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BRIEF REPORT

# Physical and Social Warmth: Warmer Daily Body Temperature Is Associated With Greater Feelings of Social Connection

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Growing evidence suggests that physical warmth and social warmth—feeling socially connected to others—are linked. In particular, thermoregulatory systems that maintain a relatively warm internal body temperature may also support feelings of social connection. However, it is unknown whether and how feelings of physical and social warmth fluctuate together across time in daily life. To this end, the current study examined tympanic temperature, a measure of internal body temperature, and feelings of social connection assessed multiple times a day over 1 week. Consistent with hypotheses, moment-to-moment changes in tympanic temperature covaried with feelings of social connection across assessments. Thus, warmer body temperatures, in the nonfebrile range, were associated with greater feelings of social connection, and cooler body temperatures were associated with lower feelings of social connection. These findings provide further evidence for the link between physical and social warmth and contribute to an understanding of the dynamic fluctuation of affective experience across time.

*Keywords:* within-person variation, interpersonal relationships, interoception, thermoregulation, experience sampling



Social connection is critical for well-being (Baumeister & Leary, 1995) and health (Uchino, 2004). However, little is known about whether feelings of connection dynamically change across time and what might relate to such fluctuations. Indeed, feelings of connection likely wax and wane, even over a day, in response to momentary, naturalistic influences, but no studies have examined this possibility. The current study approaches the question of how feelings of connection change across time from the long-standing perspective within affective science that subjective experience (mind) and physiological responding (body) are intimately linked (James, 1884; Schachter & Singer, 1962). Should social connection be a basic need (Baumeister & Leary, 1995; Panksepp, Nelson, & Bekkedal, 1997), the subjective experience of connecting with others may rely on mechanisms similar to those processes that support other basic needs in the body. Therefore, variation in feelings of connection outside the acute laboratory setting were examined alongside a possible biological correlate of social connection: physical warmth.

Mechanisms that support social connection are theorized to stem from those systems that regulate other fundamental biological processes in the body (Panksepp et al., 1997). One such system that has received particular attention is the thermoregulatory system, which maintains core body temperature at an optimal level of functioning. Hence, mechanisms that support a relatively warm internal body temperature may also help monitor and maintain feelings of social connection (Inagaki, Irwin, Moieni, Jevtic, & Eisenberger, 2016). Unlike another well-known theory linking external environmental heat and acts of aggression toward others (Anderson, 1989), the link between warmth and social connection suggests that the *internal* temperature of the body may relate to feelings of social connection. Thus, internal physical warmth may relate to internal, subjective feelings of "social warmth."

As preliminary support for this possibility, warmer oral temperature (a close indicator of internal temperature) averaged over a 7-hr period, is associated with greater feelings of social warmth (Inagaki, Irwin, et al., 2016). In a related vein, though not about internal temperature, evidence from acute experimental lab paradigms show that physical warmth can causally influence social warmth. Exposure to cutaneous (external) warmth increases feelings of social warmth compared to nonwarm stimuli (IJzerman & Semin, 2009; Inagaki, Irwin, & Eisenberger, 2015; Kang, Williams, Clark, Gray, & Bargh, 2011; cf. Lynott et al., 2014). Furthermore, whole-body hyperthermia (vs. sham control) reduces

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depressive symptoms across a 6-week measurement period, suggesting that alterations to internal body temperature can causally impact affective experience (Janssen et al., 2016).

The link between physical and social warmth may stem from common, or overlapping, neurobiological mechanisms that support both processes. Consistent with this possibility, neural activity to a socially warm experience overlaps with some of the same neural regions that activate to cutaneous warmth (Inagaki & Eisenberger, 2013). In addition, endogenous opioids, which help maintain internal body temperature (Adler, Geller, Rosow, & Cochin, 1988) and daily feelings of social connection (Inagaki, Ray, Irwin, Way, & Eisenberger, 2016), also contribute to physical warmth–induced feelings of social connection (Inagaki et al., 2015). Taken together, physical warmth can causally impact social warmth, and both physical and social warmth may share neurobiological mechanisms. However, whether *internal* body temperature and feelings of connection vary together beyond a single point in time is unknown.

