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# Experimental framework and methods for the assessment of skin wetness sensing in humans

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**The study of the human ability to both detect the presence and estimate the amount of wetness on the skin has grown in scientific interest over the last century, due the implication of wetness in comfort and skin health. In 1900, Bentley demonstrated that skin wetness is detected based on touch and temperature stimuli combining to produce sensations of liquidity, and that wetness perception increases with cold touch. It has since been demonstrated that, in the absence of a skin hygroreceptor (i.e., wetness receptor), the biophysical effects of moisture on the skin – conductive heat transfer and mechanical interaction – excite specific cutaneous mechanoreceptors and thermoreceptors. The resulting afferent signals are centrally integrated to generate our perception of skin wetness. As well as providing a theoretical foundation for the understanding of this aspect of somatosensation, these insights have helped develop a methodological framework for the study of human skin wetness sensing, which relies on assessing the independent and interactive effects of thermo-tactile stimulation of the skin in the presence of a liquid. This chapter will provide an overview of the experimental framework and methods available to evaluate the biophysical and psychophysical responses to controlled dry and wet stimuli applied to skin, and the resulting wetness perception. We will use example scenarios of skin-moisture interactions (e.g., arising from contact with a wet surface or from sweat production), to critically evaluate the methods, noting their accuracy, reliability and efficiency, and discuss their inherent limitations and commonly encountered difficulties. It is hoped that these considerations will guide and further develop research of this relatively little-investigated, yet fundamental, aspect of somatosensation.**

## 1. INTRODUCTION

Humans experience the sensation of wetness every day, for example, when having a shower in the morning, sweating during exercise, or coming into contact with a wet object. The ability to sense wetness enriches our perception, bringing a new depth to sensations, which enhances the way we interpret the world around us. Furthermore, it provides an important signal for behavioural responses, aimed at maintaining both thermoregulatory homeostasis (e.g., sweat-induced skin wetness drives thermal discomfort and triggers cool-seeking behaviours) [1] and skin health (e.g., incontinence-associated wetness drives discomfort and triggers drying behaviours) [2]. This ability to detect wet stimuli on the skin is termed wetness perception. Wetness is currently believed to be a percept generated in the central nervous system, as humans do not seem to possess hygroreceptors, which are specific receptors for encoding wetness [3,4]. Such specialised neurons are found in certain insects, and detect and quantify relative humidity. This is in contrast to other sensations, such as touch and temperature, where different types of mechanoreceptor and thermoreceptor encode specific aspects of skin stimulation [5,6]. Given that humans, as well as other animals, frequently come into contact with moisture, and that this interaction is essential in our lives, it is perhaps surprising that hygroreceptors do not appear to exist in mammals [7]. However, due to the high sensitivity that humans have for detecting wetness, it is of interest to probe how touch and temperature signals convey such a sensation.

*History of wetness perception*

In 1900, Bentley proposed that the sensation of liquidity was made up of specific components that formed a perception of wetness when combined in specific ways [8]. To understand how the sensation was formed, Bentley attempted to reconstruct the sensation of liquidity through synthetic experimentation, where he manipulated the substance touched and its temperature to create a wetness illusion. At one point, Bentley writes, "molasses, benzine and even mercury passed under certain thermal conditions for water: an indication of how widely the organism is obliged to draw upon its resources for the completion of so simple a perception as that of a liquid" (1900, p. 415-416). Although the use of dangerous liquids is now not acceptable, this work is still very relevant in modern-day wetness perception research, where we vary specific touch and temperature factors to increase or decrease perceived wetness.

Bentley also demonstrated the difference between passive and active wetness perception, where passively applied liquids were always felt as wet, but with active touch when there was an interaction between liquid on a solid surface and the skin, other percepts such as oiliness appeared. Bentley concluded that actual moisture on the skin is not even sufficient to generate the perception of wetness, as a liquid applied with little change in pressure and/or temperature did not evoke wetness. Further, a wetness illusion could be created where a thin rubber sheath was placed on the finger, which was then lowered into a liquid: the participants truly felt wetness, especially when the water was cold.

A study by Sullivan (1923) found that, in general, the perception of liquidity was made up of blends of pressure and temperature, while solidity was composed of pressure alone [9]. Further, the perception of 'semi-liquidity' (viscous liquid) was typically a blend of intense pressure and temperature, whereas liquidity was produced from weak pressure and temperature. In related work in the same period, explorations were made into other concepts associated with liquidity such as stickiness [10], clamminess [11], and oiliness [12]. Thesewere linked more to tactile aspects such as the stick-slip phenomenon, in which friction varies during an interaction due to changes in surface tension and adhesive forces, although clamminess was also associated with coolness, and oiliness with warmth. Later work added other related concepts, such as spreadability and viscosity, occurring from specific interactions between wetted surfaces and the skin that are particularly affected by the thermal conductivity of fluids [13].

