Tilburg University

Validation of the ISP131001 sensor for mobile peripheral body temperature measurement

Sarda, Elisa; Klein, Richard A.; Dujols, Olivier; Ijzerman, Hans

Published in:
International Review of Social Psychology

DOI:
[10.5334/irsp.409](https://doi.org/10.5334/irsp.409)

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):
Sarda, E., Klein, R. A., Dujols, O., & Ijzerman, H. (2021). Validation of the ISP131001 sensor for mobile peripheral body temperature measurement. *International Review of Social Psychology*, 34(1), [409].
<https://doi.org/10.5334/irsp.409>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

EXPLORATORY REPORT

Validation of the ISP131001 Sensor for Mobile Peripheral Body Temperature Measurement

Elisa Sarda^{*†}, Richard A. Klein[‡], Olivier Dujols^{*} and Hans IJzerman[§]

Previous studies have indicated that temperature regulation is related to social behavior (for an overview, see IJzerman et al., 2015; IJzerman & Hogenzeil, 2017). However, precise causal relationships between temperature and social behaviors are unclear. These links may be better understood by frequently measuring temperature in daily life and mapping those measurements onto social behaviors. The primary purpose of the present study was to enable such studies by validating a new wireless temperature sensor, the ISP131001 from Insight SiP, for human peripheral temperature measurement in daily life. In our exploratory dataset, we found moderately high correlations between two ISP131001 sensors and a comparison sensor ($r = .82$ for the average of our two ISP sensors). These correlations replicated in our confirmatory dataset ($r = .94$ for the average of our two ISP sensors). A secondary purpose of this report is the inclusion of a standard set of relevant measures for social thermoregulation research. We believe that this standard protocol of measures be included in all future social thermoregulation studies in order to facilitate and encourage data re-use and aggregation across studies.

Keywords: peripheral temperature measurement; mobile measurement; validation; measurement protocol; social thermoregulation

Introduction

Compared to other core survival needs in humans, temperature has been examined only sparingly (see, Ekman et al., 1983, as a first notable example to the contrary). Humans and other endotherms need to constantly regulate temperature due to external fluctuations in the environment (Cannon, 1932). A notable exception to this dearth of research on temperature are findings on social thermoregulation (IJzerman et al., 2015), which have suggested that temperature regulation can affect social behavior. But research on social thermoregulation has not been able to show exactly whether and how people's temperature is causally linked to their social behaviors. To facilitate such research, we validate a new wireless device, the ISP131001 mobile temperature sensor, so that peripheral body temperature can be measured in everyday life. Further, to better map out social thermoregulatory mechanisms, we have identified important predictors of temperature regulation. We have created a protocol so that these predictors are recorded in social thermoregulation research from this day forward. Better documentation of

such known correlates can help map social thermoregulatory mechanisms across studies.

Social thermoregulation

In the last few years, researchers have found links between social relationships and temperature regulation, or *social thermoregulation*. The basic idea is that other people can help us regulate our temperature in a variety of ways that likely extends beyond huddling and hugging (IJzerman et al., 2015; IJzerman et al., 2018). Without adequate thermoregulation, one dies. Because regulation of body temperature is expensive energetically, animals (including humans) can reduce these energy expenditures by regulating temperature with the help of conspecifics (e.g., IJzerman et al., 2018; for a review, see IJzerman et al., 2015).

Newborns rely on social thermoregulation when they must depend on their parents to regulate their temperature (see Winberg, 2005). In adults, thermoregulation has been linked to social behaviors in various studies. IJzerman and colleagues (2012) for instance find that exclusion (versus inclusion) in a ball-tossing game leads to lower peripheral temperature. Recently, IJzerman, Neyroud, Courset, Schrama, and Pronk (2018) found in one study and two replications (one of which was pre-registered) that holding colder (versus warmer) cups led people to think of loved ones (this depends on previous relationships).

Although these results seem to demonstrate a straightforward and strong link between temperature regulation

* Université Grenoble Alpes, LIP/PC2S, FR

† Université de Nantes, LPPL, FR

‡ Tilburg University, NL

§ Université Grenoble Alpes, Institut Universitaire de France, LIP/PC2S, FR

Corresponding author: Elisa Sarda (sarda.ely@gmail.com)

and interpersonal processes, not all of the effects in this literature have been successfully replicated (e.g., original study Williams & Bargh, 2008, failed replication Lynott et al., 2014; original study Bargh & Shalev, 2012, failed replication Wortman, Donnellan & Lucas, 2014), very few studies have been pre-registered, and many (if not most) studies relied on small sample sizes too low to provide meaningful evidence (e.g., IJzerman & Semin, 2009; Williams & Bargh, 2008). Promisingly, a recent meta-analysis of social thermoregulation research does seem to provide general support for a link between social relationships and temperature, one that holds when applying various known techniques to reduce the effects of publication bias as much as possible (IJzerman et al., 2021).

One of the most convincing findings on social thermoregulation comes from two studies conducted in 12 countries suggesting that the variety and complexity of our relationships can protect our bodies from the cold (IJzerman et al., 2018). Despite these positive findings, the exact *causal* relationships and mechanisms are not yet well understood. Do peripheral temperature changes lead to changes in social behavior and in turn protect core body temperature? Are peripheral temperature changes in response to social events epiphenomenal or an important chain in a larger causal process? To better understand and model such predictors, future studies need to systematically investigate the relationship between temperature fluctuations and social behaviors. This requires 1) studying (peripheral and core) temperature changes in daily life and 2) measuring known predictors (like height, sex, weight, medicine use, health, and relationship variables) so as to map social context onto temperature fluctuations.

