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ABSTRACT

While evidence exists that a person's peripheral temperature responds to his state of arousal or stress, it also responds to other environmental factors. Wrist temperature has been found to vary with ambient temperature, and to increase during the school day. Before wrist temperature can be established as a valid measure of anxiety, stress, or arousal, extraneous variables must be identified and their effects minimized. To address this issue, a study was conducted which examined the effect on wrist temperature of ambient temperature, outside air temperature, time of the school day, and grade level differences among students. On 9 days from November to February, 19 sixth graders, 17 seventh graders, and 18 eighth graders strapped on Bio-Temp wrist bands used to measure their wrist temperatu es. Readings were taken at 8:40, 8:50, 9:00, 11:30, and 2:40 during the school day. Careful measurements were also made of ambient and outside temperatures. Analysis of data revealed a systematic increasing trend for mean wrist temperature from the earliest reading to the latest for every grade level. The mean wrist temperatures for all students were "corrected" for the point in the circadian thermal cycle, for shared variation with ambient temperatures, and for the warming of the wrist when coming into the classroom from the outside. A model for explaining wrist temperatures was developed. (NB)

A Study of Repeated Wrist Temperature of Sixth, Seventh, and Eighth Graders

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A Study of Repeated Wrist Temperature of Sixth, Seventh, and Eighth Graders

While abundant evidence exists that peripheral temperature responds to the state of arousal, anxiety, or stress of an individual (Bass, Mittenberg, & Peterson, 1981; Boudewyns, 1976; Ellman, 1983; Freedman & Ianni, 1983; Gillespie & Peck, 1980; Kappes, 1983; Kluger, 1982/83; Matthews & El-Amin, 1985; Moore-Ede, 1982; Piedmont, 1983; Vasilos & Hughes, 1979), it also responds to other factors in the environment (Freedman & Ianni, 1983; Kappes & Chapman, 1984; King & Montgomery, 1980; Matthews, 1984), hampering the observer's effort to interpret changes in wrist temperature. In particular, wrist temperature varies with ambient temperature, the temperature of the air in which the measured wrist is found. If the individual recently left an environment of substantially different temperature, the wrist temperature will be changing toward homeostasis with the ambient air but may well be much higher (if the previous environment was warm) or lower (if the previous environment was cold) than predictable from either inner factors or the ambient temperature at the point of measurement. Evidence points to other factors as well; for example, wrist temperature seems to increase during the school day, perhaps as part of the circadian biological cycle. Based on circadian rhythm, studies of temperature measurement have identified early morning, around 5:00 a.m., as the time of day for the lowest temperature (97.16° F) and late afternoon, between 5:00 and 8:00 p.m., as the peak temperature time (98.35° F) of the daily cycle (Aschoff, 1960; Deryagina, 1984; Minors & Waterhouse, 1981; Weston, 1979). The rate of increase in temperature through the school day is constant in the morning but decreases after about 11:00 a.m. Regardless of the cause, measurements taken at different times of the day are not directly comparable. When such measures are aggregated, extraneous factors tend greatly to increase the overall error variance of wrist temperature measurements.

To control for extraneous effects on wrist temperature, laboratory studies can control the ambient temperature with precision and allow the measured wrist to achieve equilibrium with the laboratory air. Comparable measurements may be made at identical times of the day, even though such a solution generally makes observations very expensive. The kind of control possible in a laboratory is quite impossible in research studies in which students are in schools.

Within the current body of research which aims at establishing wrist temperature as a valid measure of a set of internal factors and of which anxiety, stress, and arousal are probably component parts, a clear need exists to permit field observations, even though the control of extraneous variables is necessarily limited under field conditions. Another approach to control is to determine in advance the effects of extraneous variables on wrist temperature and remove them by subtracting their components from the observed wrist temperature. This paper reports 1) research directed at identification of these effects and 2) a model of wrist temperature whose parameters enable the adjustment of observed wrist temperature to minimize the effects of the extraneous variables identified earlier.