Work from Gagge et al. in 1967 introduced ideas of thermal comfort, using perceptual scales for both ratings of comfort and temperature sensations. This linked concepts such as sweating, heat transfer, and thermoregulatory physiology together [14]. Sweeney and Branson later took this further by investigating moisture sensation in sensorial comfort, by using both absolute and difference thresholds [15] and magnitude estimation to rate moisture sensation [16], including considering comfort in-wear factors. The exploration of wetness has evolved from perceptual descriptions to psychophysical ratings, and these previous studies have allowed us to further develop the investigation of wetness on different levels, such as by accurately manipulating temperature and in the perception of sweating, more of which we cover below.

*Directions in wetness perception research*

There are many directions in current wetness perception research, which can be discussed most simply when divided according to the source of moisture and underlying research question. For example, one may be interested in investigating the minimum amount of skin wetness that can be detected at the finger pad, as this is relevant to optimise the design of absorbent products that involve individuals touching a wet material to determine its state - consider a parent touching an infant's diaper to check its dryness. In addition, one may be interested in investigating regional differences across the body in the sensitivity to wet fabrics applied on the skin at different moisture saturations. These differences are relevant to optimise the design of sports clothing to maintain comfort during physical activity - consider an individual running and experiencing a sweaty t-shirt sticking to different parts of their torso. Different biophysical and psychophysical assessment methods can therefore be derived depending on whether a detection threshold or magnitude estimation approach is required, that is, whether one aims to determine the intrinsic sensitivity of the skin to moisture, or the participant's ability to differentiate amongst moisture levels and assess their relative salience.

For the purpose of devising appropriate testing methodologies, the interaction between the skin and moisture can broadly be divided into two categories: one where the source of moisture is *external* to the body such as touching a cloth to determine if it is wet, or when wet clothing rubs against the skin; and one where the source of moisture is *internal* to the body, such as when sweat, urine, teardrops, or other bodily fluids are produced. This initial differentiation is essential, as it determines the specific scenario within which skin-moisture interactions will occur, and the resulting thermo-tactile inputs

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Key words: Wetness, moisture, hygroreception, temperature, thermosensation, touch, mechanosensation, biophysics, psychophysics, skin

that are likely to take place at the skin interface. Ultimately, this initial evaluation will inform the development of specific hypotheses as well as the appropriate experimental methods. In short, thermal factors may be more relevant for externally-generated and mechanical factors than for internally-generated moisture (Figure 1).

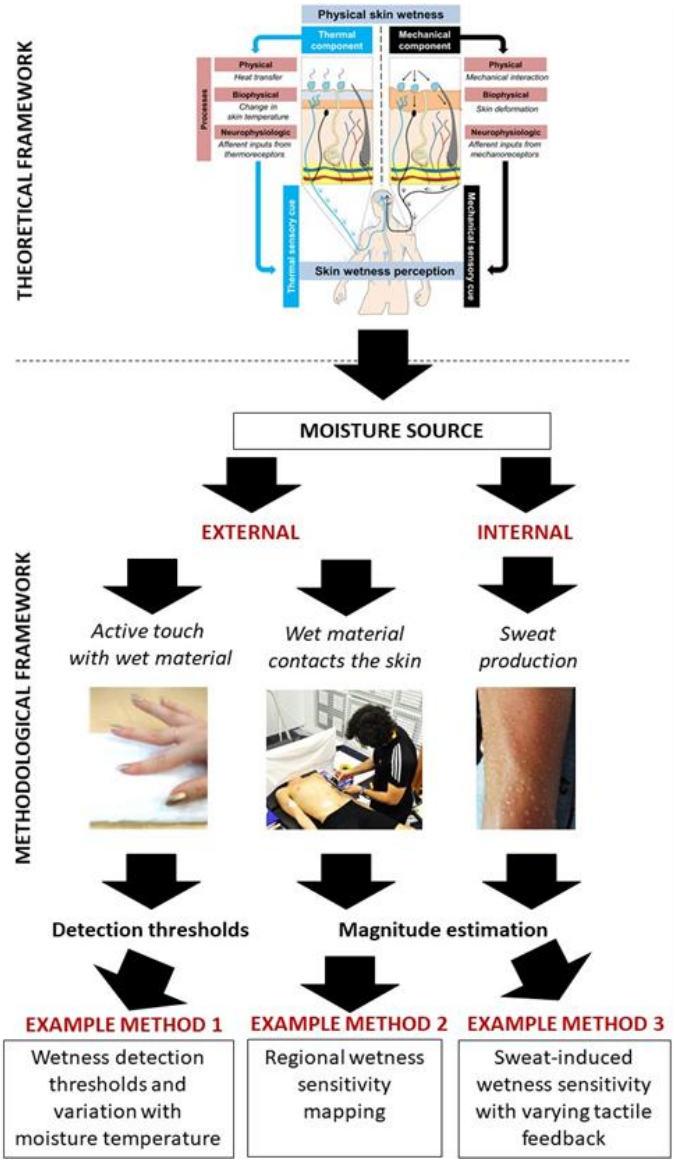


Figure 1: The methodological framework outlined in the chapter presented schematically as a flow diagram. *(theoretical framework pending permission for republication).*