Although some evidence links physical and social warmth, previous work has been experimental in nature, based on small sample sizes and/or single assessments. The present study aimed to replicate and extend the link between physical and social warmth beyond the acute laboratory setting with a larger sample of participants and assessment points using a highly naturalistic design embedded within people's daily lives. Based on the theorized overlap between physical and social warmth and previous findings linking body temperature with feelings of connection (Inagaki, Irwin, et al., 2016), within-subject body temperature was hypothesized to be positively correlated with within-subject feelings of social connection.

## Method

### Procedure

**Participants.** In this study, 214 individuals (118 female) were recruited via flyers and a voluntary database of individuals interested in research studies for a study examining associations between daily body temperature and feelings in social situations. A power analysis in G*Power (Erdfelder, Faul, & Buchner, 1996) using $\alpha = .01$, Cohen's $d = .50$, and power of .80 determined a sample size of 200 would be necessary to detect an association between body temperature and feelings of connection. Therefore, we aimed to run a sample of at least 210 individuals to guard against data loss due to technical error or noncompliance. Data collection ended after at least 200 participants had completed at least 75% of their daily assessments and had complied with all study instructions. Due to missing data on demographic variables ($n = 1$; see next paragraph) and extreme readings on the body temperature values ($n = 2$; see the Tympanic Temperature section), the final sample for primary analyses consisted of 211 participants.

**Screening.** During screening, participants were excluded for the following factors known to affect core or tympanic temperature measurement: pregnancy, smoking, prescription medication use (including birth control), body mass index $\gtrsim$30, and problems with the ear (infection, soreness, or other problems with inner ears; recent surgery). Age was restricted to 18–25 years to control for age-related changes in body temperature. All participants needed to have a personal smartphone device to complete the daily assessments. Mean age of the sample was 21.200 years ($SD = 2.145$), and race–ethnicity was as follows: 9.8% Black, .5% Latino, 57.9% White, 24.8% Asian, 6.5% Multiracial. Demographic data were missing for one participant due to a technical error. Participants received $70 in exchange for participation. Procedures were run in accordance with the University of Pittsburgh's Human Research Protection Office.

**Intake session.** During an initial visit to the lab, participants received instructions for completing the daily assessments, as well as training for collecting tympanic temperature, and had additional factors known to affect core body temperature measured.

Specifically, percentage of body fat ($M = 22.161\%$, $SD = 8.347$) and weight ($M$ lb. $= 151.073$, $SD = 27.487$) were measured with a Tanita Scale (model BC554; Tanita Corporation of America), and trait levels of feelings of social connection were measured using the Social Connectedness Scale ($M = 45.981$, $SD = 9.553$, $\alpha = .930$; Lee & Robbins, 1995) for the covariate set.

**Daily assessments.** To assess daily feelings of social connection, we sent participants SMS text messages five times a day for 7 days. The timing of the text messages was calibrated to each participant's sleep–wake cycle such that there was a waking, midmorning, afternoon, evening, and bedtime text. However, there are no hypothesized effects related to time of day in the current study. Texting was chosen as a method for sampling because it is a ubiquitous form of communication and allows participants to use their personal electronic device. Participants were sent texts via an automated web-based service (Lettermelater.com). Of the full sample, an average of 89.070% of possible responses were received.

### Measures

**Daily feelings of social connection.** Participants received a text with a link to a Qualtrics survey where they reported their feelings of social connection ("I feel accepted by others and connected to them") and feelings of social disconnection ("I feel out of touch and disconnected from others") on a 1 (*not at all*) to 7 (*very much*) scale. Both items were taken from previous work that assessed daily feelings of connection outside of the lab (Inagaki, Ray, et al., 2016). Two items assessing positive and negative affect, respectively, were also assessed but are reported in a separate article.

**Tympanic temperature.** Internal temperature was collected via the tympanic membrane (ear) using Braun ThermoScan 07 (Braun Corporation) thermometers. The tympanic method was chosen because it is a commonly used, relatively noninvasive measure of internal body temperature. The tympanic membrane, as opposed to oral temperature (used previously; Inagaki, Irwin, et al., 2016), is also less susceptible to environmental influences such as the temperature of the surrounding environment and the temperature of recently ingested food or drinks. It is important to note that tympanic temperature is also correlated with core body temperature (Castle, Toledo, Daskal, & Norman, 1992), the gold standard for clinical diagnoses, the temperature measurement that is least susceptible to external changes (i.e., compared to cutaneous temperature, which varies widely depending on environmental changes in temperature) and the temperature measurement most relevant to the current theory.

After reporting on their feelings of connection, participants recorded their own tympanic temperature. To ensure reliability at each measurement period, we instructed participants to take their temperature two times (waiting 3 min in between the measurements). Due to between-ear variability (Childs, Harrison, & Hodkinson, 1999), temperature was collected from the right ear only. An average of the two measurements was calculated for each time point ($M$ = 36.851 °C, $SD$ = .423). Two participants with tympanic readings that were consistently outside the normotensive range and were therefore suspected to be ill were excluded from final analyses, leaving a final sample of 211 participants. Nevertheless, the pattern of results did not change substantively with these participants included.

## Analytic Approach

To examine how tympanic temperature relates to social connection, we analyzed multilevel models in which assessments over time were nested within individuals. Specifically, we examined the relationship between body temperature and social connection within-subject at Level 1 and the between-subjects variation in these links at Level 2 using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015) in R (R Development Core Team, 2006). Raw data and the R script needed to re-create the primary analyses can be found at osf.io/at6d8. For our primary analysis, we estimated the following model:

$$WConnect_{it} = \beta_{0it} + \beta_{1it} WBodyTemp_{it} + \varepsilon_{it}$$

$$\beta_{0it} = \beta_{00} + \beta_{01} BBodyTemp_i + \beta_{02} TraitConnect_i + \beta_{03} Gender_i + \beta_{04} Ethnicity_i + \beta_{05} Weight_i + \beta_{06} PercentFat_i + u_{0i}$$

$$\beta_{1it} = \beta_{10} + u_{1i}$$

In this model, $WConnect_{it}$ refers to person $i$'s rating of social connection at assessment $t$, and $WBodyTemp_{it}$ refers to person $i$'s body temperature at assessment $t$ (averaged across the two recordings at that time point). Both the intercept and slope were allowed to vary randomly across participants. Within-subject body temperature readings were centered within-subject with each person's empirical Bayesian estimate of their mean body temperature. The person means for body temperature ($BBodyTemp_i$) and all person-level covariates were included at Level 2 as predictors of $WConnect_{it}$. Gender ($Gender_i$; 0 = male; 1 = female) and ethnicity ($Ethnicity_i$; 0 = white; 1 = other) were dummy-coded, whereas mean body temperature ($BBodyTemp_i$), trait social connection ($TraitConnect_i$), weight ($Weight_i$), and percentage body fat ($PercentFat_i$) were grand-mean-centered prior to analyses. Note that the within-subject associations were highly similar without these covariates included within the model (see https://osf.io/at6d8). A parallel model was run with daily social disconnection as the outcome.

We also modeled day-level random effects to account for correlated within-day error structure, but the variance due to day was very small, and their inclusion did not alter the pattern of results; as such, these random effects were excluded from the final models for simplicity. We also conducted exploratory analyses examining whether the within-subject links between body temperature and social connection were moderated by each covariate but found no significant associations (all $p$s $> .07$). Because there is not a standard method for obtaining effect size estimates in multilevel models (e.g., Nezlek, 2012) and issues with standardizing variables in such models (Hox, 2002), we report the unstandardized coefficients and confidence intervals (CIs) for the unstandardized estimates. We computed bootstrapped CIs using 1,000 parametric resamples from the model.