From November to February, a study of repeated measures of student wrist temperatures was undertaken in the Felton Laboratory School, which is associated with South Carolina State College at Orangeburg, South Carolina. The study was designed to estimate the effect on wrist temperature of 1) ambient temperature; 2) outside air temperature; 3) time of the school day; and 4) grade level differences among students.

Methods

Sample

For purposes of this study, students from sixth, seventh, and eighth grades were included. Felton Laboratory School is a graded elementary and middle school which is attended principally by the children of faculty and staff of South Carolina State College. Therefore, its students come from homes characterized by intellectualism, high personal expectations, reverence for books and education, and upward social mobility. The great majority are black. From this capable population, 19 sixth graders, 17 seventh graders, and 18 eighth graders were chosen to participate in the study.

Of the 19 sixth graders, 9 were boys and 10 were girls. With the exception of 1 white girl, all sixth graders were black. Of the 17 seventh graders in the study, 6 were boys and 11 were girls. All 17 students were black. Of the 18 eighth graders, 9 were boys and 9 were girls. All eighth graders were black.

Procedure

On each of nine different days, each set of students strapped on Bio-Temp[1] wrist bands by which they measured their wrist temperatures. With the liquid crystal part of the band on the under side of the wrist, the children wore the bands like wristwatches from the beginning of school until the last reading toward the end of the day. The wrist temperature indicator ranges from 72°F to 100°F with an accuracy of plus or minus 0.5°F.

Careful measurement was made, also, of both ambient temperature and outside temperature. Outside temperature was measured because it had been shown to be associated with wrist temperature in an earlier study (Matthews, 1984). Throughout the day, 5 different readings were taken according to the following schedule:

Time	Reading
8:40 a.m.	1
8:50 a.m.	2
9:00 a.m.	3
11:30 a.m.	4
2:40 p.m.	5

Please note that the earliest three readings occurred close together, just after the beginning of school. Researchers were particularly interested in the behavior of the wrist temperature as children came into the school from the colder outside and as the ambient temperature settled to its steady daytime level.

The 54 students were measured on each of nine days. A single card was punched for each subject/day combination. On this card were punched the student's identifying number, grade level, section number, sex, race, and five sets of three measures--ambient temperature, outside temperature, and wrist temperature--taken at the five different times of day.

If all students in each class had exhibited perfect attendance during the nine days of the study, 486 (54 x 9) cards would have been generated. Actually, only 468 were produced.

Analysis

Data were analyzed to allow correction of wrist temperature for shared variation with ambient temperature, outside temperature, and time of day. To this end, the data were aggregated by student identifier, reducing the data to 54 records, each of which reflected the student's grade level, section number, race, sex, and the five sets of wrist temperature, ambient temperature, and outside temperature. Wrist temperature, ambient temperature, and outside temperature were averaged across all nine days (or fewer, for occasional absentees) for each of the five readings. From this data set, another was formed in which 270 (54 students x 5 readings) records were generated, one for each of the five daily readings. Each record contained the grade level, wrist temperature, ambient temperature, outside temperature, and the reading number (Reading 1 was earliest and Reading 5 was latest). This data set was sorted by grade level into three data sets on which mean wrist temperature, mean ambient temperature, and mean outside temperature were computed for each of the five readings. The means derived appear in Table 1.

Examination of Table 1 reveals a systematic increasing trend for mean wrist temperature from the earliest reading (Reading 1) to the latest (Reading 5) for every grade level. Ambient temperature and outside temperature tend to increase strongly from reading to

Table 1

Mean Wrist Temperature, Ambient Temperature and Outside Temperature by Grade for Each of Five Daily Readings

		Reading				
Variable	N	1	2	3	4	5
Grade 6						
Wrist Temperature	19	85.15	86.23	86.83	89.40	90.67
Ambient Temperature	19	67.24	68.89	69.22	70.78	72.97
Outside Temperature	19	41.74	42.84	43.37	49.97	54.58
Grade 7						
Wrist Temperature	17	85.51	86.25	86.75	88.57	90.79
Ambient Temperature	17	67.93	68.53	68.62	70.12	73.87
Outside Temperature	17	42.88	43.60	43.53	45.61	49.89
Grade 8						
Wrist Temperature	18	87.38	88.24	88.64	89.88	91.05
Ambient Temperature	18	72.46	73.34	73.55	71.51	73.25
Outside Temperature	18	41.59	41.75	41.19	45.09	46.68

reading, as well. The most striking exception to this rule is the ambient temperature for Grade 8, which is at its lowest in Reading 4.