When moisture is externally generated (e.g., when touching a wet object), one may expect that thermal factors like moisture temperature and the related heat transfer, may be highly variable, and therefore play a larger role in determining variance in our wetness perception. By contrast, when moisture is internally generated (e.g., when sweat is produced), the thermal conditions are more constrained - sweat temperature is likely equal to skin temperature). Accordingly, the biophysical and psychophysical assessment of thermal cues when moisture is externally generated may take priority over the evaluation of mechanical components.

Conversely, when moisture is internally generated (e.g., incontinence) one may expect that mechanical factors such as the adhesion and friction of wet continence pads to the skin, may play a greater role than thermal factors such as elevated temperature and humidity in the microclimate surrounding the skin and the incontinence pad. In this case, the biophysical and psychophysical assessment of tactile cues when moisture is internally generated may take priority over the evaluation of thermal components.

The methodological framework outlined above is presented schematically in Figure 1, which provides a flow diagram for method selection. In this chapter, we use three examples to highlight potential methodological pathways. These examples are not exhaustive, and we would like to emphasise that, as this field is ever expanding, alternative methodologies and approach could be developed. Yet, we believe that the theoretical foundation of these examples and related methods cover a broad spectrum of conditions and could form the basis for further methods development. The first of these examples will focus on evaluating wetness detection thresholds from touch interactions between the index finger pad and externally wet stimuli, and assessing threshold modulations at different moisture temperatures. The second will focus on comparing wetness perception of stimuli applied to various locations across the body and the production of associated body maps. Finally, post-exercise skin wetness perception will be examined, considering sweat production and different tactile inputs. The production of a consistently implemented methodology is critical in this research field as it not only allows for a wider comparison of scientific constructs, but also presents possibilities to develop specific informative and diagnostic tests. This is relevant in industrial applications, for example the improvement of moisture management products [17], within clinical contexts such as the design of early diagnostic tests for individuals with sensory disorders [18], and in leisure and performance applications such as the management of sweat patterns in sports clothing [19].

## 2. MATERIALS

### 2.1. Hardware

The typical hardware that may be used in wetness perception experiments [20] [21] [22] [23] are:

1. Force plate (e.g., 0 to 5 N)
2. Thermal plate and controller (e.g., 10 - 45 °C)
3. Thermal probe (consider the size and temperature of the probe, e.g., 10 - 45 °C) and controller (e.g. Physitemp Instruments Inc., Clifton, NJ, USA)
4. Water bath(s) to change the temperature of applied liquids (e.g., 15 - 45°C) (e.g. Techne FRB2D, Cole-Parmer, Stone, UK)
5. Thermocouples to measure surface temperature (e.g., 0.08 mm wire diameter, 40 Gauge) (e.g. 5SRTC-TT-TI-40-2M, Omega, Manchester, UK)
6. Indoor air quality monitor or combined thermometer and hygrometer to measure air temperature and humidity (e.g. 440dP, Testo, Lenzkirch, Germany)
7. Infrared thermometer to measure surface temperature remotely (e.g. TG56, FLIR Systems, Wilsonville, OR, USA)
8. Items to obscure the stimulation from the participant, depending on the type of perceptual assessment scales used (e.g., screen, glasses, headphones)
9. Scale and stadiometer or tape measure (for measuring weight and height of the participant)
10. Climatic chamber
11. Water perfused suit

**2.2. Consumables** [21]:

1. Skin tape (e.g. 25 mm width Transpore, 3M, Loughborough, UK)
2. Graduated plastic syringes
3. Tissues

*Environmental conditions:* Depending on the experiment, specific thermal and humidity conditions may be required, but typical, standard, or neutral conditions would be a room between 20 and 25 °C and roughly 50% relative humidity depending on clothing, with atmospheric pressure around 100 kPa.

## 3. METHODS

Investigations of wetness perception rely heavily on the use of single-blind psychophysical testing (Notes 4.1 & 4.2)[00]. This is a branch of sensory examination which focuses on the quantification of specific modalities such as haptic touch, thermal inputs and auditory cues. It relies on a stimulus-response paradigm (Note 4.3)[0], in which a series of specific stimuli are prepared by an experimenter and are introduced to a participant wearing a blindfold or otherwise visually obscured from the stimulus (Note 4.4)[0]. The participant's sensory responses are recorded, and the collation of these responses across various conditions allows the target sensory modality to be further assessed according to the chosen psychophysical test [24]. Psychophysical testing can be broadly divided into two categories depending on the desired nature of the outcome: threshold determination & magnitude estimation (Notes 4.3-4.5).

