Data Mining and Time-Series Analysis as Two Complementary Approaches to Study Body Temperature in Obesity

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ABSTRACT

Obesity is becoming a pandemic worldwide but the mechanisms that cause obesity are not well understood. One possibility are metabolic differences between lean and obese people, for which body temperature may offer a proxy which is relatively easy to measure. In the present contribution, we present results from two complementary methodological approaches to measure skin temperature as a function of body weight: in the first study temperature at the axilla and anthropometric measures were collected at a single time point in 1,073 male and female employees of all ages of the Universidad Nacional Autónoma de México (UNAM), whereas in the second study a 1-week continuous monitoring was realized of the skin temperature of the non-dominant wrist of 22 male young adults. In spite of the methodological differences, both studies indicate a higher mean temperature of the obese with respect to the lean subjects, possibly reflecting how obese people offset excess calorie intake by a higher heat transfer to the environment. On the other hand, with respect to the variance of the temperature over groups of underweight, normal weight, overweight and obese subjects, the first study that was realized in controlled circumstances did not detect any differences between groups, whereas the differences that were detected in the second study probably indicate behavioural differences between groups such as the level of physical activity.

CCS CONCEPTS

•General and reference → Empirical studies; Measurement; Experimentation; Design; •Mathematics of computing → Time series analysis; •Information systems → Data mining;

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KEYWORDS

Obesity; body temperature; data mining; time-series analysis

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1 INTRODUCTION

The digital revolution, besides offering unprecedented opportunities for obtaining, storing and analysing big, deep data, also offers unprecedented challenges. Almost all data gathered in the data revolution represents the properties and behaviour of Complex Adaptive Systems [10]. Unfortunately, our capacity to model such systems in a meaningful way is, to put it mildly, primitive. Additionally, we are generating data much faster than we can understand and successfully model it. Wearable technologies, for instance, allow us to measure certain physiological variables, such as body temperature and heart rate, with unprecedented depth, as well as behavioural variables through, for example, physical activity [3]. However, such data does not typically come in a controlled way, as would be much more the case in a clinical or epidemiological study say, thus making its interpretation more difficult. Given the large amounts of data available from multiple epidemiological and clinical studies, we believe it is important to combine data from both types of study: traditional epidemiological/clinical studies and data from more specifically digital technologies, to compare and contrast results and analyse the advantages and disadvantages of the different paradigms.

In this paper we will highlight such a synergistic interaction between data sources, comparing data and hypotheses gleaned from two distinct data sets: a medium scale study of 1,073 academic and non-academic employees of Mexico's largest university, the Universidad Nacional Autónoma de México (UNAM), and a study of data from wearable technologies for 22 male young adults from the general population. We will do this concentrating on one important physiological variable - skin temperature - and its relation to body mass index (BMI), in particular to obesity, a global epidemic and one of the world's most important health problems [5, 13]. This is a pilot study, where we explore how the different data sources highlight different elements of the phenomena, each with its distinct advantages and disadvantages. We will conclude by showing how the combination of data can lead to new insights that could be helpful in the global fight against obesity.

2 METHODS AND MATERIALS

2.1 Temperature: A fundamental biomarker

Temperature, of course, has long been identified and accepted as an important health indicator, especially as a biomarker for the presence of disease, as in the case of fever. However, it is an enormously complex variable [6]. To begin with, temperature is spatially heterogenous, with measurements taken at different points, either internally such as mouth, rectum, tympanic membrane, or superficial skin temperature at the armpit, wrist, etc. – yielding quite different results. Moreover, it is a variable that is known to vary in accordance with different physiological states, not just in acute fever, but in others, such as menopause, hot flashes, age etc. Further complicating this is the fact that temperature can also depend on environment and behaviour. For example, the shiver response is a direct response by the organism in order to maintain homeostasis in the light of an abrupt negative temperature change. Similarly, temperature changes in response to physical activity by the generation of heat due to muscle activity. Taking obesity as a state that is different both physiologically and behaviourally from that of normal weight, we may ask if there are any systematic differences in temperature between obese and normal weight people.