Next, the correlation between wrist temperature and ambient temperature was computed within each grade level. The Pearson product-moment correlation coefficient (*r*) was used to study the association between the two variables. For Grade 6, *r* = 0.55; for Grade 7, *r* = 0.58; and for Grade 8, *r* = 0.04. (Please recall that these correlations were observed on data that had been aggregated over 9 days. The value of Pearson's *r* on unaggregated data can be expected to be far less.) This interesting pattern of correlation coefficients can be explained partly by examining the range of ambient temperature available when wrist temperatures were observed. Table 1 confirms that the eighth grade readings were made in the best regulated room, as far as room temperature was concerned. While eighth grade ambient temperature, averaged over all five readings and aggregated over all days, ranged only 1.74 degrees (from 71.51 to 73.25), the sixth grade readings ranged 5.73 degrees (from 67.24 to 72.97), and the seventh grade readings ranged 5.94 degrees (from 67.93 to 73.87).

In support of the argument that the observed lack of association between wrist temperature and ambient temperature for eighth graders is related to the truncated range of ambient temperature, one can examine the variance of wrist temperature in the three grades. In the sixth grade, the variance of wrist temperatures was 7.78 squared degrees. In the seventh grade, it was 10.14 squared degrees. For the eighth grade, where ambient temperature was most nearly controlled, the variance was only 3.46 squared degrees. (Of course, if ambient temperature had been controlled precisely, its correlation with wrist temperature would have been 0.00, since it would have no variation and, consequently, could share none with the wrist temperature.) The reduction in variance for eighth grade wrist temperature measures is probably the result of the improved control of ambient temperature in the room in which the measures were made.

Figure 1 is a graphic representation of the mean wrist temperature from Table 1. Even though wrist temperature for Grade 8 has been shown to be unrelated to ambient temperature, wrist temperatures for Grade 8 in Figure 1 rise parallel to those for Grades 6 and 7, where the ambient temperatures rise throughout the school day. If the rise in wrist temperature was related solely to a consonant increase in ambient temperature, the graph of measures for Grade 8 should not be as nearly parallel to those of Grades 6 and 7 as they are. Clearly, another factor is elevating wrist temperature through the part of the school day examined by the research. From Figure 1, it appears as a roughly linear function of the time of day. Moreover, and adding a great deal of complication to the analysis, this factor seems tightly confounded with ambient temperature which, in two grades, also increases over the observational period of the day. The true correlation of ambient temperature and wrist temperature is almost certainly less than the reported values (0.55 and 0.58 for Grades 6 and 7, respectively) because of this confounding between the time of day and ambient temperature. Since the variables increase together, their effects combine, and a computed correlation coefficient between

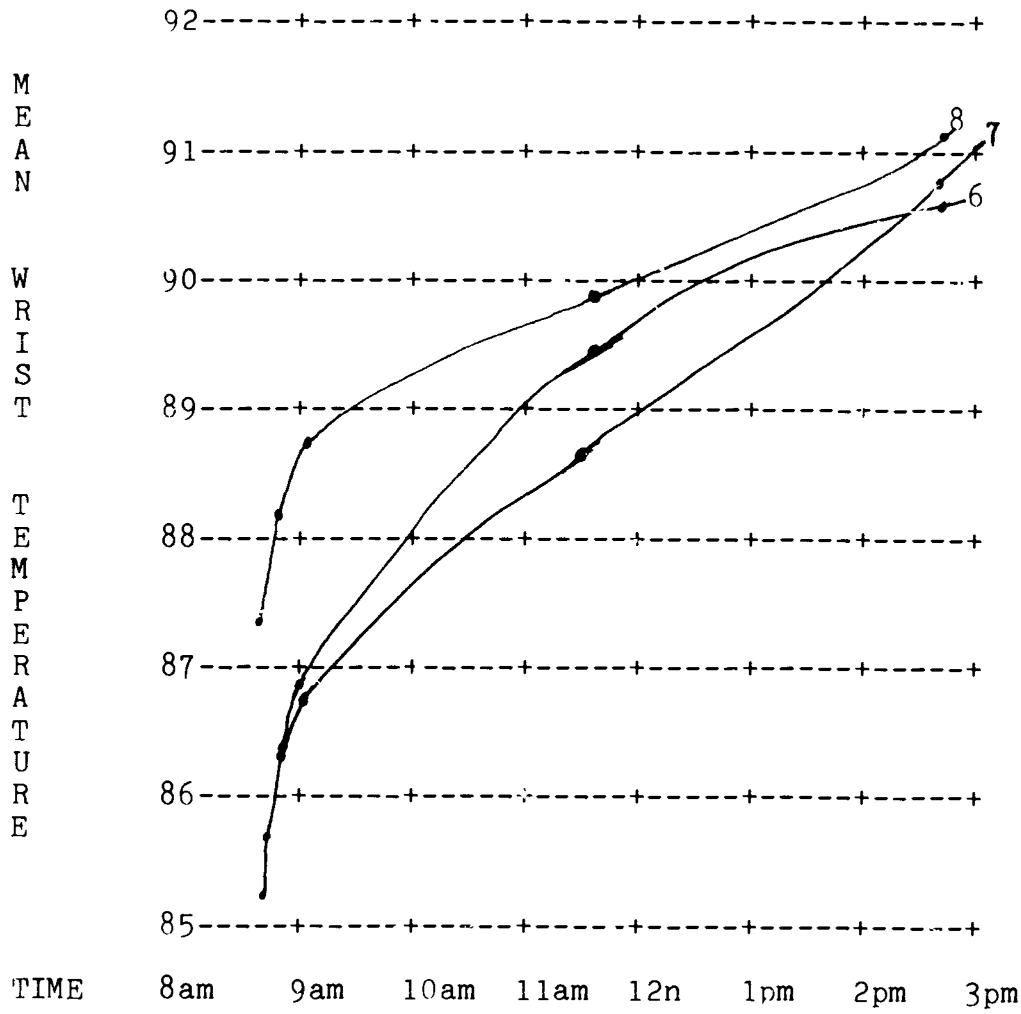

Figure 1. Mean Wrist Temperature by Time for Grades 6-8.

either of them and wrist temperature is increased artificially by the variation which the other factor has in common with both wrist temperature and the other variable.

The most probable cause of the steady rise in wrist temperature throughout that part of the day covered in the study is the circadian thermal cycle (CTC). Researchers vary in their descriptions of the CTC, but most agree that it reaches a low point around 5:00 a.m. and increases until about 5:00 p.m. The early part of the rise is steep but becomes more gentle after about 11:00 a.m. In the present study researchers used the number of hours between 5:00 a.m. and the time a wrist temperature was measured to operationalize the point in CTC. Thus, for measures at 8:40, 8:50, 9:00, and 11:30 a.m., the CTC measures were 3.66, 3.83, 4.00, and 6.50, respectively. The 2:40 p.m. measurement (as would any measurement taken after 12:00 noon) was held to a CTC measure of 7.00, since the rate of increase beyond that point seems substantially less than that in the earlier part of the day.

Since the linear association between wrist temperature for Grade 8 and ambient temperature was suppressed by the tight control of ambient temperature for that grade, the Grade 8 measures provide the best opportunity to estimate the effect of CTC on wrist temperature. Using the data in Table 1 and the five CTC measures just cited, Pearson's r is easily computed as 0.97. The regression of wrist temperature on CTC for the Grade 8 means is 0.88 Fahrenheit degrees/CTC unit (which is an hour per unit before noon and presumed to be constant thereafter). Presumably, when the CTC begins to fall, after about

5:00 p.m., the wrist temperature will decrease as well, but no wrist temperature measures were taken in that part of the cycle. For purposes of measuring wrist temperature in schools, these measures are of little value.