The first of these is threshold determination, which use a series of stimuli varying across a range of predetermined characteristics. In classical psychophysics, the stimuli can be introduced to the participant in several ways: the method of limits that increases the magnitude of a stimulus until a specific response is reached; the method of constant stimuli in which the stimuli are introduced in a random or balanced order; and the method of adjustment, in which the participant adjusts the stimulus magnitude to a certain detection level, or to match another stimulus. Thresholds can also be estimated using adaptive staircase procedures, in which changes to the stimulus are made according to the participant's previous response(s), thus allowing the progressive and specific testing of a particular threshold [25,26]. The establishment of the detection threshold can either be in its absolute state, showing the minimum magnitude of a stimulus required to elicit a positive response, or as a differential threshold, which denotes the minimum difference between stimuli for them to be perceived as different [24]. The threshold determination methodologies in this chapter will focus on absolute values.

A second form of psychophysical testing is magnitude estimation. This can also be approached in two ways, the most common being the sequential presentation and subsequent rating of a stimulus. This involves, for example, a continuous visual analogue scale on which the participant must mark a point to reflect their perception, an unbounded rating scale where the participant uses their own ratings to quantify a percept that can subsequently be normalised, or a graduated Likert scale forming of a series of descriptors with numerical counterparts. Alternatively, a participant may be presented with a stimulus and be asked to generate one of equal magnitude using the method of adjustment [27], but this technique is likely to be of less use in wetness perception due to the methods required to create the stimulus.

**3.1. Participants**

Participants are typically screened for inclusion criteria to limit the variance of results and maintain applicability to a healthy population, unless a different population is specifically required. For example, it is preferable to recruit individuals from a specified age range, such that they will understand and comply with testing protocols but not have any degenerative sensory disorders [28]. For example, participants under 30 years old may be preferred, as both touch and temperature detection sensitivity decrease with age [29,30]. Lifestyle factors can also be considered, such as the recruitment of non-smoking individuals. Prolonged smoke exposure can make individuals more susceptible to dermatological diseases and actively contributes to peripheral neuropathy, which would interfere with sensation [31].

Body mass can be considered, as participants having a body mass index (BMI) above 30 kg $m^{-2}$, may have some degree of peripheral nerve impairment [32]. The same applies to a alcohol consumption above the recommended weekly alcohol intake, as exceeding this limit can result in both physical and psychological interference [33]. It is also preferable for individuals to not be taking any long-term medication, as the somatosensory effects of these may be unknown or hard to quantify. Finally, participants should not have any long-term somatosensory disorder, such as peripheral neuropathy, which may interfere with perceptual ratings.

While exclusion criteria are generally quite uniform and similar between tests, participants may also be recruited for specific characteristics. For example, in clinically-focussed studies there may be a need to recruit target individuals along with matched controls. Participants may also be required for sensory comparison studies, such as identifying perceptual differences between males and females, from different countries or environmental factors, or pre- and post-partum women. Provided all choices have a justifiable scientific basis, this is a fairly flexible component of the methodology.

Where appropriate, prior to the scheduled testing, participants' body mass and height should be recorded with a digital scale and stadiometer in order to determine their BMI and hence confirm eligibility for the study. This also applies to the completion of a health screen questionnaire to highlight any matches with the exclusion criteria. The number of participants required can be established using a sample size calculation based on data from previous or pilot studies.

***3.2. Experimental Protocol***

***3.2.1. Example 1: Wetness detection – external moisture and active touch***

The investigation aimed to establish the wetness detection threshold of the human index finger pad during active touch, and assess its modulation by moisture temperature [17]. This was achieved using a single-blind repeated measures design. Stimuli consisted of textile samples varying in the applied liquid content across the range of 0 ml – 50 ml, which was determined during pilot studies. Each of the six wetness levels were repeated multiple times and introduced in a balanced order. Each participant attended four experimental sessions, with each session representing a different temperature condition.

At the beginning of each experimental session, participants underwent a familiarisation detailing the protocols and a calibration to show the extremes of the perceptual scales and provide experimental context. During experimental sessions, they touched with the sample using only the index finger pad and provided transient responses using a modified yes/no task, in which they had to select from either 'dry' or 'wet' descriptors on a digital screen. Prior to the start of each experimental session, 1 L of water was placed into a small manually controlled thermal chamber which maintained temperature at either 25.1 °C, 29.2 °C, 33.4 °C or 37.7 °C ± 0.1 °C. These temperatures were established during pilot studies to account for thermal changes which occur during sample preparation, such that the initial participant contact with the substrate would be at 25 °C, 29 °C, 33 °C or 37 °C. Different volumes were applied to individual stimuli to moisten them prior to participant interaction using 0 ml, 10 ml, 20 ml, 30 ml, 40 ml or 50 ml of water applied with a graduated syringe.