Choosing and validating the ISP131001 sensor for use in daily life

To enable peripheral temperature measurement in daily life, we need a valid and reliable device that is easy to use and comfortable to wear for long periods. We considered several options (please see **Table 1** for a list of possible options; see also IJzerman et al., 2017). Wireless solutions are needed if we expect participants to wear these devices as they go through their daily routines. It is also important that the data is recorded frequently (several times per minute) and only saved on one's own server. Moreover, if we ever want to use a sensor that we can rely on for

application together with other devices, it is vital that the firmware is open. This allows us to alter the frequency of measurement and to communicate measurement information to a device that can manipulate temperature (an actuator). Further, we preferred a sensor that could measure every second. Finally, if we are to implement the solution in larger, multi-site studies, the solution needs to be affordable. Because of all those reasons, we chose the ISP131001 sensor.

The ISP131001 sensor is a wireless device that measures temperature, movement, and air pressure. It is small and mobile, records temperature frequently (once per second), and is affordable (<100 Euros per sensor; exact price depends on amount ordered). It is composed of a small processor, a temperature sensor, and a thin cable connecting the sensor to a battery. The overall size of the device is $12.5 \times 25 \times 3$ mm. The sensor communicates via Bluetooth Low Energy with an open-source smartphone app that our lab, the CO-RE Lab, developed: the *Bio-App for Bonding* (Frederiks et al., 2018; IJzerman et al., 2018). The smartphone app has a temperature module that displays a running log of temperature measurements (see **Figure 1** for a photo of the sensor and the smartphone application). Beyond the temperature module, we also programmed an algorithm into the app to record infant crying, a module

Figure 1: Sensor and Smartphone Application. *Picture of the hand is one of the co-authors and thus posted with consent.*

Table 1: Specifications of existing solutions measuring peripheral temperature.

Device	Wireless	Data saved on one's own server only?	Recording frequency
Thermistors	No	Yes	Once per second
Thermocouples	No	Yes	Once per second
iButton	Yes	Yes	Once per minute
BlueMaestro Tempodisc	Yes	No	Once per second
ISP131001 sensor	Yes	Yes	Once per second

to record electrodermal activity, a module to self-report experienced affect through a dial button, an existing experience sampler module, and a module to turn on a device to manipulate temperature, the EmbrWave (Frederiks et al., 2018).

However, as the ISP131001 sensor had not been used in behavioral science before, it is unknown how accurate or suitable it is for research. As such, we chose to validate the sensor with a better-known (and non-mobile) sensor (the *ADInstruments MLT422/A Skin Temperature Probe*) to gauge its suitability for studying human peripheral skin temperature. To also determine whether a more comfortable position than the finger can be used, we attached the sensor to two different body parts: the index finger and the wrist. Moreover, to understand the reactivity of the sensors in different temperature conditions, in addition to baseline temperature measurements, we also took measurements after participants dipped their hands in cold or hot water. Finally, as we more generally seek to link social behavior to temperature, we also make available on the OSF a protocol for measuring important variables related to peripheral temperature (<https://osf.io/xf7uk>).

Research Overview

We focused on three research questions: To what level are the ISP131001 sensors correlated with the validation sensor overall, regardless of the position of the sensors on the finger/wrist or the temperature condition (baseline, cold, hot; Research Question 1)? Are the sensors reliably correlated to our validation sensor regardless of the position of the mobile sensor (fingertip/wrist; Research Question 2)? Are the mobile and validation sensors reliably correlated at different temperature levels (baseline, cold, hot; Research Question 3)? We also conducted auxiliary analyses based on these findings to gain insight about the optimal uses of the ISP131001 sensors. Finally, we included a standard protocol measuring variables related to temperature regulation, which we hope will be reused in thermoregulation studies that follow ours (we did not analyze data from this protocol because the sample size was too small in our study). By measuring these known predictors across studies, meta-analysts can then gather data from different studies to start to map how social behavior maps onto temperature regulation and how these are (potentially) moderated by people's social networks and by people's self-reported individual differences.

Method

Power analysis and participants

In order to determine sample size, we ran a power analysis in PANGEA (Westfall, 2015) crossed with a random stimuli-in-treatments (Clark, 1973) design. We specified participants as a random factor and device, condition (baseline, hot, cold), and position of the sensor (index or wrist) as fixed factors. Assuming an effect size of $r = 0.40^1$ ($d = 0.87$), 24 participants would allow 99% power. With 12 participants (e.g., after splitting the data into exploratory and confirmatory datasets), we would have 89% power for the same effect sizes. Notably, we did not have any a priori

expectations for what magnitude of correlation to expect, and the mere presence of a correlation is only minimally informative when assessing whether a device is suitable for real-world use. Thus, below we focus on observed effect sizes and confidence intervals.

Twenty-four participants, 18 women and 6 men ($M_{\text{age}} = 24.4$, $SD_{\text{age}} = 4.28$) took part in this study. Participants were recruited via either our student participant pool or inviting people from around the building where we conducted our study. The study took approximately 45 minutes for each participant to complete.

Procedure and materials

The entire study took place in a lab room at Université Grenoble Alpes.² The study consisted of two parts. First, participants completed a questionnaire measuring variables related to social thermoregulation. Next, we measured the peripheral body temperature of the participants in three temperature conditions: baseline, after dipping their hand in cold water, and after dipping their hand in hot water.

Questionnaire details

After filling out informed consent forms, participants completed a questionnaire in Qualtrics, where they answered questionnaires theoretically *likely* related to social thermoregulation (see e.g., IJzerman et al., 2018). These questionnaires were completed in a random order, and demographics were answered after the last questionnaire. The entire dataset for this part of the study, as well as the questionnaire, are available on the OSF Project Page: <https://osf.io/4nkqe/> and <https://osf.io/7h5sc/>. These questions form the protocol we have in mind to be used for future social thermoregulation studies. The latest update of the protocol using these questionnaires will be updated on the OSF as we move forward with this line of research (<https://osf.io/xf7uk/>). The following scales are included in this protocol (all reliabilities are reported based on the exploratory subset and will be updated after the inclusion of the confirmatory analyses).