Wrist temperature means were residualized by removing the component attributable to shared variation with the CTC. Simple subtraction of the product of the regression weight and the CTC deviation about its mean left the mean of the residualized measures unchanged from their mean before residualization, as shown in Table 2. Figure 2 displays graphically the data in Table 2. Comparison of Figures 1 and 2 reveals the extent to which the residualization has removed a great portion of the variability in wrist temperatures of all three grades.

Next, in a similar fashion, the wrist temperatures underwent another adjustment for their association with ambient temperature. The correlation between wrist temperature (corrected for the CTC) and ambient temperature is r = 0.96 across all 15 measures (5 measures for 3 grades). The standard deviations of wrist temperature (corrected for the CTC) and ambient temperature are 1.01 and 2.31, respectively. Consequently, the change in (corrected) wrist temperature for each degree of change in ambient temperature is seen to be 0.42 Fahrenheit degrees.

Table 3 reports the value of wrist temperature after adjustment for both CTC and ambient temperature. Figure 3 displays the adjusted values. The extent to which the variance of wrist temperature has been reduced by the two adjustments, for time of day and for ambient temperature, is easily seen by comparing Figures 1 and 3. Most

Table 2

Mean Wrist Temperature, Corrected for Circadian Thermal Cycle by Grade for Each of Five Daily Readings

		Reading				
Variable	N	1	2	3	4	5
		Grade 6				
Wrist Temperature	19	86.29	87.22	87.67	88.22	88.87
		Grade 7				
Wrist Temperature	17	86.65	87.24	87.59	87.39	88.99
		Grade 8				
Wrist Temperature	18	88.52	89.23	89.48	88.70	89.25

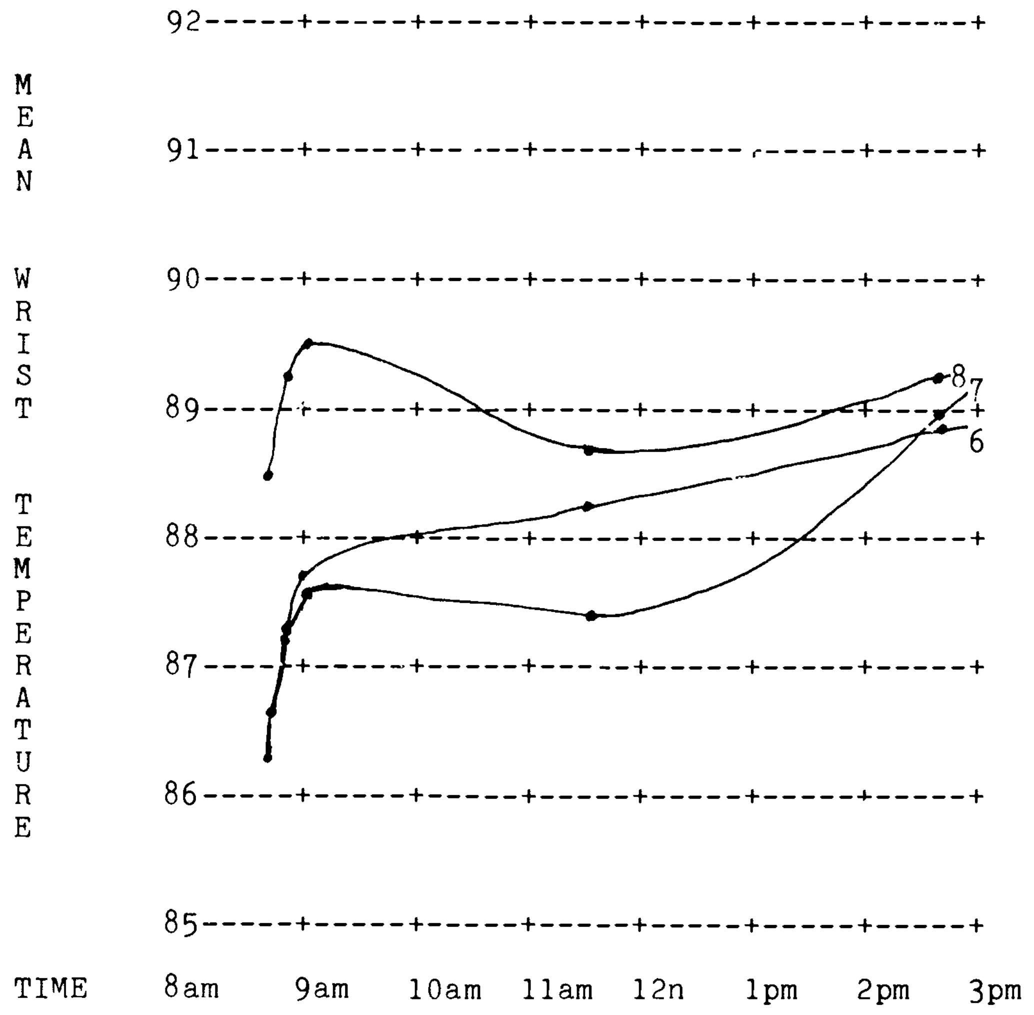

Figure 2. Mean Wrist Temperature by Time for Grades 6-8 Adjusted to Correct for Shared Association with the Circadian Rhythm Cycle.

Table 3

Mean Wrist Temperature Corrected for Circadian Thermal Cycle and Ambient Temperature by Grade for Each of Five Daily Readings

		Reading				
Variable	N	1	2	3	4	5
		Grade 6				
Wrist Temperature	19	87.80	88.04	88.35	88.23	87.97
		Grade 7				
Wrist Temperature	17	87.87	88.21	88.52	87.68	87.71
		Grade 8				
Wrist Temperature	18	87.83	88.17	88.33	88.41	88.21

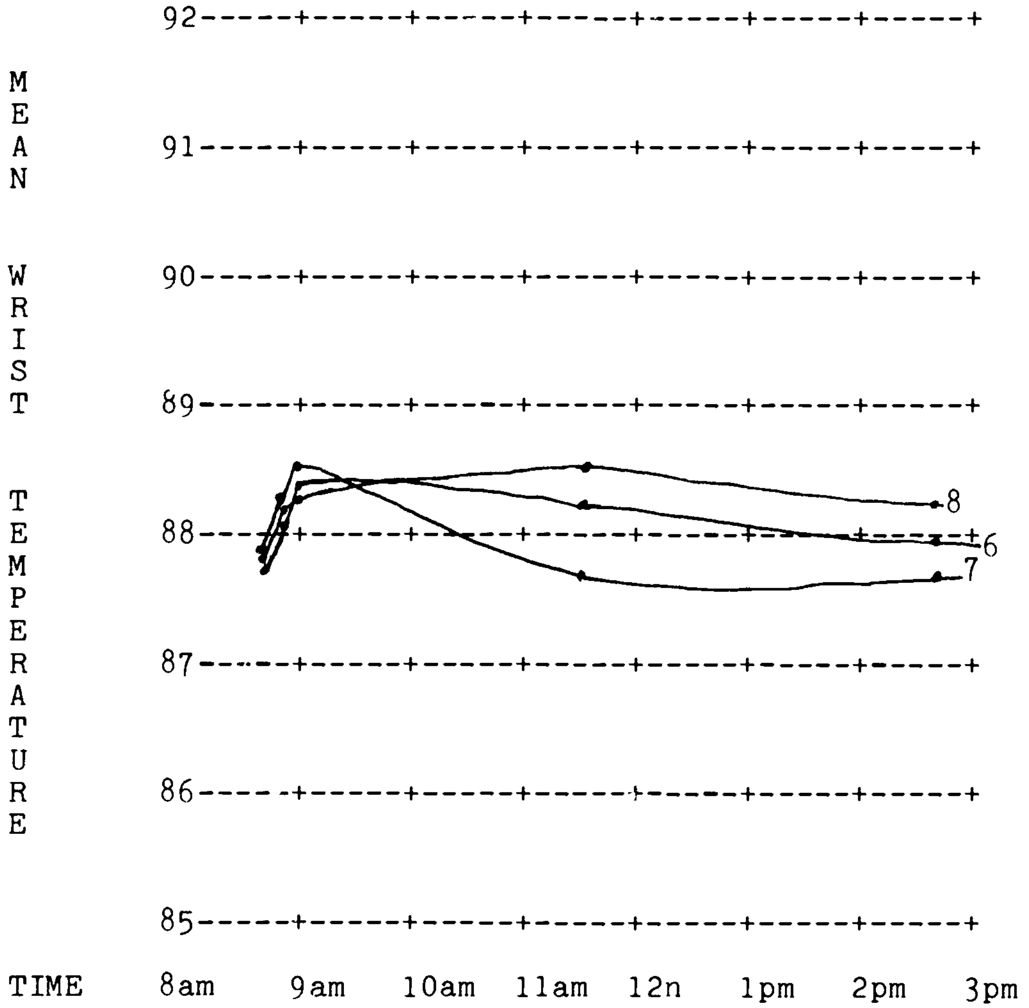

Figure 3. Mean Wrist Temperature by Time for Grades 6-8 Adjusted to Correct for Shared Association with the Circadian Rhythm Cycle and Ambient Temperature.

impressive is the close agreement of all scores in the first three readings. Recall that these readings all occurred within 20 minutes of each other at the very beginning of the school day. The actual shape of the gradewise curves in Figure 3 is unreliable, since most of the shape depends upon two sets of measurements, taken at 11:30 a.m. and at 2:40 p.m. A comparison between Figures 2 and 3 reveals the success of the double residualization. For the purpose of this study, curves which show minimum change over the school day are a desirable end since such curves evidence sophisticated control of extraneous variables. Figure 3 seems to rule out any gradewise difference overall; that is, no systematic trend in wrist temperature is observed from Grade 6 to Grade 8.

As a student enters a warm room from outside on a winter morning, one would expect the wrist temperature to increase rapidly. This phenomenon is evident in the present research. Figure 3, particularly, reveals the pattern of warming wrist temperature in the morning when wrist temperatures were first observed. Clearly, the wrist temperatures warmed rapidly in the heated room when students came from outside to begin classes. In fact, wrist temperatures warmed in a manner similar to the warming of unheated, cooler objects surrounded by warmer air.

The warming of unheated objects to match a warmer ambient temperature is a common phenomenon in physics and has been studied precisely. It follows the function:

$T = W + (C - W)\exp(Kt)$, where

T is the temperature of the warming object,

W is the warm ambient temperature,

C is the colder temperature of the object when observation begins,

K is a constant, and

t is the elapsed time since the first observation.

Notice that when $t = 0$, the second term on the right becomes $(C - W)$ and $T = C$. Given negative values of K, as time goes on, T will become closer and closer, though ever more slowly, to W. The value of K is necessarily always nonpositive.

Although human wrists are exothermic objects (they give off heat in normally heated rooms), they approximate the warming behavior of lifeless objects when the ambient temperature increases. They change from the steady wrist temperature characteristic of the colder air (T_c) to that which is characteristic of the warmer air (T_w). Though their temperatures do not change as much as that of the surrounding air, if one could determine T_c and T_w, one could use the functional relationship above to predict the warming behavior of the wrist. These final (homeostatic) temperatures may be approximated from Figure 3. Using a warming function, one may use either the beginning temperature of the warming body (i.e., allow $t = 0$ when the subject enters the warmer room) or the orignal temperature measurement made in the warmer room (i.e., allow $t = 0$ when the initial measurement is made). Table 1 reports the mean outside temperature which, for the entire study, was substantially lower than the ambient temperature in the classrooms.

In every case, then, a warming function may be presumed to be operating, with its greatest effect shown at the beginning of the day when the middle school student enters the warmer classroom from outside.

Using a simple computer program to estimate the value of K which would "explain" the first three data points for each grade in Figure 3, C (made at 8:40 a.m.) was the first measurement. W was estimated by sight from Figure 3 as 88.5 degrees. Using these estimators, the value of K which gave the closest fit to Readings 2 and 3 was K = -4.5.

Discussion

The mean wrist temperatures for each of three grades at each of three readings have been "corrected" for the point in the circadian thermal cycle (CTC), for shared variation with ambient temperature, and for the warming of the wrist when coming into the classroom in the morning from outside. The model for explaining wrist temperature has been developed as follows:

$T_c = T_w - (T_a - \overline{X}_a)b_a - (P - \overline{X}_P)b_c + (C - W)\exp(Kt)$, where

T_c = corrected wrist temperature,

T_w = observed wrist temperature,

T_a = observed ambient temperature,

$\overline{X}_a$ = mean ambient temperature,

b_a = regression weight for regression of ambient temperature on wrist temperature

P = point in CTC (1 hour for each hour after 5 a.m. until 12:00 noon and constant thereafter),

$\overline{X}_P$ = mean of CTC points

b_c = regression weight for regression of CTC on wrist temperature,

C = initial wrist temperature corrected for CTC and ambient temperature,

W = asymptotic corrected wrist temperature (estimated extrapolation from later readings after correction for CTC and ambient),

K = warming constant, always negative, and

t = elapsed time since initial reading.

Looking at the right half of the equation, one can see that it is made up of four terms. First is the observed wrist temperature, the basis of subsequent corrections to remove the effects of contaminating variables. Second is a term which corrects for ambient temperature variations. The third term makes a correction for shared variation concomitant to the circadian thermal cycle. Finally, the fourth term corrects early readings for the rapid warming of the wrist after coming into a heated space from a colder environment.

The implications for research seem to be these:

1. One may ignore the second term in the model above only when conducting studies in environments where the ambient temperature is rigidly controlled.

2. The third term may be ignored if: 1) all measurements are made at the same time of day or 2) all readings are made in the

afternoon, while the circadian thermal cycle seems to be at a maximum and relatively invariant.

3. The fourth term may be ignored when subjects are allowed to condition for a short time to the room in which measurements are to be made.

In the present study, K = -4.5 when t is measured in hours. In this case, warming will be half finished in 10 minutes. Half of the remaining warming will be completed in another 10 minutes, etc. Particularly since W must be estimated rather crudely, most researchers will prefer to condition students in the environment in which measurements are to be taken for about 1 hour before the first measurement so that the fourth term may be ignored safely.

The success of residualizing observed wrist temperature for effects of ambient temperature and the circadian thermal cycle, revealed in Figures 2 and 3, may be somewhat misleading. Actually, three curves are being "fitted" to fifteen data points. In such a case, the fitting may be expected to be quite good. Careful examination of Figure 3, particularly after removing the effect of warming which affects the first three readings to a great degree, indicates a slight downward slope of, perhaps, .05 degrees/hour. This slope could have been corrected by using a different time than 12:00 noon or a different point of origin than 5:00 a.m. for fixing the point on the circadian thermal cycle. Departing from these points would have caused a better fit to a horizontal line but would have been without much basis in theory.

Previous studies in the line of research of which this study is part have provided cogent evidence that one's level of anxiety or stress can effect changes in wrist temperature substantially greater than one Fahrenheit degree (Matthews, 1984). Results of this study will be used in subsequent studies in the series to remove large components of error variability which may now be discarded more safely. In effect, this study will increase the "signal to noise" ratio for subsequent studies by allowing a more rational apportionment of the error sum of squares than has been possible previously.

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Footnotes

[1]Bio-Temp Wrist Bands (Biotic-Band) may be purchased from Bio-Temp Products, Inc., 1950 West 86th Street, Indianapolis, Indiana, 46260.