When participants arrived at the laboratory, their height was recorded with a stadiometer and weight recorded with a scale to confirm eligibility for the study. Participants were seated for the duration of the experiments. Prior to experimental interactions, participants were familiarised with study protocols and rating scales to ensure they were correctly and consistently used. The protocol involved four different stimulus combinations; cold-wet, warm-wet, cold-dry and warm-dry, which demonstrated the extremes of each possible wetness and thermal combination. Each stimulus was presented under standard test conditions and the most appropriate response on the psychophysical form shown, providing a frame of reference as well as acquainting participants with procedures.

Following the familiarisation, a single thermocouple was affixed to the centre of the index finger pad using surgical skin tape, ensuring the thermocouple tip was in contact with the skin but not covered by tape. Participants then placed their non-dominant hand through an aperture in an L-shaped screen which obscured the experimental set up from sight and hence limited visual cues (Figure 2). The base of the screen included a foam mat to reduce conductive heat transfer and could be inverted to allow for left- or right-hand dominance.

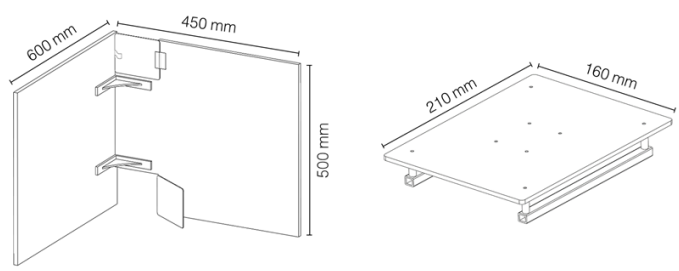


Figure 2: L-shaped obscuring screen used to limit visual cues available to participants with multiple apertures to allow for variations in participant hand dominance (left) and modifiable thermal plate used to maintain skin temperature of participants between stimuli (right).

Participants placed their index finger on a fixed-position thermal plate (Figure 2), which maintained a neutral skin temperature ($T_{sk}$) at 33 °C and hence established a thermal baseline. When the stimulus had been prepared, the participant was given the command 'contact' and moved their hand from the thermal plate to contact the stimulus at a static resting pressure. Participants had previously been informed of the commands and the positioning and transfer of the finger has been demonstrated and practiced. The stimulus was always positioned correctly below the finger, and was slightly adjusted before contact if necessary. Upon transient contact participants completed a digital form to record their perceptions, taking no more than 3 s. Both a dichotomous response method (dry/wet) and a 100 mm visual analogue scale (very dry to very wet) were used. The responses associated with the dichotomous method were assigned binary scores for subsequent analyses, with a 'dry' response as 0 and a 'wet' response as 1.

After a contact period of 3 s the participant was prompted to remove their finger from the stimulus using the command 'lift'. Post-contact perceptual assessments, analogous to those used during contact, were completed again within 3 s. When finished, participants used the command 'done', at which point the stimulus would be replaced with a cotton towel. The participant was instructed 'dry', and would statically press their index finger on to the dry towel to collect residual water for 5 s. This was repeated regardless of wetness to prevent any learning effect or bias. Before the next stimulus, the participant's index finger was returned to the thermal plate to maintain $T_{sk}$ at 33 °C. This also served as a perceptual refractory period with a minimum duration of 20 s, during which time the next stimulus was prepared before cyclically repeating the protocol. All stimuli were repeated and presented in a balanced order. Each participant attended individual experimental sessions for the different temperature conditions.

Overall, detection threshold tests are slightly more time consuming than magnitude estimation tests as they require a large number of repeats, both within and between participants, to provide a high resolution and low noise output. However, they have been shown to be a reliable methodologies that participants readily complete [24].

#### *3.2.2. Example 2: Wetness magnitude estimation – external moisture and passive touch*

The method aimed to establish differences in regional wetness sensitivity across the body, which was achieved using a single-blind psychophysical approach [34]. A series of sites were mapped across the left and medial areas of the body, assuming perceptual symmetry on opposite sides of the body. Participants underwent a brief familiarisation detailing the study protocols and a calibration using the volar, or palm-side, of the forearm. The stimuli consisted of a square thermal probe with a contact surface of 25 $cm^2$ with attached cotton square, to which 0.8 ml of water was applied. The temperature of the probe was regulated to be either $T_{sk}$ – 5 °C, $T_{sk}$, or $T_{sk}$ + 5°C, as established with an infrared thermometer for a specific site, with each temperature condition representing a different experimental session. The stimuli were contacted sequentially on the mapped sites, during which time participants reported the local wetness sensation on a digital visual analogue scale, from dry to completely wet.