The association between temperature and BMI has been studied before but without any clear conclusions. Two contradictory hypotheses exist: there might be a *causal mechanism* if obese people have a lower body temperature such that they accumulate more fat because they dissipate less excess calories as heat [11], or there might be a *protective mechanism* if obese people have an increased body temperature to dispose of excess calories to avoid accumulating more fat [12]; a third possibility is that the average body temperature is not necessarily different between normal-weight and obese people but that the skin temperature is distributed differently over the whole body surface [12]. Using point measurements of oral temperature, one study found that temperature is proportional to weight [4], whereas another found an inverse relationship [1]. Using continuous measurements of wrist temperature with Thermochron iButtons®, lower mean temperature and alterations in circadian and ultradian cycles were found in obese women [2]. Using continuous measurements of core body temperature using telemetric pills, one study found no differences [8], whereas another study detected higher temperatures in the obese participants [9]. Using continuous rectal measurements, a reduced temperature was found for the obese subjects, but only during diurnal hours [7].

2.2 Methodology: Study 1

The study "Obesity and Type 2 Diabetes as a Complex Adaptive System" was carried out over the period February - June 2014 in order to analyse the health status of academics and non-academics in the UNAM, concentrating particularly on obesity and type-2 diabetes mellitus. Participants were males and females of all ages. A sample of 1,076 volunteers was formed and physiological, genetic, blood chemistry and anthropometric data obtained, as well as epidemiological data from an extensive questionnaire that covered: demographic information, family history, personal history, nutrition, lifestyle and health knowledge. Axilliary temperature was taken at a single time moment by qualified medical practitioners using a standard thermometer and registered visually to $0.1^{o}C$ accuracy. The participants were seated and had fasted for at least 8 hours. Measurements were taken in different buildings of the university and as much as possible it was attempted to recreate the same conditions in each session. Typically, 20-30 subjects were tested daily in a three hour session. For BMI, weight was measured using a standard scale and height using a stadiometer. Both measurements were taken by qualified medical professionals and in the same session that temperature was measured.

2.3 Methodology: Study 2

All measurements were made in Mexico City during the same climatic season (rainy season August-October 2016) in 22 male young adult volunteers (20-40yo) from the general population. The model DS1922L of Thermochron iButton® (Maxim/Dallas Semiconductor Corp., USA) was fixed to the non-dominant wrist using medical tape and monitored skin temperature continuously for 1 week with a sampling frequency of 1/3min, a resolution of 0.0625°C and an accuracy of $\pm 0.5^{\circ}$C. Simultaneously, an actigraph wGT3X-BT® of the company Actigraph was used to monitor physical activity. Weight and height were recorded, skin folds were measured at 4 sites (upper arm, calf, stomach centrally and laterally) and waist-hip ratio was measured. In this pilot study, we focused on males because in females the timing of the 1-week monitoring period with respect to the monthly menstrual cycle is important and requires a separate investigation.

3 RESULTS

3.1 Results from Study 1

For Population 1, of the 1,076 original measurements of axillary temperature, 3 measurements were omitted from further analysis because they responded to unrealistic temperatures 16.3, 32.2 and 34.2° C. Of the 1,073 measurements included in the study, 225 (21%) measurements corresponded to participants with BMI $>$ 30 (obese), 505 (38%) participants with 25 $<$ BMI $<$ 30 (overweight) and 415 participants with 18.5 $<$ BMI $<$ 30 (normal weight), and 28 with BMI $<$ 18.5 (underweight), using the standard definitions from BMI. The mean temperatures for the obese and normal groups were 36.24°C and 36.16°C respectively. A two-tail, heteroskedastic t-test to compare the two values was performed, with a corresponding p-value of 0.006, showing that the average temperature of the obese group and the normal group are strongly statistically different, with the obese having a higher average temperature than the normal BMI group. We can also test for equality of other higher order moments between the two groups. For instance, for the variances of the two groups, 0.127 and 0.136 respectively, there was no statistically significant difference.

