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Central Temperature Changes Are Poorly Perceived during Epidural Anesthesia

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Hypothermia and shivering are common during epidural anesthesia for cesarean delivery but are not always accompanied by a sensation of coldness. To test the hypothesis that central temperature changes are not perceived during epidural anesthesia, we measured central and skin temperatures and thermal perception in 30 patients undergoing cesarean delivery with epidural anesthesia. Central temperature decreased 1.0 ± 0.6° C from control values during anesthesia and surgery, but thermal perception scores did not reflect central temperatures ($P = 0.56$) or changes in central temperature ($P = 0.63$). A feeling of warmth was significantly correlated with increased mean skin temperature ($P = 0.02$) and increased upper body skin temperature ($P = 0.03$). We conclude that central temperature is poorly perceived and is less important than skin temperature in determining thermal perception during high levels of epidural anesthesia. (Key words: Anesthesia, complications: hypothermia. Anesthesia: epidural. Anesthesia, obstetric: cesarean delivery. Hypothermia: anesthesia-related; thermal perception. Temperature measurement: bladder; skin surface; tympanic.)

SHAKING TREMOR is common during epidural anesthesia for cesarean delivery[1–3] and other abdominal surgeries.[4] Although a cold sensation usually precedes shivering in unanesthetized individuals,[5] patients with uncontrollable tremor during epidural anesthesia do not necessarily feel cold.[6–8] This observation initially suggested that the etiology of tremor during epidural anesthesia might be unusual, but it has been demonstrated that this tremor is, in fact, normal thermoregulatory shivering triggered by central hypothermia.[7]

It remains unclear why normal thermoregulatory shivering during epidural anesthesia is not accompanied by a sensation of cold. Epidural anesthesia causes a decrease in central temperature but skin temperature increases in the area of the body affected by sympathetic blockade.[1,4,7,8] Animal studies reveal that changes in skin temperature are more important than changes in central temperature in prompting behaviors designed to preserve normothermia.[9,10] Consequently, skin temperature may be more important than central temperature in determining thermal perception in humans as well. In other words, hypothermia and shivering during epidural anesthesia may not be accompanied by a cold sensation because increased skin temperature is more important than decreased central temperature in determining thermal perception. We tested the hypothesis that central temperature changes are poorly perceived in humans with high levels of epidural anesthesia. We also tested the hypothesis that bladder temperature estimates central temperature during cesarean delivery.

Materials and Methods

PATIENT MANAGEMENT AND DATA COLLECTION

The study protocol was approved by the Institutional Review Board at the University of Chicago, and written, informed consent was obtained from 30 healthy parturients at term undergoing elective cesarean delivery with epidural anesthesia. All patients were ASA physical status 1 or 2, were not in labor, and were without medical problems, history of recent febrile illness, or ruptured membranes. Other than prenatal vitamins, they denied any drug ingestion (including aspirin, acetaminophen, or nonsteroidal antiinflammatory agents).

In the labor room, patients were given 30 ml Bicitra® orally, and a lumbar epidural catheter was inserted *via* the L2–L3 or L3–L4 interspace. To increase the range of central temperature changes during surgery, patients were randomly assigned to receive, before and during anesthesia, 20 ml/kg of intravenous fluids for hydration, either warmed ($n = 13$) or at ambient temperature ($n = 17$).[1,2] Warmed fluids were ≈ 38° C when infused; ambient temperature was 22–24° C.

On arrival in the operating room, the patients were covered with a light cotton blanket and given 2% lidocaine with epinephrine (1:200,000) *via* the epidural catheter. A 3 ml test dose of anesthetic was followed by sufficient lidocaine in divided doses to achieve a T4–T2 anesthetic

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level (measured by loss of sensation to pin prick). Arterial blood pressure was monitored oscillometrically every 1–3 min (Dinamap™ 1846 SX, Critikon Inc., Tampa, FL). Systolic blood pressures < 100 mmHg or < 80% of baseline were treated with additional intravenous fluid and, if necessary, intravenous boluses of ephedrine 5–10 mg.

Epidural opioids and intravenous opioids or sedatives were avoided during the study period to prevent their influence on measured variables.[11–13] If patients required such medications for clinical management, data collected after their administration were not used in analysis. The surgeon cleansed a patient's abdomen with scrub solution at ambient temperature only after anesthesia was verified to at least a T6 level.