## Results

In line with our hypothesis, within-person variation in tympanic temperature significantly predicted within-person variation in feelings of social connection (see Table 1 and Figure 1 for an example of one participant's responses). That is, when participants had a warmer body temperature (within the nonfebrile range), they reported feeling more connected, and when they had a cooler body temperature, they reported feeling less connected. Notably, despite this strong within-person association between body temperature and social connection, we did not observe a parallel between-person association; that is, people who generally had higher body temperatures did not necessarily report greater levels of social connection on average across assessments. The significant within-person, but not between-person, finding further highlights the value of examining fine-grained daily fluctuations to further understanding of affective experience.

Further, the within-person links between body temperature and social connection emerged above and beyond all covariates, in-

Table 1
*Results of Multilevel Model: Predictors of Daily Social Connection and Disconnection*

| Predictor | Connection | | Disconnection | |
|---|---|---|---|---|
| | *b* (*SE*) | 95% CI | *b* (*SE*) | 95% CI |
| Within-Person body temperature | .13** (.043) | [.05, .21] | −.07 (.047) | [−.16, .02] |
| Between-Person body temperature | −.22 (.237) | [−.69, .29] | .11 (.203) | [−.31, .54] |
| Trait social connection | .06*** (.006) | [.05, .07] | −.05*** (.005) | [−.06, −.04] |
| Gender[a] | .17 (.313) | [−.44, .80] | .04 (.270) | [−.51, .57] |
| Ethnicity[b] | −.23* (.115) | [−.45, −.003] | .36*** (.099) | [.16, .55] |
| Weight | .00 (.005) | [−.01, .01] | −.00 (.004) | [−.01, .01] |
| Body fat percentage | −.02 (.016) | [−.05, .02] | .01 (.014) | [−.02, .03] |

*Note*. Within-person body temperature was person-mean-centered; between-person body temperature, trait social connection, weight, and body fat percentage were grand-mean-centered. CI = confidence interval.
[a] 0 = male, 1 = female. [b] 1 = White, 0 = all other ethnicities.
* $p < .05$. ** $p < .01$. *** $p < .001$.