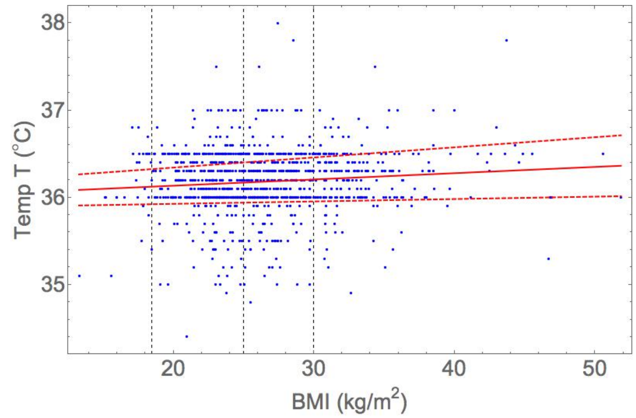
Table 1: Linear regression of skin temperature T vs. BMI in Study 1 (for individual data points and for points clustered in deciles), and for Study 2 (for week averages and for day-per-day averages). Regression parameters include slope, intercept and 95% confidence intervals (CI). Statistical significance (*) is considered for $p < 0.05$.

	Study 1		Study 2	
	points	deciles	7-day mean	1-day mean
slope	0.0072	0.0067	0.0093	0.015
intercept	35.99	36.00	33.69	33.524
CI_{slope}	0.0028	0.0024	-0.019	0.0019
	0.012	0.011	0.038	0.029
$CI_{intercept}$	35.88	35.89	32.88	33.15
	36.11	36.12	34.51	33.90
t_{slope}	3.18	3.56	0.68	2.25
$t_{intercept}$	590.34	708.93	86.9	174.92
F	10.15	12.64	0.46	5.06
p	0.0015 (*)	0.0074 (*)	0.50	0.026 (*)
R^2	0.0094	0.61	0.022	0.027

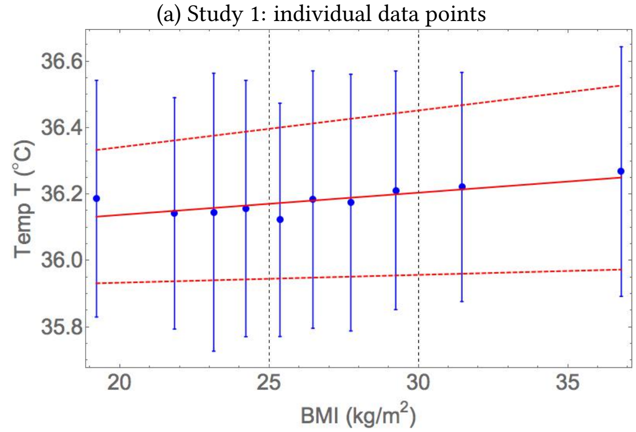
The results of a linear regression for all 1,706 individual data points of temperature against BMI can be seen in Figure 1(a). For visualisation purposes we also divided the sample population, ranked by BMI, into deciles, with each decile containing 107 measurements, see panel (b), where the error bars indicate the standard deviation in temperature for the deciles. As can be observed, there is a clear increasing tendency for the average temperature, but no trend for the dispersion in temperature. Finally, in Figure 2(a), we see the normalized distributions for the temperatures of the 4 BMI groups. Here also, it can be appreciated that the average temperature increases from the control group to the obese group, but the width of the distribution is similar, reflecting the controlled conditions during which the temperature measurements were taken.