At the start of an experimental session, participants arrived at the laboratory and changed into specified test clothing. Their body mass was recorded using a digital scale and their height using a stadiometer. A washable marker pen was then used to indicate the stimulation sites across the left and medial body. Following preparation, participants sat at rest for 15 minutes to adjust to environmental conditions, during which time they were familiarised with the experimental procedures. Calibration procedures consisted of six stimuli varying in both temperature and wetness (dry, $T_{sk}$ - 5 °C; wet, $T_{sk}$ - 5 °C; dry, $T_{sk}$; wet, $T_{sk}$; dry, $T_{sk}$ + 5 °C; wet, $T_{sk}$ + 5 °C), which were applied to the left volar forearm in a randomised order. Participants were instructed to associate each stimulus with the anchor points on the visual analogue scale.

Participants were instructed to stand throughout experiments. The local $T_{sk}$ at the first test site was recorded using an infrared thermometer. A square thermal probe (Figure 3) was set at the corresponding test temperature (either $T_{sk}$ – 5 °C, neutral $T_{sk}$, or $T_{sk}$ + 5 °C). A 100% cotton fabric swatch was then applied to the thermal probe and wetted with a pipette using 0.8 ml of water to ensure full saturation. Participants were notified just before stimulus application, at which point the stimulus was applied statically on the skin site for 5 s. During this time the participant completed their perceptual rating, and the stimulus was removed before proceeding to the next skin region. The order of testing was counterbalanced between thermal conditions, and the order of body regions was counterbalanced between and within participants.

Overall, the use of visual analogue scales in magnitude estimation studies is simple and efficient. The basis of the psychophysical rating scales is easy for participants to grasp, potentially due to many similar real-life scenarios in which they are employed, and is a rapid way to collect large data sets. This rapidity can be mostly attributed to the use of digital rating scales, as hard copies require manual measurements that are very time consuming and can easily lead to errors. However, consistent results are highly reliant on the correct explanation and calibration of rating scales, such as giving examples for anchor points, stating if there is a midpoint to the scale, or clarifying whether it is linear.

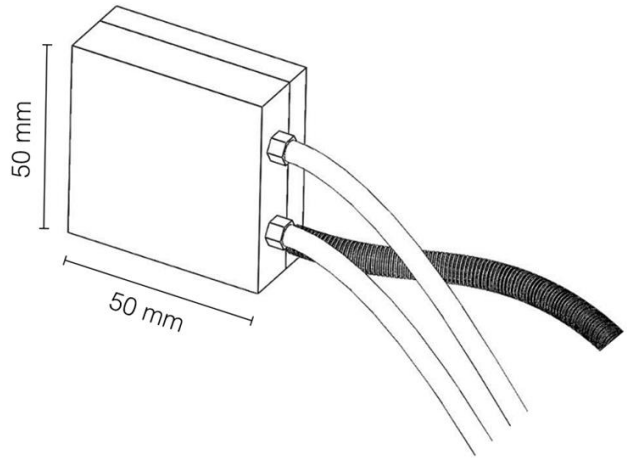


Figure 3: A square thermal probe which was wrapped in wetted cotton fabric and applied to participants' skin.

#### *3.2.3. Example 3: Wetness magnitude estimation – self produced moisture and active interaction*

The study aimed to establish if the perception of skin wetness can be significantly altered by manipulating tactile cues, independently from the level of physical skin wetness [35]. This was achieved using an incremental walking protocol which caused participants to consistently generate physical skin wetness in the form of sweat. Prior to beginning, participants were familiarised with the experimental protocols and allowed to acclimate to the surroundings. The walking protocol was conducted under two conditions, one using a tight-fitting shirt and the other using a loose-fitting shirt. In each condition, wetness perception was recorded using verbal responses to a 7-point Likert scale every four minutes (-3 dripping wet; -2 wet; -1 slightly wet; 0 neutral; +1 slightly dry; +2 dry; +3 very dry).

On experimental days, participants were requested to arrive at the laboratory 30 minutes prior to their scheduled start time to allow for preparation of procedures and bodily acclimation. Before beginning, participants were asked to void their bladder and their semi-nude body mass was recorded on a digital scale. Participants then wore the first layer of either tight- or loose-fitting clothing and were asked to rate their wetness in order to establish a baseline of sensation. Participants then put on the second layer of clothing, consisting of an impermeable jacket and trousers to prevent sweat dissipation.

Participants were moved to the treadmill where they began the 45 minutes incremental walking protocol (5 km $h^{-1}$; gradient: +2 to +16 %). During the protocol, participants were instructed to rate their wetness sensations every five minutes. As soon as a slightly wet response was given, participants were requested to detail whether this included chest, back, arms or thighs, and of these which was the wettest. Subsequent to finishing the walking protocol, participants removed their clothing, at which point their semi-nude body mass was again recorded. With a minimum of 48 hours separating the trials, the protocol was repeated, this time using whichever of the tight- or loose-fitting clothing options that was not previously worn.