The *Experiences in Close Relationship-Revised (ECR-R*; Wei et al., 2007) questionnaire is a 36-item questionnaire measuring adult attachment in close relationships (sample item: "I turn to my partner for many things, including comfort and reassurance"). Response options ranged from 1 = *strongly disagree* to 7 = *strongly agree*. The questionnaire is composed of two subscales: one measuring anxiety (exploratory sample: $\alpha = 0.94$; ω_h : 0.61; ω_t : 0.97; confirmatory sample: $\alpha = 0.87$; ω_h : 0.37; ω_t : 0.95) and one measuring avoidance (exploratory sample: $\alpha = 0.97$; ω_h : 0.88; ω_t : 0.98.³; confirmatory sample: $\alpha = 0.92$; ω_h : 0.46; ω_t : 0.96).

The *Social Thermoregulation and Risk Avoidance Questionnaire (STRAQ-1*; Vergara et al., 2019) is composed of 23 items and 4 subscales. The most important scales for this type of research are the Social Thermoregulation subscale (exploratory sample: $\alpha = 0.77$; ω_h : 0.64; ω_t : 0.89; confirmatory sample: $\alpha = 0.65$; ω_h : 0.64; ω_t : 0.88; sample item: "When I feel cold I seek someone to cuddle with"), which measures individual differences in the desire to

rely on other people to regulate temperature; the Solitary Thermoregulation subscale (exploratory sample: $\alpha = 0.82$; ω_h : 0.45; ω_c : 0.94; confirmatory sample: $\alpha = 0.87$; ω_h : 0.66; ω_c : 0.93; sample item: “When I feel cold I don’t turn on the heater”), which measures individual differences in the degree to which people desire to regulate temperature by themselves; and high temperature sensitivity (exploratory sample: $\alpha = 0.91$; ω_h : 0.68; ω_c : 0.98; confirmatory sample: $\alpha = 0.88$; ω_h : 0.75; ω_c : 0.94; sample item: “I am sensitive to heat”). Response options for the entire scale ranged from 1 = *strongly disagree* to 5 = *strongly agree*.

The Social Network Index (SNI; Cohen et al., 1997) measures the number and type of social networks a person engages in frequently, including friends, family, romantic partners, co-workers, and others (12 total). For each relationship, participants have to say if they have some contact in that social domain and with how many people they have contact at least once every two weeks. Answers are scored from 0 to 12, with 12 indicating that a participant is engaged in all types of social relationships. This questionnaire is composed of 3 subscales: the level of social embeddedness, the social network diversity, and the network size (no reliability information available for this scale).

Single-Item questions

At the end of the questionnaire we also asked participants questions about their sex, age, height, weight and native language; whether they are in a romantic relationship; and the country of birth of their parents.⁴ We also added questions on whether people smoke (and, if yes, how many cigarettes per day), whether they use medication (and, if yes, which kind of medication), and whether they use birth control pills (only for women). Finally, we asked our female participants to predict their next menstrual cycle.⁵

Temperature measurements

Once participants completed the questionnaire, we began the peripheral body temperature measurement portion of the study. We used three sensors: two wireless ISP131001 sensors (ISP131001 Sensor 1, ISP131001 Sensor 2) and the wired comparison device: the ADInstruments MLT422/A Skin Temperature Probe (Liu et al., 2013; Gao et al., 2012). We attached the temperature sensors to the participant’s

non-dominant hand: two sensors were attached to the index finger and the other one to the wrist (note: the finger is typically known as the most sensitive place to measure peripheral temperature changes; Huizenga et al., 2004).

We measured on the wrist as well because this would be much more comfortable for participants to wear at home if the wrist showed similar results as the fingertip. The comparison sensor was always attached to the finger, along with one of the two ISP131001 sensors. The other ISP131001 was attached to the wrist, and we randomly varied which of the two ISP131001 sensors was attached in which location in case there were unit-specific differences.

In order to assess the sensors across various temperature ranges, we measured the peripheral body temperature of each participant in three conditions: (1) at baseline, (2) after the participant dipped their hand in cold water (10 degrees Celsius) for 20 seconds, (3) after the participant dipped their hand in hot water (40 degrees Celsius) for 20 seconds (see **Figure 2**, for a schematic overview on our temperature’s measurements). We used a *Techné FTE10 ADC* liquid bath and a *Cold pressor Techné RU 200* to cool the water and a *Techné immersion circulator TE-10A Tempette* to heat the water and keep it at constant temperature.

Every session followed the same order for temperature measurement. First, we recorded peripheral body temperature with all three devices for five minutes as a baseline measurement. After this, we removed the sensors from the participants’ hands and had participants dip their non-dominant hand in a cold (on average 10 degrees Celsius) water bath for approximately 20 seconds. Once participants dried their hands, we reconnected the three temperature sensors in the same positions as before and measured peripheral body temperature for five minutes. Then, after again removing sensors from participants’ hands, they again dipped their non-dominant hand in the same water bath, but now with hot (40 degrees Celsius) water for 20 seconds. Once participants dried their hands, we again measured peripheral body temperature with our three devices in the same positions for five minutes. When the third peripheral body temperature recording was finished, the study was complete. Finally, we thanked the participants and briefly explained the objective of the study.

Figure 2: Schematic overview of position of our temperature measurements. *Picture of the hand is one of the co-authors and thus posted with consent.*

Results

Analysis plan

All analyses were conducted in R (R Core Team, 2012), primarily using mixed effects models with the lme4 package (Bates et al., 2015) to examine the relationship between the temperature readings from our three sensors. We used mixed models because the temperature was measured more than once on the same participant. The ISP131001 sensors recorded temperature approximately once per second for a total of 15 minutes. The mixed models allow us to consider both the variability within and between participants. The dataset and analysis code are available on the OSF page: <https://osf.io/hbcw7/>. In accordance with the guidelines for Exploratory Reports, we split our data into two random samples: we used the first sample (12 participants) to explore our data, leaving the remaining data (12 participants) to confirm our predictions.⁶

The confirmatory data will give us the least biased estimate of the performance of the ISP sensors. As we have two ISP sensors, we present two separate but identical analyses for each research question: first, we present the relationship between our first ISP sensor (ISP Sensor 1) and the MLT probe, and then we present a parallel analysis examining the relationship between the second ISP sensor (ISP Sensor 2) and the MLT probe (see **Table 2** for more details on the analyses). Finally, we added auxiliary analysis testing the relationship between the average of the ISP sensors and the MLT probe. Again, we do not analyze the questionnaire data, as the sample size is too small to draw any meaningful conclusions.