3.2 Results from Study 2

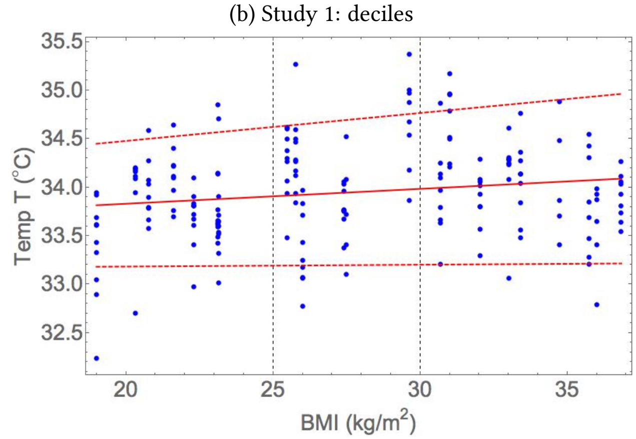
The 22 participants of Study 2 were divided into the categories of normal weight (9 subjects), overweight (4 subjects) and obese (9 subjects) using the standard definitions from BMI. The objective was to monitor in all participants skin temperature and actigraphy continuously for 1 week. In the case of 2 obese and 2 overweight subjects less than 7 continuous days were recorded, curiously, they reported the monitoring as being tedious, whereas all control subjects commented that they got accustomed very quickly to the measuring devices. In the following, only results for the temperature time series will be given, to be compared with the results of study one, and the results on actigraphy will be reported elsewhere. Figure 3 shows the 1-week continuous time series of the wrist temperature of a control subject with normal weight where it can be appreciated that skin temperature varies throughout the day, with lower temperatures associated to physical activity (vasoconstriction) and higher temperatures during rest (vasodilatation); there is also a clear day-night circadian pattern [6]. In this study, given its longitudinal nature, statistical analysis can be carried out at different levels. Firstly, one can form temperature histograms and consider a mean of the distribution such that all measurements over the multiday



(a) Study 1: individual data points

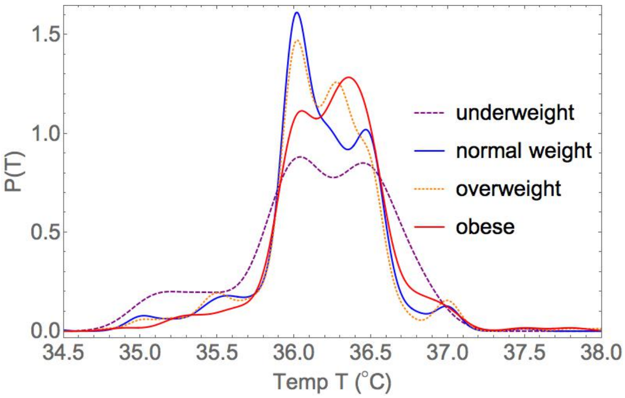


(b) Study 1: deciles

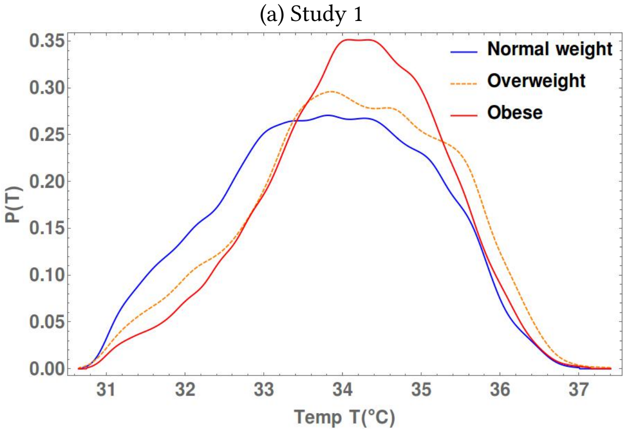


(c) Study 2: day-per-day averages

Figure 1: Linear regression of temperature T against BMI, for (a) Study 1 using all 1,073 individual data points, (b) Study 1 using deciles, and (c) Study 2 using day-per-day temperature averages for all 22 subjects. Shown are the linear regression (continuous line) and the 95% confidence intervals (dashed lines). Numerical values are given in Table 1. Vertical gridlines indicate the BMI limit values for the underweight, normal weight, overweight and obese populations.