Like visual analogue scales, the use of Likert scales to collect perceptual data is simple and efficient. It is easy for participants to comprehend and allows them to rate their perceptions while undergoing other continuous uninterrupted tasks, for example during exercise. An issue which can occur in such scenarios is the size and position of the scale, as it needs to be clearly legible for participants. Again, consistent results rely greatly on the correct explanation and calibration of rating scales.

### 3.3. Analysis

#### *3.3.1. Example 1: Wetness detection – external moisture and active touch*

In this study, the independent variables were temperature and volume. Wetness perception was the dependent variable. Coding dry and wet responses as 0 and 1 respectively allowed a perceptual response ratio to be calculated for any given volume. For example, 5 dry responses and 7 wet responses would generate a value of 0.42 (5/12). Perceptual ratios and corresponding volumes were plotted against each other and fitted with a sigmoidal curve. The point at

which the response exceeded 0.5 (50 %) was considered the threshold for wetness detection. The threshold values were established for every participant by reading the volume at the 0.5 intersection, and means calculated for each participant and each temperature condition (Figure 4).

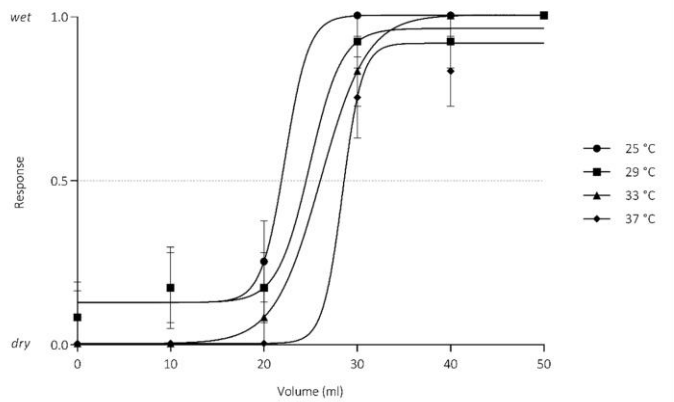


Figure 4: An example of the sigmoidal curves fitted for each respective temperature within a single participant. Each point represents the ratio of responses from repeated stimuli with 95% confidence intervals.

### *3.2.2. Example 2: Wetness magnitude estimation – external moisture and passive touch*

The dependent variable in the study was wetness perception, while the independent variables were stimulus location and temperature. Changes in perceptual responses can be mapped to show regional variations in wetness perception and show how these perceptions are correlated with stimulus temperature (Figure 5). This gives insights into regional sensitivity at different temperatures as well as intra- and inter-individual variability. Similarly, if sufficient participants are recruited, the information can reflect differences in perception according to sex, age and other demographics, or under different conditions, such as pre and post exercise. Due to the large number of variables, an ANOVA model is typically used to assess changes in the dependent variables.

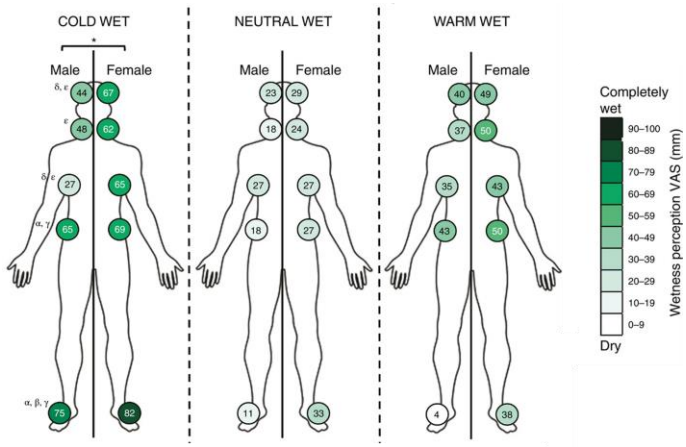


Figure 5: Body maps of wetness perceptions in males (n = 10) and females (n = 10) resulting from the application of the cold wet, neutral wet and warm wet stimuli at rest [34]. *(pending permission for republication).*

### *3.3.3 Example 3: Wetness magnitude estimation – self produced moisture and active interaction*

In this study, the independent variables were condition (loose- and tight-fitting clothing) and time (10 levels, in 5-minute intervals). The dependent variable was wetness sensation. The mean wetness sensation at each 5-minute time interval was established across participants in both the loose- and tight-fitting clothing conditions. As wetness sensation was recorded on a Likert scale and constitutes ordinal data, a non-parametric method was used to assess if there were significant differences between the two conditions as a function of time. A graphical representation is shown in Figure 6.