Exploratory results (12 participants)

Research Question 1: How correlated are the ISP131001 sensors with the validation sensor?

We ran linear mixed effect models to assess the correlation between our new sensors and the validation sensor. In **Table 3**, we reported complementary information

for analyses testing Research Question 1, such as Standardized coefficients, p -values, and η_p^2 . The R^2 of the full model testing the relationship between ISP Sensor 1 and the MLT probe was 0.71, 95% CI = [0.70, 0.72]. This analysis revealed a positive relationship between these two sensors ($r = 0.55$, 95% CI = [0.53, 0.56]),⁷ such that temperature readings from ISP Sensor 1 are strongly related to temperature changes in the MLT probe, when we controlled for sensor position and participant temperature condition.

We then ran the same analysis with the second ISP unit (ISP Sensor 2). This is partially a replication and partially to test another ISP unit for consistency. The R^2 of the full model was 0.63, 95% CI = [0.63, 0.64]. These analyses revealed a significant positive relationship between ISP Sensor 2 and the MLT probe ($r = 0.36$, CI = [0.34, 0.38]), such that temperature changes on ISP Sensor 2 are related to temperature changes in the MLT probe, when we controlled for the others variables. Thus, for the second ISP sensor the correlations with the MLT probe were lower than our first sensor. Altogether, this suggests that there is a considerable amount of noise when using the ISP Sensor on the finger and on the wrist.

Table 3: Standardized coefficients, p -values, and η_p^2 for the analyses testing Research Question 1 (exploratory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP1 (overall)	0.62***	0.30
MLT ~ ISP 2 (overall)	0.33***	0.13

* Denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Table 2: Overview of our Analyses.

Research Question	DV	IV	Random factors
1. How correlated are the sensors overall, regardless of the position of the sensors or the temperature condition?	MLT probe	-ISP sensor (1 or 2 according to the analysis) -2 orthogonal contrasts for the temperature condition (C1: comparing cold and hot taken together to the baseline, and C2: comparing cold to hot) -centered variable for sensor positions - interaction terms	slope and intercept of participant number
2. Are the sensors sufficiently correlated regardless of the position of the sensor?	MLT probe	-ISP sensor (1 or 2 according to the analysis) -2 orthogonal contrasts for the temperature condition -dummy coded variable for sensor positions - interaction terms	slope and intercept of participant number
3. Are the sensors sufficiently correlated at different temperature levels?	MLT probe	-ISP sensor (1 or 2 according to the analysis) - dummy coded variable for the temperature condition -centered variable for sensor positions -interaction terms	slope and intercept of participant number

Research Question 2: Are the sensors reliably correlated to our validation sensor regardless of the position of the mobile sensor?

In order to answer our second research question, we first examined the correlation between our new sensors and the validation sensors at different sensor positions (finger/wrist). In **Table 4**, we reported complementary information for analyses testing Research Question 2, such as Standardized coefficients, p -values and η_p^2 . Analyses testing the relationship between ISP Sensor 1 and the MLT probe indicated that the correlation between these two sensors was larger when sensors were placed in the same position (i.e., both on the finger): ($r = 0.61$, 95% CI = [0.59, 0.62]), than when one was on the finger and one was on the wrist: ($r = 0.32$, 95% CI = [0.30, 0.34]). Similarly, analyses testing the relationship between ISP Sensor 2 and the MLT probe showed that the correlation between these two sensors was bigger when sensors were placed in the same position: ($r = 0.50$, 95% CI = [0.49, 0.51]) than in different positions: ($r = 0.04$, 95% CI = [0.03, 0.06]). These analyses suggest that the wrist does not correlate very well with temperature changes on the finger in our study.

Research Question 3: Are the mobile and validation sensors reliably correlated at different temperature levels?

In order to answer our third research question, we examined the correlation between our new ISP sensors and the validation sensor at different temperature levels (baseline, cold, hot). In **Table 5**, we reported complementary information for all the analyses testing Research Question 3, such as Standardized coefficients, p -values, and η_p^2 . Analyses testing the relationship between ISP Sensor 1 and the MLT probe showed that the relationship between the two sensors was stronger at baseline ($r = 0.80$, 95% CI = [0.79, 0.80]) than in the hot ($r = 0.55$, 95% CI = [0.54, 0.56]) and cold ($r = 0.55$, 95% CI = [0.55, 0.58]) conditions. Similarly, analyses testing the relationship between ISP Sensor 2 and the MLT probe again revealed that the correlation between these two sensors was stronger at baseline ($r = 0.77$, 95% CI = [0.76, 0.78]) than in hot ($r = 0.39$, 95% CI = [0.37, 0.40]) or cold ($r = 0.33$, 95% CI = [0.32, 0.35]) conditions. These analyses suggest that the ISP sensors (which measure more infrequently) do not capture changes as

well as the validation sensor (which measures every millisecond).

Auxiliary analysis testing the relationship between the average of the ISP sensors and the MLT probe

After exploring the sensors individually and finding somewhat lower correlations than we had hoped, we decided to explore averaging readings from both ISP sensors (one on the wrist and one on the finger) and comparing that average with the MLT probe, our validation sensor. We used the same overall linear mixed effects model as before but replaced the individual measures from the two ISP sensors with their average reading per each timepoint. We also removed the position variable as it does not make sense with the present model.⁸

The R^2 of the full model was 0.84, 95% CI = [0.83, 0.84]. In **Table 6**, we reported complementary information for all the analyses that follow, such as standardized coefficients, p -values, and η_p^2 . Analysis again revealed a significant positive relationship between the average of the ISP sensors and the MLT probe ($r = 0.82$, 95% CI = [0.82, 0.83]), such that temperature changes averaged between the ISP sensors were highly correlated with temperature changes in the MLT probe, controlling for temperature

Table 5: Standardized coefficients, p -values and η_p^2 for the analyses testing Research Question 3 (exploratory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP1 (baseline)	0.93***	0.64
MLT ~ ISP1 (hot)	0.59***	0.30
MLT ~ ISP1 (cold)	0.59***	0.32
MLT ~ ISP 2 (baseline)	0.80***	0.60
MLT ~ ISP 2(hot)	0.34***	0.15
MLT ~ ISP 2 (cold)	0.32***	0.11

* Denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Table 4: Standardized coefficients, p -values, and η_p^2 for the analyses testing Research Question 2 (exploratory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP1 (same position)	0.62***	0.37
MLT ~ ISP1 (different position)	0.62***	0.10
MLT ~ ISP 2 (same position)	0.33***	0.25
MLT ~ ISP 2 (different position)	0.33***	0.01

* Denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Table 6: Standardized coefficients, p -values, and η_p^2 for the correlation between the average of the two ISP sensors and the MLT probe (exploratory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP _{average} (overall)	0.71***	0.68
MLT ~ ISP _{average} (baseline)	0.87***	0.84
MLT ~ ISP _{average} (hot)	0.72*	0.70
MLT ~ ISP _{average} (cold)	0.72**	0.75

* Denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

condition. The correlation between the average of the ISP sensors and the MLT probe was stronger at baseline ($r = 0.91$, 95% CI = [0.91, 0.91]) than in hot ($r = 0.84$, 95% CI = [0.83, .84]) or cold ($r = 0.87$, 95% CI = [0.86, 0.87]) conditions. These analyses show that the correlation between the average of our two sensors (placed in different positions) is higher than previous correlations in which we used the ISP sensor units separately. In addition, the two sensors together seem to capture change in temperature better, as the correlation with the validation sensor increased in the hot and cold conditions. A visual representation of exploratory correlations between sensors is presented in **Figure 3**.

Confirmatory results

Based on these exploratory findings, we proposed—prior to pre-registering⁹ the hypothesis on the OSF and with the journal—that averaging readings from two ISP sensors produces the most suitable and accurate method for use in daily life. Therefore, in our confirmatory results we focus on the correlation between the average of the two ISP sensors and the MLT probe. Because the size of the correlation is critical to our interpretation, we focus on the effect size in our confirmatory analysis. We used a relatively arbitrary minimum effect size difference of less than $r = 0.15$ change from our exploratory result as replicating the effect with a similar effect size. Both the point estimate and confidence interval range had to fall within this ± 0.15 range to be considered a replication. We would consider confirmatory results larger than that range as substantially stronger correlations and confirmatory results smaller than that range as substantially weaker correlations.

If the point estimate fell within the ± 0.15 range but the 95% CI did not, we included a note acknowledging the ambiguity. In addition, we re-ran the exploratory results for the individual sensors and reported in **Table 8** complementary information for analyses testing research questions 1, 2, and 3, such as Standardized coefficients, p -values, and η_p^2 . However, to constrain our flexibility in interpreting the results, we did not focus on these results as the basis for our overall conclusions.

Relationship between the average of the ISP sensors and the MLT probe

We conducted exactly the same analyses on the average of two sensors as presented in the exploratory section, this time using the remaining 12 participants from our hold-out sample, which were unseen by the first author prior to her analyzing them. We chose to focus primarily on correlation between MLT probe and the two averaged ISP sensors, as 1) the average of the two sensors had a higher correlation and 2) the average of the sensors seemed to capture change better than one sensor alone (as auxiliary analyses again demonstrated the superior accuracy of the two averaged sensors). The dataset and analysis code are available on the OSF page: <https://osf.io/hbcw7/>.

The R^2 of the full model was 0.92, 95% CI = [0.92, 0.92]. In **Table 7**, we report complementary information for all the analyses that follow, such as Standardized coefficients, p -values, and η_p^2 . Analyses revealed a significant positive relationship between the average of the ISP sensors and the MLT probe ($r = 0.94$, 95% CI = [0.93, 0.94]), such that temperature changes averaged between the ISP sensors were highly correlated with temperature changes in the MLT probe, controlling for temperature condition. According to our replication criteria for the confirmatory split, the observed effect for this overall correlation replicated our exploratory result with a similar effect size.

Table 7: Standardized coefficients, p -values, and η_p^2 for the correlation between the average of the two ISP sensors and the MLT probe (confirmatory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP _{average} (overall)	0.84***	0.88
MLT ~ ISP _{average} (baseline)	0.88***	0.90
MLT ~ ISP _{average} (hot)	0.85***	0.88
MLT ~ ISP _{average} (cold)	0.87***	0.90

* Denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Figure 3: Visual representation of correlations between sensors in 3 experimental conditions (exploratory sample).

Table 8: Standardized coefficients, p-values, and η_p^2 for the analyses testing Research Question 1, 2, 3 (confirmatory sample).

	Standardized coefficients (beta)	η_p^2
MLT ~ ISP1 (overall)	0.66***	0.48
MLT ~ ISP1 (same position)	0.66***	0.54
MLT ~ ISP1 (different position)	0.66***	0.15
MLT ~ ISP 2(overall)	0.76***	0.51
MLT ~ ISP 2 (same position)	0.76***	0.64
MLT ~ ISP 2 (different position)	0.76***	0.23
MLT ~ ISP1 (baseline)	0.74***	0.56
MLT ~ ISP1 (hot)	0.63***	0.46
MLT ~ ISP1 (cold)	0.63***	0.50
MLT ~ ISP 2 (baseline)	0.95***	0.71
MLT ~ ISP 2(hot)	0.76***	0.51
MLT ~ ISP 2 (cold)	0.76***	0.49

Figure 4: Visual representation of correlations between sensors in 3 experimental conditions (*confirmatory sample*).