(a) Study 1



(b) Study 2

Figure 2: Normalized distributions $P(T)$ for temperature T for the underweight, normal weight, overweight and obese populations of Studies 1 and 2.

period and for a particular person or BMI group have been averaged. This leads in the case of 1 week-average per participant to only 22 data points, and the linear regression of average temperature vs. BMI shows a positive relation but is statistically not significant, see Table 1. However, we can also increase the size of the sample by considering the per day temperature histogram for each participant. Thus, for a participant who was tracked over N days, we have N data points associated with the mean temperature over a given one day interval. This leads to an estimate of the inter-day dispersion in temperature and a larger sample size. Figure 1(c) shows the linear regression analysis for the day-per-day averaged temperature against BMI of all participants. Again we find a positive correlation, with a slope comparable to the one obtained in Study 1, and now the correlation is statistically significant, see Table 1. The intercept obtained in Study 2 is about 2.5°C smaller than the intercept of Study 1, due to the lower average temperatures at the wrist than at the axilla. Distributions of the temperature time series for the three groups are shown in Figure 2(b). To get an idea of the significance of these differences, we studied the moments of the distributions of the individual subjects using a Kruskal-Wallis and post-hoc test in IBM SPSS 22: we found that the average temperature increases from the control group over the overweight group to the obese group with $p = 0.089$, the standard deviation decreases from SD=1.21 for the control and the overweight groups to SD=1.09 for the obese group with $p = 0.017$ (*), skewness becomes gradually more negative from Skew=-0.1 for the control group over Skew=-0.3 for the overweight group to Skew=-0.35 for the obese group with $p = 0.14$, and kurtosis increases from a platykurtic distribution Kurt=2.2 for the control group over Kurt=2.5 for the overweight group to an approximately gaussian distribution Kurt=2.75 for the obese group with $p = 0.038$ (*).

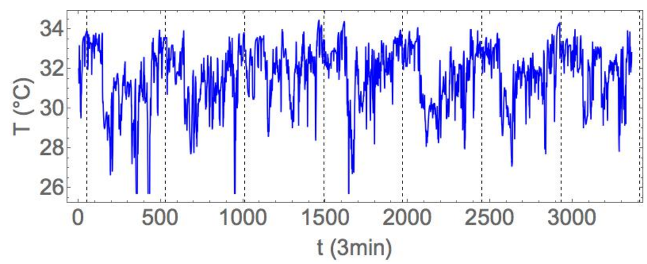


Figure 3: 7-day continuous wrist skin temperature registration of a normal-weight subject of study two. Vertical gridlines at midnight.

4 DISCUSSION

The most striking result is that both sets of data, from very different measuring protocols, transverse versus longitudinal population, and very different measuring devices, thermometer versus wearable device, and different measurement points, axiliar versus on the wrist, both lead to the same conclusion about temperature as a function of BMI: that the obese have higher average temperatures than those of normal weight. Furthermore, there is a clear linear relationship between temperature and BMI. In the case of Population 2, due to its reduced size relative to the first study population, the statistical significance of the difference in means is non-significant, with a p-value of 0.50 as opposed to 0.0015.

Interestingly, however, in terms of higher moments of the distribution there is no apparent consistency. In Study 2, there is a clear, statistically significant difference between the variances of the temperature of the obese group and the normal group. Similarly, there is a statistically significant difference in the kurtosis of the two groups.

The resolution of why the higher order moments have a distinct behaviour between the two study populations as a function of BMI we believe has its origin in the very different protocols under which temperature is measured in the two studies. In Study 1, as emphasised, the ensemble of temperature measurements is associated with 1,073 single measurements that, as much as possible, were taken under the same experimental conditions. On the other hand, in Study 2, the ensemble of temperature measurements of a single person is taken over a multi-day period. This means that the conditions over which the measurement is taken are highly heterogeneous. For example, covering such different activities as sleeping, eating and physical exercise, where it is known that there are responses in temperature to these changing conditions.

Of course, the differences between the obese and the normal, as seen in the higher moments of the distributions in Study 2, may also have an intrinsic physiological component that, for some reason, is not manifest in the data of the first study. However, given the strong differences in the measurement conditions for the two studies, which are principally due to the range of activities or behaviour over which the measurements are taken, we believe that it is more likely that the differences are due to this factor. Further support for this idea can be gleaned from our figures. For the distributions of the four BMI groups for the first study, as seen in Figure 2(a), the variances of the four groups are all much smaller than those see in Figure 2(b). This is consistent with the much higher degree of environmental uniformity with which temperature was measured in the first population. Additionally, lower skin temperatures have been associated with exercise [14] and this may explain the higher kurtosis and lower variance of the distribution for the obese versus the control subjects as seen in Figure 2(b).