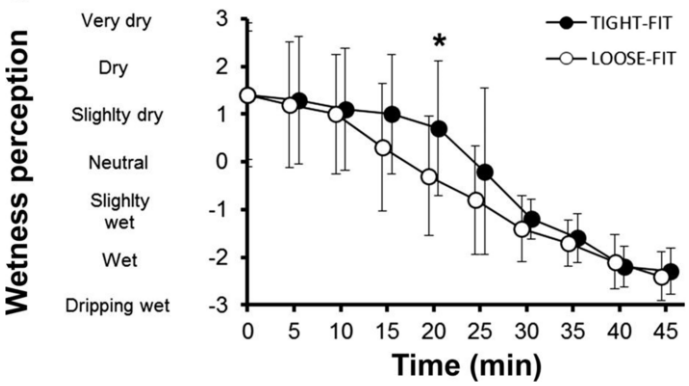


Figure 6: Means ± SD (n = 10) for wetness perception across time throughout the tight-and loose-fitting trials. Despite that during both tight-fit and loose-fit trials the level of physical skin wetness did not differ at any time point, the overall perception of skin wetness was significantly reduced during the tight-fit trial as opposed to the loose-fit trial. This main effect significantly interacted with time, 20 min after the exercise protocol was initiated (*P < 0.05) [35]. *(pending permission for republication).*

## 4. NOTES

### 4.1. Participants' needs

While there are many hypotheses that researchers would like to investigate, all of the psychophysical experiments must account for the needs of participants. It is important that participants fully understand the nature of the task and what is required of them, and this should be explained clearly, concisely, and hopefully with some enthusiasm. The use of consistent commands such as 'lift', 'touch' or 'dry' will also act as signposting points which help to guide participants through stimuli interactions until they become almost rhythmic. Depending on the nature of the methodology, it may be useful for specific interactions to be demonstrated or for participants to practise them to improve technique and consistency as part of a familiarisation process. However, the sufficient learning of protocols needs to be balanced with limiting potential for learning effects or response bias. The need for clarity also applies to the use of rating scales and calibration protocols, such giving examples of anchor points, encouraging participants to rate stimuli independently or simply reassuring them to trust their own judgement.

### 4.2. Experimental duration

There should be an established timescale that participants are aware of. This aims to ensure that they complete the tasks and corresponding perceptual recordings effectively, without either lingering or rushing. Additionally, an optimum length of session needs to be established. The more research data that needs to be collected, the longer an experimental session will take, and may require splitting into smaller sessions. If a single session is too long, participants may lose motivation, become distracted, rush or otherwise disengage with the task. However, it is also important to set boundaries within the experiment and know when to do when participants do not comply with the protocols of the test or fail to attend sessions.

### 4.3. Experimental design

Depending on the specific methodology, different aspects of the experimental design may need to be considered. A common aspect is the repetition of stimuli, which needs to be established based on the desired resolution, accuracy and precision of the resulting data, as well as accounting for time constraints (Note 4.2). The order in which stimuli are presented also needs to be decided, both within and between participants, such as presenting stimuli in a counter balanced as opposed to a random order. If there is long term exposure to wetness, changes in physical skin characteristics such as increased hydration levels or dermal plasticity should also be considered and the study adjusted accordingly.

Another aspect to consider in the experimental design is the potential of heat transfer, be this between stimuli, participants, or the ambient environment. For example, a solution is prepared at 35 °C and applied to a fabric sample. By the time interaction occurs, heat energy may have been lost to the ambient environment such that the actual temperature is much lower than anticipated.

This can be accounted for by assessing the thermal decay across the range of samples and adjusting temperatures accordingly.

**4.4. Between-participant variation**

Additionally, variation between participants that is not being regulated as part of inclusion criteria needs to be considered. For example, when creating an L-shaped obscuring screen to limit visual cues for participants, both the varying diameter of participant arms, their seated eye level, and hand dominance needs to be accommodated. While this may seem trivial, it may interfere with interactions and subsequent perceptions.

**4.5. The psychophysical task**

A clear distinction between psychophysical approaches needs to be maintained. In the determination of sensory thresholds, both a two alternative forced choice method (2AFC) and a yes/no task basis (Y/N) are used (see also Chapter 1). The 2AFC allows participants to choose which of two stimuli correspond best to a single descriptor, whereas Y/N involves only a single stimulus to which either a positive or negative response must be assigned [36,37]. The latter is often modified such that the single stimulus is assigned to one of two opposing descriptors. Both 2AFC and Y/N can be equally effective in determining different physiological measures, but their success is pivotal on the accompanying methodology.

**4.6. Temperature manipulation**

While approaches to manipulating temperature vary, many are applicable with appropriate justification. For example, when stimuli and the skin are in contact, the stimulus could either have been manipulated in relation to physical skin properties (e.g., $T_{sk}$ - 10°C), or the skin itself can be maintained at a specific baseline condition (e.g., 33 °C) to ensure the same transient magnitude of change between participants. Typically, the former is used in passive touch and the latter in active touch studies.

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