Central temperature was measured at the tympanic membrane using a cotton-tipped thermocouple (Mon-a-Therm®, St. Louis, MO). In 20 of the patients, bladder temperature was measured using a 16-Fr urinary catheter with a temperature sensor in its distal end (CathTemp, Mon-a-Therm®). Mean skin-surface temperature was determined from a commonly used weighted average of four skin-surface temperatures (Te): $0.3 \cdot Te_{chest} + 0.3 \cdot Te_{arm} + 0.2 \cdot Te_{leg} + 0.2 \cdot Te_{thigh}$.[14] Upper body skin temperature was determined from a formula we derived: $0.2 \cdot Te_{upper\ arm} + 0.1 \cdot Te_{forearm} + 0.1 \cdot Te_{finger} + 0.4 \cdot Te_{chest} + 0.2 \cdot Te_{neck}$. Thermocouple probes were connected to Mon-a-Therm® two- or three-channel electronic thermometers (models 6500 and 7000) with accuracies near 0.1° C. Patients reported their thermal perception on a three-point scale: 0 = cool, 1 = neutral, and 2 = warm. Each patient was instructed to report only her temperature sensation and not the thermal comfort or discomfort that the perception produced. Each time a patient was questioned, she was asked specifically if she felt cool, neutral, or warm. Shivering was graded as present or absent.

Data on temperature, thermal perception, and shivering were recorded in the labor room before induction of anesthesia (control values) and then at 10-min intervals beginning with the induction of anesthesia and continuing until the completion of surgery. The investigator collecting the data was unaware of the temperature of the intravenous fluids given to the patient. Thermal perception and temperatures were analyzed at the time of skin incision (after the induction of approximately a T4 level of epidural anesthesia) and at the time of lowest central temperature recorded during surgery (before any sedatives or opioids were administered). These two points were chosen to provide the widest possible range of central temperatures for analysis and to increase the chance of identifying a statistically significant correlation between central and perceived temperature. If central temperature was lowest at the time of skin incision, the same temperature value was used again to provide two data points for each patient. Comparisons of tympanic and bladder temperatures were made before the induction of anesthesia (control) and at skin incision, delivery of the fetus, uterine closure, fascial closure, and skin closure.

Statistical Analysis

Statistical analysis of thermal perception scores as a function of central and skin temperatures and temperature changes was performed using ordinal logistic regression (see Appendix).[15] While standard logistic regression is used to describe relationships between an outcome variable recorded on a two-point scale and continuous independent variables, ordinal logistic regression is appropriate when the outcome being assessed is measured on a scale having three or more points. In this case, we used a three-point scale to measure thermal perception: cold, neutral, or warm. Ordinal logistic regression was used to estimate the probability of a patient feeling cold, neutral, or warm depending upon her central temperature, change in central temperature, mean skin temperature, or upper body skin temperature. Using data from this study, we determined that if a change in temperature of 1° C doubled the odds of feeling warm or cold, our study had 80% power for detecting the effect using two-sided 5% significance tests.

Two-tailed, unpaired Student's *t*-tests were used to compare temperature data between patients in the two intravenous fluid temperature groups and between patients who did and did not shiver. Time-dependent differences between tympanic membrane and bladder temperatures were analyzed by repeated-measures analysis of variance and Dunnett's test. Results are presented as means ± standard deviation and as ranges; $P < 0.05$ was considered statistically significant.

Results

The clinical data describing the patients who participated in this study are listed in table 1. Three patients whose intravenous fluids were warmed and six patients given intravenous fluids at room temperature required extra fluid or ephedrine to maintain systolic blood pressure > 100 mmHg after induction of epidural anesthesia.

TABLE 1. Patient Characteristics

Age (yr)	28 ± 6
Height (cm)	163 ± 8
Weight (kg)	82 ± 15
Lidocaine dose (mg)	560 ± 130
Duration of surgery (min)	100 ± 30

Data are mean ± SD.

Central (tympanic) temperature decreased 0.5 ± 0.3° C (range −1.1 to 0° C) from control values at skin incision, and the mean maximum decrease during surgery was 1.1 ± 0.6° C (range −2.4 to −0.2° C). Central temperature decreases were similar in patients given room temperature intravenous fluid (−1.2 ± 0.6° C, range −2.4 to −0.5° C) and those given warmed fluid (−0.8 ± 0.5° C, range −1.8 to −0.2° C), $P = 0.08$. The lowest central temperature occurred at the time of skin incision in only one patient; in all others, the lowest central temperature was observed later. The mean maximum decrease in bladder temperature during surgery (−1.4 ± 0.6° C, range −2.7 to −0.4° C) was similar to the decrease in tympanic membrane temperature (−1.1 ± 0.6° C, range −2.4 to −0.2° C), $P = 0.23$. Tympanic temperature was always slightly higher than bladder temperature, but values were similar at the two sites except at the time of uterine closure, when bladder temperature was significantly (0.31 ± 0.26° C [range 0 to 0.8° C]) lower than tympanic membrane temperature ($P = 0.006$) (fig. 1).

Thermal perception at the time of skin incision and at the time of lowest central temperature did not reflect central temperatures ($P = 0.56$) or changes in central temperature ($P = 0.63$). At the time of skin incision, 7 patients felt cool, 16 patients felt neutral, and 7 patients felt warm. Similarly, 9 patients felt cool, 12 patients felt neutral, and 9 patients felt warm at the time of lowest central temperature. Patients were equally likely to feel cool, neutral, or warm across the range of central temperature changes (fig. 2).

Mean skin temperatures increased 0.5 ± 0.9° C (range: −1.5 to +2.2° C) after induction of anesthesia. High skin temperatures increased the probability that a patient felt warm (fig. 3) ($P = 0.02$). All patients with mean skin temperatures greater than ≈35° C felt warm, and no patient with mean skin temperatures less than ≈32.5° C felt warm. Relatively high upper-body skin temperature also increased the probability that a patient felt warm ($P = 0.03$) (fig. 4). All patients with upper-body skin temperatures greater than ≈34.5° C felt warm, whereas no patient with upper-body skin temperature lower than ≈32.5° C felt warm.

Shivering occurred in 21 patients at some time during the study. The decrease in central temperature was greater in patients who did not shiver (−1.4 ± 0.7° C, range −2.0 to −0.3° C) than in those who did shiver (−0.9 ± 0.4° C, range −2.4 to −0.2° C) ($P = 0.02$). For most patients who shivered, central temperature decreased by at least 0.3° C. Central temperature decreased by at least 0.5° C in 27 patients during the study. Of these hypothermic patients, 8 (30%) did not shiver.

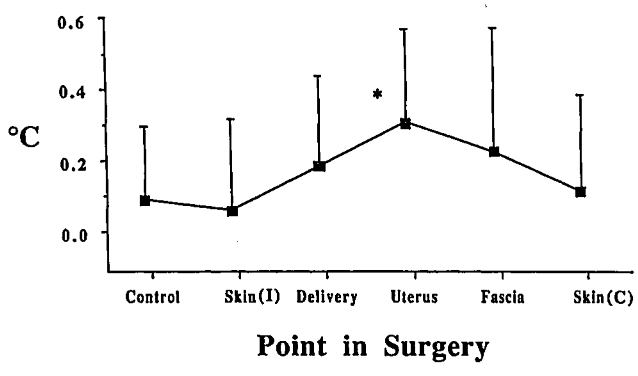

FIG. 1. The difference (mean ± SD) between tympanic membrane and bladder temperature during cesarean delivery in 20 patients. Control values were recorded just before induction of epidural anesthesia. Subsequent values were recorded at skin incision (skin [I]), delivery of the infant (delivery), closure of the uterine incision (uterus), closure of the abdominal fascia (fascia), and skin closure (skin [C]). Tympanic membrane temperatures were higher than bladder temperatures at all times. However, only during uterine closure was the difference significantly higher than control (*).

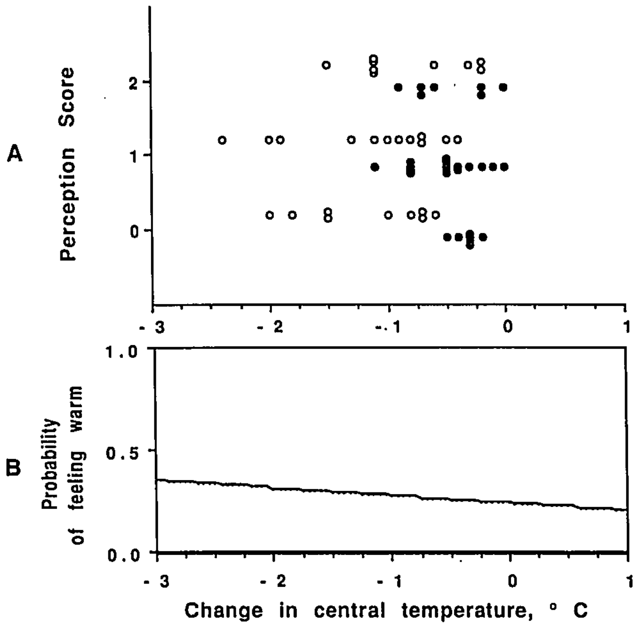

FIG. 2. *A:* The range of central temperature changes during anesthesia and surgery are plotted against thermal perception scores (0 = cool, 1 = neutral, and 2 = warm). Each patient contributed two data points: one at the time of skin incision (solid symbols) and a second at the time of lowest central temperature (open symbols). *B:* The probability of a patient feeling warm is plotted as a function of change in central temperature. The likelihood of feeling warm was the same across the range of measured central temperature changes ($P = 0.63$).

Discussion

Healthy, unanesthetized humans maintain a nearly constant central temperature despite exposure to a variety

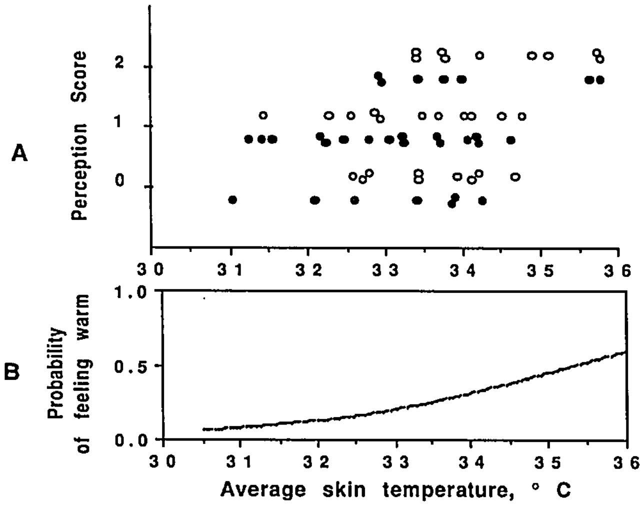

FIG. 3. *A:* The range of mean skin temperatures during anesthesia and surgery is plotted against thermal perception scores (0 = cool, 1 = neutral, and 2 = warm). Each patient contributed two data points: one at the time of skin incision (solid symbols) and a second at the time of lowest central temperature (open symbols). *B:* The probability of a patient feeling warm is plotted as a function of mean skin temperature. Higher mean skin temperature significantly increased the probability that a patient would feel warm ($P = 0.02$).

of environments. Well-regulated temperature results from integration by the hypothalamus and lower thermoregulatory centers, of thermal inputs from both the skin (an early indicator of a change in thermal environment) and central tissues (hypothalamus, spinal cord, abdomen, *etc.*).[5,16,17] Approximately 90% of thermal input to the hypothalamus is from central tissues and the remaining 10% is from the skin surface; changes in skin temperature are most important when they are extreme or rapid.[18] Thermoregulatory efferent responses may be classified as autonomic (*e.g.*, vasoconstriction, shivering, sweating) or behavioral (*e.g.*, covering skin to prevent heat loss, manipulating ambient temperature).[5]

Thermal perception (*i.e.* cognizance of specific thermal sensations)[18] in humans is well preserved throughout a wide range of ambient temperatures and prompts behavioral maneuvers designed to regulate body temperature. Unlike autonomic thermoregulation, which is activated by changes in central temperature, thermal perception is determined primarily by thermal input from the skin. Skin temperature and central temperature usually change in parallel, however. In the absence of anesthesia, skin temperature decreases during hypothermia because of vasoconstriction.[18,19]

Epidural anesthesia produces conflicting thermal states: skin temperature increases in the area affected by sympathetic blockade, while central temperature decreases.[1,4,7,8] Hypothermia during epidural anesthesia results from redistribution of heat within the body.[8] Little heat is lost to the environment. Rather, anesthetic-induced sympathetic blockade warms the relatively cool peripheral tissues, including the skin, and body heat is redistributed from the central to the peripheral compartment.

Patients' perception of temperature did not correspond to a change in central temperature. However, our patients perceived warmth with increases in mean skin temperature and upper body skin temperature. The degree of central hypothermia experienced by our patients is adequate to stimulate vasoconstriction and shivering in the absence of anesthesia.[19] In fact, many of our patients shivered. Decreases in central temperature of this magnitude in animals are adequate to stimulate behaviors designed to preserve heat.[10] In the absence of anesthesia, this degree of central hypothermia would confer a sensation of coldness and prompt thermoregulatory behaviors. Surprisingly, this degree of central hypothermia was actually accompanied by a sensation of warmth in patients with relatively high skin temperature. That central temperature was less important than skin temperature in determining thermal perception is consistent with results in animals indicating that behavioral responses (*e.g.*, pushing a button to receive a burst of warm or cool air) are better elicited by cutaneous than central temperature perturbations.[9,10]

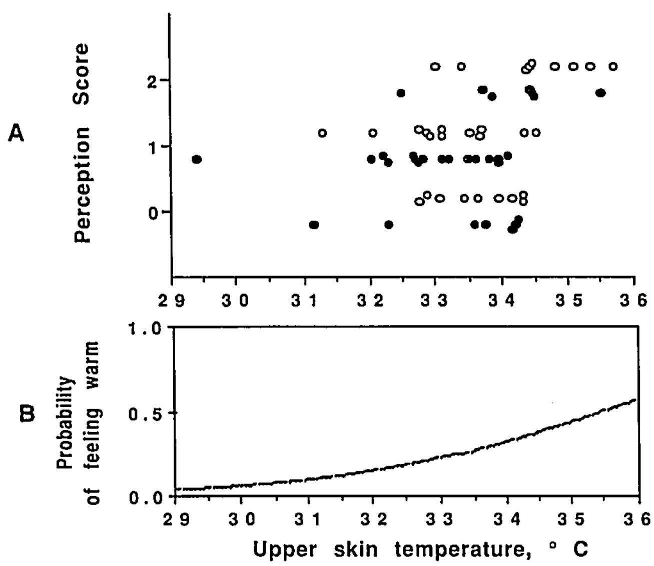

FIG. 4. *A:* The range of upper body skin temperatures during anesthesia and surgery is plotted against thermal perception scores (0 = cool, 1 = neutral, and 2 = warm). Each patient contributed two data points: one at the time of skin incision (solid symbols) and a second at the time of lowest central temperature (open symbols). *B:* The probability of a patient feeling warm is plotted as a function of upper-body skin temperature. Higher upper-body skin temperature significantly increased the probability that a patient would feel warm ($P = 0.03$).

Although skin-surface temperatures increased after induction of epidural anesthesia, thermal sensation from most skin was prevented by an anesthetic block sufficient for surgery. Two hypotheses may explain why some patients felt warm during epidural anesthesia. First, tonic cold-receptor input to the central regulating system is inhibited during anesthetic blockade of the lower body.[18] The absence of tonic cold input (which is the dominant thermal input at typical ambient temperatures) may be perceived as a feeling of warmth. Alternatively, the warmth may be real; that is, a sensation of warmth may be conferred by increased skin temperature in parts of the body affected by sympathetic blockade where sensation is still present. The second hypothesis is supported by the finding that in patients with spinal cord transection, skin temperature in the sentient part of the body influences thermal perception and thermoregulatory responses.[20]

Tremor during epidural anesthesia is normal thermoregulatory shivering, which results largely from central hypothermia, and is preceded by peripheral vasoconstriction above the level of sympathetic block.[7] It does not result from systemic absorption of epidural anesthetic,[21] and stimulation of spinal thermal receptors probably contributes little.[6,22,23] Our results agree with those of previous studies[8]: some of our hypothermic patients shivered and others did not. Shivering may be suppressed when increases in skin temperature during epidural anesthesia decrease total cold input to the thermoregulatory system.[24] Consistent with this hypothesis is the observation that increasing skin temperature in anesthetized dogs decreases the shivering threshold.[25] Clinical studies in humans have demonstrated that cutaneous application of radiant heat rapidly suppresses shivering following general anesthesia before a significant change in central temperature can occur.[26]

Warming intravenous fluids before they are administered has minimized epidural anesthesia–related hypothermia in some cases,[1,2,23] but has proved ineffective in others.[3,**] In our patients, warmed intravenous fluids did not prevent hypothermia. Larger amounts of fluid administered more rapidly may have produced different results. These data suggest that cold intravenous fluids contribute less to central hypothermia during epidural anesthesia than does redistribution of heat within the body.[8]

Our study included only parturients. Our conclusions about thermal perception and central temperature may not apply to other patients undergoing epidural anesthesia. However, our results are consistent with those obtained previously in nonpregnant volunteers during epidural anesthesia.[7,8] Had central hypothermia been greater, our results may have been different, but the observed changes in central temperature were physiologically and clinically significant (as evidenced by shivering in many patients). Our study also did not manipulate skin temperatures. Further studies in which central and skin temperatures are manipulated independently over wider ranges would confirm our conclusion that skin temperature, rather than central temperature, is the primary determinant of thermal perception in patients with high levels of epidural anesthesia.