Examining the correlation between the average of the ISP sensors and the MLT probe as a function of temperature condition, in contrast to the exploratory result where we found small differences between temperature conditions, in the confirmatory split the correlation was virtually identical between temperature conditions: $r = 0.95$, 95% CI = [0.94, 0.95] at baseline, $r = 0.94$, 95% CI = [0.93, 0.94] in the hot condition, and $r = 0.95$, 95% CI = [0.95, 0.95] in the cold condition. This suggests that the ISP sensors were highly correlated with the MLT probe across all temperature variations. A visual representation of confirmatory correlations between sensors is presented in **Figure 4**. Because our confirmatory results replicated our exploratory results, there was no further need to explore our confirmatory dataset.

Discussion

Our primary goal was to validate the ISP131001 sensor for use in human peripheral temperature measurement. Thus, in two independent samples with sufficient power (considering the assumptions in our power analysis), we tested the degree to which our mobile ISP131001 sensor, or the average of two ISP sensors, correlated with measurements taken by a comparison device (the MLT422/A Skin Temperature Probe). Our analyses indicate a high correlation between our ISP131001 sensors and the MLT probe, especially when the average of two ISP devices is taken, suggesting that the ISP131001 sensor is a reasonably accurate device for these purposes. A secondary purpose was to create a standard protocol of relevant measures for social thermoregulation research. The entire protocol

is available on the OSF page: <https://osf.io/7h5sc/>. By ensuring relevant variables are measured, we encourage social thermoregulation researchers to use this protocol in future studies to facilitate data re-use and aggregation.

Our exploratory results on the correlation between each individual ISP sensor and the validation sensor indicate that this correlation was far from perfect and varied based on the position of measurement and the temperature condition (whether the participant was measured at baseline or had dipped their hand in cold or warm water). We noted—before analyzing our confirmatory dataset—that the correlation between the two sensors was stronger when both sensors were positioned on the finger, compared to when one was on the finger and the other on the wrist.

Our exploratory results also showed that averaging the readings from the two ISP sensors resulted in a substantially higher correlation with the validation sensor. The higher correlation from averaging two ISP sensors held across all three temperature conditions (baseline, hot, cold). Thus, the two sensors together seem to capture change in temperature better than only one sensor. These exploratory findings suggested that individual ISP sensors *may* be suitable for mobile temperature measurement depending on the application and the degree of precision required. However, using a second ISP device and averaging the two temperatures appeared to be a much more precise solution, suitable for a wide range of studies examining peripheral temperature in humans.^{10,11}

When we moved on to our confirmatory results, we again found that averaging the measurements of the two ISP sensors resulted in a high correlation with the validation (MLT probe) sensor. Somewhat in contrast to the exploratory results, this correlation was highly consistent across temperature conditions.

We conclude that the ISP131001 sensor (which is wireless and mobile but not waterproof) could be a viable alternative to measure peripheral body temperature depending on the needs of the researcher. Experimenters should gauge for themselves whether these mobile temperature sensors are suitable for their research question on a case-by-case basis and should take into account a minimal loss of accuracy when they plan their studies.

It is important to note that the current study was conducted in the lab, as required for the wired MLT sensor. Thus, we conducted a precise split-half validation study; the accuracy of the ISP sensors beyond the lab is still unknown. More research will be needed 1) to validate the ISP sensor outside of the laboratory and 2) to study the relationship between temperature fluctuations and social behaviors in daily life situations, for instance by asking participants to wear ISP sensors for several days and filling in questionnaires about their interpersonal relationships.

Limitations

In terms of the study itself, a firm limitation is that the two ISP sensors were never attached in exactly the same position on the body: they were rotated between being attached to the finger and the the wrist. It is also impos-

sible to directly compare the two ISP sensors when they're measuring the same temperature to inform how consistently different individual ISP sensors measure. In future studies it would be informative to attach several ISP sensors in the same position to be fully certain that they are measuring the same temperature and to directly test reliability between units.

A second limitation is that our ISP sensors may overestimate the temperature (at least as compared to our reference sensor in our exploratory data). We suspect that this is due to a calibration issue. Because of this, we recommend using two sensors to get the most accurate temperature reading with the ISP sensor.

In general, there are trade-offs when considering which method of peripheral temperature measurement to use. The ISP131001 sensor only measures temperature once per second, for example; whereas, the MLT probe measures every millisecond. Thus, for research questions requiring extremely responsive or accurate temperature measurement, there may not yet be an alternative to traditional wired temperature sensors.

Constraints on generality

We think that the devices should perform similarly as the present report across various populations and scenarios, but consider possible differences in accuracy in different measurement conditions (e.g., in very hot or cold environments the devices may be less accurate as compared to room temperature, and in the field the accuracy may be different than in the lab). Two critical considerations are that the device 1) should maintain secure skin contact throughout the measurement period and 2) is not waterproof.

Conclusion

To date, peripheral temperature has been measured mostly by non-mobile solutions that are hard to use in everyday situations. In this article we have investigated a new, convenient wireless temperature sensor: the ISP131001. According to our results, this sensor shows promise as a device to study temperature constantly in daily life. Averaging the reading from two ISP sensors resulted in accurate measurement overall, and the accuracy was considerably lower when taking the reading from only a single ISP device. Because of this study, we are reprogramming our smartphone app to more easily measure with multiple sensors in the field at the same time. While two sensors certainly seem better than one, this obviously means increased costs for researchers (although the price per sensor is less than 100 euros, and the cost further decreases when multiple sensors are bought at once).

With this information from our investigation of the ISP131001 and various temperature measurement solutions, and the protocol of measurements we have proposed to identify links between thermoregulation and social behaviors, we hope to give future researchers a better sense of their options for peripheral temperature measurement in the lab and in daily life.

Notes

- ¹ The choice of this expected correlation is partly arbitrary, but we undershot what we expected, for the purpose of our power analysis. We performed various power analyses considering different scenarios. Even if it was probably justified to expect a correlation higher than $r = 0.40$ (as one should expect that two measures measuring the same should have quite a high correlation), we decided to take a lower bound in order to ensure that our study would have sufficient power.
- ² We measured ambient temperature with a Tempo Disc Bluetooth Temperature Sensor Beacon and Data. The room averaged 24.15 ($SD = 1.14$) degrees Celsius between the different sessions.
- ³ We always first report Cronbach's alpha, because it is the most well-known measure of reliability. However, Cronbach's alpha is suboptimal as a reliability measure as it tends to underfit data for heterogeneous samples. We therefore also report the Omega Coefficient (both hierarchical and total), which is a more robust estimate of the reliabilities of self-report instruments (Dunn, Baguley, & Brunsden, 2014; Revelle & Zinbarg, 2009; Sijsma, 2009).
- ⁴ We asked participants for their parents' birth country, as asking about ethnicity is not permitted in France.
- ⁵ Note that we should have asked a backward counting question (Gangestad et al., 2016; Vickers, 2017), but this was a mistake in our protocol. This has been updated on our OSF page: <https://osf.io/xf7uk/wiki/home/>.
- ⁶ The third author performed the data split, and the first author analyzed the results of the exploratory sample, without having access to the second half of the data.
- ⁷ The reported R^2 has been calculated by applying the Nakagawa and Schielzeth (2013) approach. More precisely, it is a marginal R^2 , which is more appropriate for use with mixed effects models compared to the R^2 calculation used in standard regression. Please note that the interpretation of this statistical index is similar to the interpretation of R^2 in standard regression, but the calculation is not equivalent to the R^2 calculation in standard regression.
- ⁸ Here the two ISP sensor were always placed in different positions.
- ⁹ The pre-registration on OSF: <https://osf.io/csj29>.
- ¹⁰ Both the correlation coefficient and confidence interval ranges have to fall within ± 0.15 range (i.e., exploratory $r = 0.8$, 95% CI = [0.79, 0.81]; confirmatory $r = 0.7$, 95% CI = [0.68, 0.72]).
- ¹¹ More details on inconsistent results across temperature conditions and inconsistency between correlation coefficient and confidence interval in confirmatory results will be discussed in the final version of the discussion, according to our results.

Acknowledgements

We thank MSH-Alpes for access to their SCREEN platform for conducting the research.

Funding Information

The preparation of this work was partly funded by French National Research Agency "Investissements d'avenir" program grant (ANR-15-IDEX-02) awarded to Hans IJzerman.

Competing Interests

The authors have no competing interests to declare.

Author Contributions

ES was in charge of planning of the study, data collection, statistical analysis, OSF preregistration, and drafting and revising the manuscript. RK supported the planning of the study, gave feedback on the statistical analyses, and contributed to drafting and revising the manuscript. OD performed code review and provided feedback on the OSF page. HIJ contributed to the preparation of our study, gave feedback on the statistical analyses, and helped write the manuscript. The project page is available at <https://osf.io/45xwc/>.

References

- Bargh, J. A., & Shalev, I. (2012). The substitutability of physical and social warmth in daily life. *Emotion*, 12, 154–162. DOI: <https://doi.org/10.1037/a0023527>
- Bates, D., Machler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67, 1–48. DOI: <https://doi.org/10.18637/jss.v067.i01>
- Cannon, W. B. (1932). Homeostasis. *The Wisdom of the Body*. New York: Norton.
- Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior*, 12, 335–359. DOI: [https://doi.org/10.1016/S0022-5371\(73\)80014-3](https://doi.org/10.1016/S0022-5371(73)80014-3)
- Cohen, S., Doyle, W. J., Skoner, D. P., Rabin, B. S., & Gwaltney, J. M., Jr. (1997). Social ties and susceptibility to the common cold. *Journal of the American Medical Association*, 277, 1940–1944. DOI: <https://doi.org/10.1001/jama.1997.03540480040036>
- Dunn, T. J., Baguley, T., & Brunsden, V. (2014). From alpha to omega: A practical solution to the pervasive problem of internal consistency estimation. *British Journal of Psychology*, 105, 399–412. DOI: <https://doi.org/10.1111/bjop.12046>
- Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*, 221, 1208–1210. DOI: <https://doi.org/10.1126/science.6612338>
- Frederiks, K., Sterkenburg, P., Lavner, Y., Cohen, R., Ruinskiy, D., Verbeke, W., & IJzerman, H. (2018). Mobile social physiology as the future of relationship research and therapy: Presentation of the bio-app for bonding (BAB). Available on Psyarxiv: <https://psyarxiv.com/xr8ma/download?format=pdf>. DOI: <https://doi.org/10.31234/osf.io/xr8ma>
- Gangestad, S. W., Haselton, M. G., Welling, L. L. M., Gildersleeve, K., Pillsworth, E. G., Burriss, R. P., ... & Puts, D. A. (2016). How valid are assessments of conception probability in ovulatory cycle