The major strength of the present study is that 2 types of data have been studied, transverse vs. longitudinal, and that both lead to the similar conclusions of temperature vs. body weight. The major limitation is the question whether the specific populations included here are representative of the general population. However, we think body temperature is such a fundamental physiological variable that it is warranted to draw general conclusions from these findings.

5 CONCLUSIONS

In this paper we have used two very different protocols to measure the relationship between temperature and BMI. In the first study population we measured temperature in a quite controlled, relatively constant environment for a relatively large number of participants, while, in the second we measured temperature over time using a wearable device. The results from both studies show the relative advantages and disadvantages of the two approaches. The traditional approach lends itself to much larger study population sizes compared to using wearable technology, where the cost of the devices and the cost in time for following potentially thousands of participants is high. However, the second approach allows for a much more in depth analysis of how temperature changes in time but with the caveat that interpreting the results is challenging due to the high degree of heterogeneity in conditions over which temperature is measured. Combining the two however, allows us to use the contrasting conditions under which measurements are taken to our advantage. We noted that the mean temperature difference between obese and normal weight participants was completely consistent across both studies, the mean being taken over two quite different ensembles, thus indicating that there really is a statistically significant difference between the average temperatures of obese and normal weight individuals. Moreover, the data is consistent with a linear relation between BMI and temperature. In the case of the variance, we saw that there was no statistically significant difference between groups in the first study population but strong differences in the second. We interpret this as being due to the relative homogeneity/heterogeneity of the conditions for temperature measurement in study one/two. We believe that the higher mean temperature of the obese is a way to offset excess calorie intake by allowing for a higher heat transfer to the environment while the lower variance in the temperature distribution for the obese seen in study two is due, principally to behavioural differences among the obese and normal weight, such as in exercise, but may also have a physiological component.

STATEMENT ON ETHICS AND COMPETING INTERESTS

The authors have declared that no competing interests exist. This research involves human subjects and private human medical data and has been performed in accordance with the Declaration of Helsinki and has been approved by the Ethics Committee of the Faculty of Medicine of the UNAM university.

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REFERENCES

[1] Kirstine Adam. 1989. Human body temperature is inversely correlated with body mass. *European Journal of Applied Physiology and Occupational Physiology* 58, 5 (1989), 471–475. DOI: http://dx.doi.org/10.1007/BF02330699

[2] M. D. Corbalan-Tutau, J. A. Madrid, J. M. Ordovs, C. E. Smith, F. Nicols, and M. Garaulet. 2011. Differences in Daily Rhythms of Wrist Temperature Between Obese and Normal-Weight Women: Associations With Metabolic Syndrome Features. *Chronobiology International* 28, 5 (2011), 425–433. DOI: http://dx.doi.org/10.3109/07420528.2011.574766 arXiv:http://dx.doi.org/10.3109/07420528.2011.574766

[3] Jaimie N. Davis, Valerie A. Hodges, and M. Beth Gillham. 2006. Physical Activity Compliance: Differences between Overweight/Obese and Normal-Weight Adults. *Obesity* 14, 12 (2006), 2259–2265. DOI: http://dx.doi.org/10.1038/oby.2006.265

[4] H. Eriksson, K. Svardsudd, B. Larsson, L. Welin, L.O. Ohlson, and L. Wilhelmsen. 1985. Body temperature in general population samples. The study of men born in 1913 and 1923. *Acta Med. Scand.* 217, 4 (1985), 347–352.

[5] G. Frühbeck, H. Toplak, E. Woodward, V. Yumuk, M. Maislos, and J.M. Oppert. 2013. Obesity: The Gateway to Ill Health - an EASO Position Statement on a Rising Public Health, Clinical and Scientific Challenge in Europe. *Obes. Facts* 2 (2013).

[6] Carl V. Gisolfi and Francisco Mora. 2000. *The hot brain : survival, temperature, and the human body.* Cambridge, Massachusetts : The MIT Press, 2000.

[7] Daniela Grimaldi, Federica Provini, Giulia Pierangeli, