092–0.591), P = 0.067
18	**ICC = 0.580 (0.270–0.781), P < 0.001**
19	ICC = 0.272 (−0.106–0.581), P = 0.077
20	**ICC = 0.739 (0.509–0.870), P < 0.001**
21	**ICC = 0.779 (0.576–0.891), P < 0.001**
22	**ICC = 0.721 (0.480–0.860), P < 0.001**
23	ICC = 0.112 (−0.266–0.461) P = 0.281
24	**ICC = 0.477 (0.134–0.719), P = 0.004**
25	ICC = 0.093 (−0.284–0.445), P = 0.316
26	ICC = 0.232 (−0.148–0.552), P = 0.113
27	ICC = 0.124 (−0.255–0.470), P = 0.261
28	**ICC = 0.420 (0.062–0.682), P = 0.012**
29	ICC = 0.143 (−0.237–0.485), P = 0.230
30	**ICC = 0.745 (0.520–0.873), P < 0.001**
Pooled Data	**ICC = 0.417 (0.359–0.472), P < 0.001**
Average of all 30 ICC values	ICC = 0.483 (0.191–0.713)
Average SweatSENSE Total Coverage (%) and Capacitance Hygrometry data	**ICC = 0.812 (0.634–0.908), P < 0.001**

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Data accessibility statement

The data that support the findings of this study are available as supplementary materials to the manuscript.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2025.104199.

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