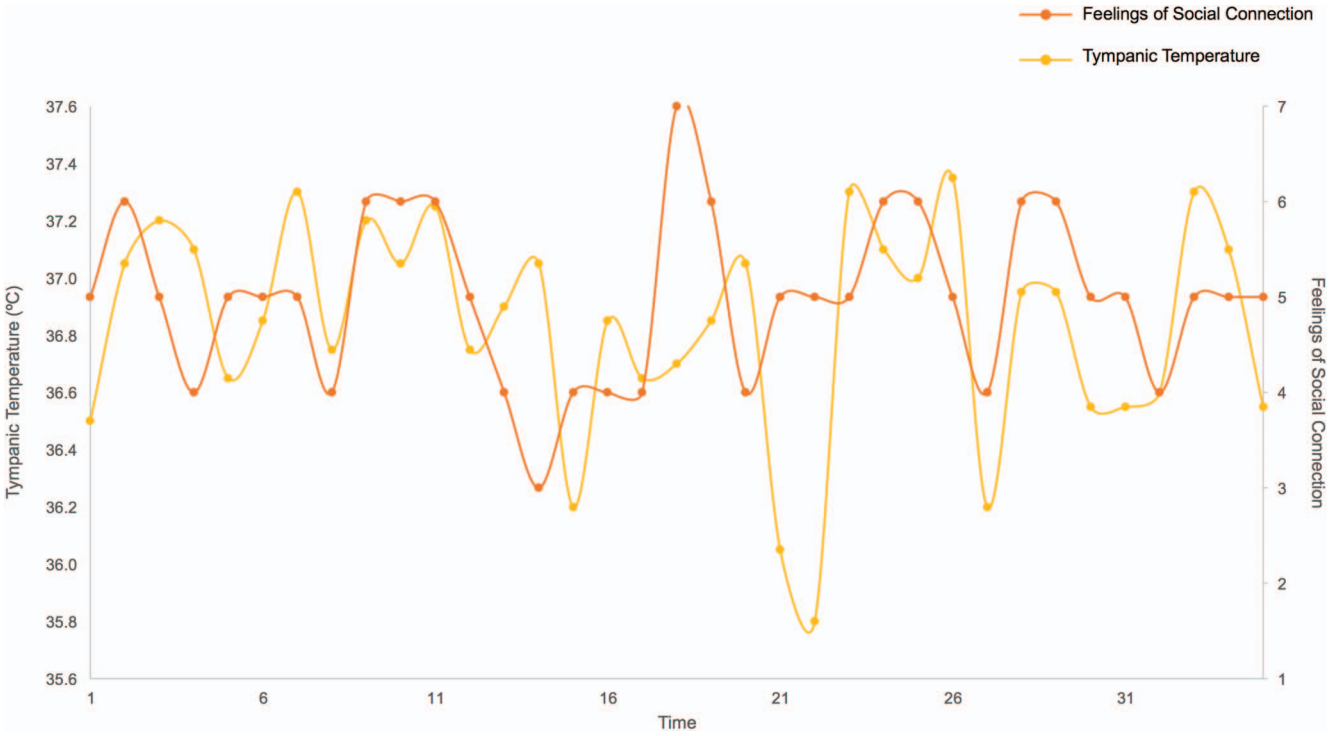


*Figure 1.* Sample data from a single participant showing moment-to-moment associations between tympanic temperature and feelings of social connection. Within-person tympanic temperature significantly predicted within-person feelings of social connection such that, within a person, warmer temperatures (in the nonfebrile range) were associated with greater feelings of connection and cooler temperatures were associated with lower feelings of connection. See the online article for the color version of this figure.

cluding trait social connection, which was a strong predictor of average daily social connection. The only other covariate to significantly predict daily social connection was ethnicity, with White participants' reporting significantly lower daily social connection than did participants from other ethnic backgrounds.

Within-person variation in feelings of disconnection was not significantly related to either within-person variation or between-person differences in body temperature (see Table 1). As with daily social connection, trait social connection and ethnicity were significant predictors, with greater trait social connection predicting significantly lower daily disconnection and White participants reporting significantly greater disconnection than did participants from other ethnic backgrounds.

## Discussion

The current results further understanding of how social connection might be maintained to show that, when measured repeatedly during one's daily life outside the laboratory setting, physical and social warmth show a corresponding dynamic pattern of responding. When internal body temperature was greater (i.e., warmer, in the nonfebrile range), so too were feelings of connection, and when temperature was lower (i.e., cooler), feelings of connection were also lower. The findings replicate previous correlational links between physical and social warmth (Inagaki, Irwin, et al., 2016) and contribute to the broader literatures on warmth and social connection and perspectives that highlight the intimate relationship between the mind and body in subjective, emotional responding.

Two limitations warrant discussion. First, causal inference cannot be made given the study design. Although previous research has shown that physical warmth can alter social warmth (e.g., Inagaki & Eisenberger, 2013), future research using continuous measures of internal body temperature, rather than measures spaced hours apart, are needed to assess the causal influence of natural fluctuations in body temperature on subsequent, momentary feelings of connection. Second, feelings of connection, but not disconnection, were related to body temperature, suggesting these are separate feelings rather than opposites of the same construct. Indeed, for some measurements participants reported comparable levels of feelings of connection and disconnection (e.g., a 4 on both scales). The pattern found here is also consistent with that in previous research examining associations between core body temperature and more general affect, such that positive affect is related to core body temperature whereas negative affect is not (Murray et al., 2009). Future research may benefit from measuring both types of feelings to better understand relationships between body temperature and social affective experience.

The health implications of the current findings are notable. A functioning thermoregulatory system maintains core temperature within normotensive range with small fluctuations throughout the day (Mackowiak, Wasserman, & Levine, 1992). The present find-

ings show that feelings of connection show a corresponding fluctuation. Therefore, one implication of the current results that will require further research is whether biological systems that support social connection at a level that promotes health and well-being function the same way that other physiological systems, such as thermoregulation, adapt to maintain function (Hofer, 1984). Additional fine-grained measurement of natural fluctuations in physical warmth beyond a single measurement may elucidate a biological underpinning of social connection, which may in turn ultimately affect well-being and health.

In conclusion, these findings provide additional support for a link between physical and social warmth but extend the link to naturalistic settings across time with an objective measure of internal body warmth.



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