- research? Evaluations, recommendations, and theoretical implications. *Evolution and Human Behavior*, 37, 85–96. DOI: <https://doi.org/10.1016/j.evolhumbehav.2015.09.001>
- Gao, X. Y., Chong, C. Y., Zhang, S. P., Cheng, K. W. E., & Zhu, B. (2012). Temperature and safety profiles of needle-warming techniques in acupuncture and moxibustion. *Evidence-Based Complementary and Alternative Medicine*, 2012, 1–6. DOI: <https://doi.org/10.1155/2012/168393>
- Huizenga, C., Zhang, H., Arens, E., & Wang, D. (2004). Skin and core temperature response to partial- and whole-body heating and cooling. *Journal of Thermal Biology*, 29, 549–558. DOI: <https://doi.org/10.1016/j.jtherbio.2004.08.024>
- IJzerman, H., Coan, J. A., Wagemans, F., Missler, M. A., Beest, I. V., Lindenberg, S., & Tops, M. (2015). A theory of social thermoregulation in human primates. *Frontiers in Psychology*, 6, 464–464. DOI: <https://doi.org/10.3389/fpsyg.2015.00464>
- IJzerman, H., Gallucci, M., Pouw, W. T., Weißgerber, S. C., Van Doesum, N. J., & Williams, K. D. (2012). Cold-blooded loneliness: Social exclusion leads to lower skin temperatures. *Acta Psychologica*, 140, 283–288. DOI: <https://doi.org/10.1016/j.actpsy.2012.05.002>
- IJzerman, H., Hadi, R., Coles, N., Sarda, E., Klein, R. A., & Ropovik, I. (2021). Social thermoregulation: A meta-analysis. Unpublished Manuscript. DOI: <https://doi.org/10.31234/osf.io/fc6yq>
- IJzerman, H., Heine, E. C., Nagel, S. K., & Pronk, T. M. (2017). Modernizing relationship therapy through Social Thermoregulation Theory: Evidence, hypotheses, and explorations. *Frontiers in Psychology*, 8, 635. DOI: <https://doi.org/10.3389/fpsyg.2017.00635>
- IJzerman, H., & Hogerzeil, L. J. (2017). People as penguins: Thermoregulation as part of the human essence. In M. van Zomeren & J. Dovidio (Eds.), *The Handbook of Human Essence*. New York, NY, US: Oxford University Press. Available on PsyArxiv: <https://psyarxiv.com/zrtg6/>. DOI: <https://doi.org/10.31234/osf.io/zrtg6>
- IJzerman, H., Lindenberg, S., Dalğar, İ., Weissgerber, S. S. C., Vergara, R. C., Cairo, A. H., ... & Zickfeld, J. H. (2018). The Human Penguin Project: Climate, social integration, and core body temperature. *Collabra: Psychology*, 37. DOI: <https://doi.org/10.1525/collabra.165>
- IJzerman, H., & Semin, G. R. (2009). The thermometer of social relations: Mapping social proximity on temperature. *Psychological Science*, 20, 1214–1220. DOI: <https://doi.org/10.1111/j.1467-9280.2009.02434.x>
- Liu, Y., Zhu, S. H., Wang, G. H., Ye, F., & Li, P. Z. (2013). Validity and reliability of multiparameter physiological measurements recorded by the equital lifemonitor during Activities of Various Intensities. *Journal of Occupational and Environmental Hygiene*, 10, 78–85. DOI: <https://doi.org/10.1080/15459624.2012.747404>
- Lynott, D., Corker, K. S., Wortman, J., Connell, L., Donnellan, M. B., Lucas, R. E., & O'Brien, K. (2014). Replication of “Experiencing physical warmth promotes interpersonal warmth” by Williams and Bargh (2008). *Social Psychology*, 45, 216. DOI: <https://doi.org/10.1027/1864-9335/a000187>
- Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R² from generalized linear mixed-effects models. *Methods in ecology and evolution*, 4, 133–142. DOI: <https://doi.org/10.1111/j.2041-210x.2012.00261.x>
- Revelle, W., & Zinbarg, R. E. (2009). Coefficients alpha, beta, omega, and the glb: Comments on Sijsma. *Psychometrika*, 74, 145. DOI: <https://doi.org/10.1007/s11336-008-9102-z>
- Sijsma, K. (2009). On the use, the misuse, and the very limited usefulness of Cronbach's alpha. *Psychometrika*, 74, 107–120. DOI: <https://doi.org/10.1007/s11336-008-9101-0>
- Vergara, R. C., Hernández, C., Guazzini, F. T. J., Lindenberg, S., Klein, R. A., & IJzerman, H. (2019). Development and validation of the social thermoregulation and risk avoidance questionnaire (STRAQ-1). *International Review of Social Psychology*, 32. DOI: <https://doi.org/10.5334/irsp.222>
- Vickers, N. J. (2017). Animal communication: When I'm calling you, will you answer too? *Current Biology*, 27, R713–R715. DOI: <https://doi.org/10.1016/j.cub.2017.05.064>
- Wei, M., Russell, D. W., Mallinckrodt, B., & Vogel, D. L. (2007). The Experiences in Close Relationship Scale (ECR)-short form: Reliability, validity, and factor structure. *Journal of Personality Assessment*, 88, 187–204. DOI: <https://doi.org/10.1080/00223890701268041>
- Williams, L. E., & Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth. *Science*, 322, 606–607. DOI: <https://doi.org/10.1126/science.1162548>
- Winberg, J. (2005). Mother and newborn baby: Mutual regulation of physiology and behavior—A selective review. *Developmental Psychobiology*, 47, 217–229. DOI: <https://doi.org/10.1002/dev.20094>
- Wortman, J., Donnellan, M. B., & Lucas, R. E. (2014). Can physical warmth (or coldness) predict trait loneliness? A replication of Bargh and Shalev (2012). *Archives of Scientific Psychology*, 2, 13. DOI: <https://doi.org/10.1037/arc0000007>

How to cite this article: Sarda, E., Klein, R. A., Dujols, O., & IJzerman, H. (2021). Validation of the ISP131001 Sensor for Mobile Peripheral Body Temperature Measurement. *International Review of Social Psychology*, 34(1): 12, 1–12. DOI: <https://doi.org/10.5334/irsp.409>

Submitted: 13 February 2020

Accepted: 07 April 2021

Published: 21 June 2021

Copyright: © 2021 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>.

International Review of Social Psychology is a peer-reviewed open access journal published by Ubiquity Press.

OPEN ACCESS The Open Access logo, which consists of a circular icon containing a stylized 'a'.