We also found that bladder temperature was similar to tympanic temperature during cesarean delivery except during maximal exposure of the bladder to ambient temperature during uterine closure. Bladder temperature was investigated as a possible site to measure central temperature because many other reliable central temperature measurement sites (*e.g.*, esophagus, nasopharynx, pulmonary artery) are inconvenient during routine epidural anesthesia . The tympanic membrane is an accepted site from which to determine central temperature, but the tympanic probes are sometimes uncomfortable. When surgical considerations dictate use of a urinary catheter, the bladder may be a convenient temperature-monitoring site. However, bladder temperature is usually slightly lower than tympanic membrane temperature,[27] and bladder temperature lags significantly when changes in central temperature occur rapidly.[28] Our data suggest that bladder temperature is appropriate for clinical monitoring during epidural anesthesia but is not sufficiently accurate for thermoregulatory research during lower abdominal surgery. Tympanic membrane temperature usually will be the least invasive and best tolerated accurate measure of central temperature in patients undergoing epidural anesthesia.

In summary, we found no relationship between thermal perception and central temperature or changes in central temperature in parturients undergoing elective cesarean section with epidural anesthesia. In contrast, a sensation of warmth was likely to be experienced by patients with relatively high mean and upper body skin temperatures. We conclude that skin temperature is more important than central temperature in determining thermal perception in these patients.

Appendix

When the dependent variable in an analysis is measured on a two-point scale (such as "feels warmer" *vs.* "does not feel warmer"), the effects of an independent variable (such as skin

** McCarroll SM, Cartwright P, Weeks SK, Donati F: Warming intravenous fluids and the incidence of shivering during Caesarean sections under epidural anesthesia (abstract). Can Anaesth Soc J 33: S72–S73, 1986.

temperature) can be described using the statistical technique of *logistic regression.*[15] This method describes the probability of observing one of the two outcomes, such as "feels warmer," as a function of the independent variable. As is the case with simple linear regression, the effect of the independent variable x is described using a linear predictor function, $a + bx$. The larger this predictor is, the higher will be the probability p of observing the "feels warmer" outcome. Because probabilities cannot be less than zero (or greater than one), the linear predictor is linked to the probability of "feels warmer" through an S-shaped function that ranges from zero to one. In the case of logistic regression, this link function is the logarithm of the odds ratio.

If we represent the probability of "feeling warmer" by p, and the corresponding log odds by L, the relationship is given by:

$$L(p) = \log [\text{odds}(p)] = \log [p/(1 - p)].$$

Any value for the log odds L can be converted to a corresponding probability, and *vice versa.* The statistical model can now be written as:

$$L(p) = a + bx$$

where x is, for example, skin temperature; $L(p)$ is the log-odds of feeling warm; and a and b are parameters estimated from the observed data using the logistic regression procedure. Roughly speaking, logistic regression estimates the percentage by which the odds of, in this case, "feeling warm" increases for a unit change in x. As b becomes larger, the probability of "feeling warm" increases rapidly. If b is close to zero, the probability of feeling warm as a function of x is nearly flat. In this case, the statistical analysis will not show statistical significance.

For example, consider figure 3. If we assume that the "neutral" and "cool" responses (0 and 1) are combined into a single "not warmer" response, we observe that at skin temperatures $< 33°$ C there are very few "warm" responses. As the skin temperature increases, the probability of observing a "warm" response also increases, as seen by the higher fraction of "warm" responses at the higher skin temperatures.

When the dependent variable is recorded on a scale with three or more points (for example, the cool/neutral/warm scale used in this study), a similar model, *ordinal logistic regression,* can be used that takes advantage of the additional gradation of response that such a scale provides. Let L_1 denote the log-odds of being "neutral" or "warm" (relative to being "cool"), and let L_2 denote the log-odds of being "warm" (relative to the other two responses). The statistical model is then:

$$L_1 = a_1 + bx$$

and

$$L_2 = a_2 + bx$$

where a_1, a_2, and b must be estimated from the data by the ordinal logistic regression procedure. The interpretation of b is the same as for standard logistic regression; we simply have used more information from the data set in order to obtain a better estimate.

Figure 3 shows the estimated probability of feeling warm, calculated from the ordinal logistic regression model. It shows a strong increase in perception of warmth as skin temperature increases. In contrast, figure 2 shows that the probability of feeling warm does not change with changes in central temperature.

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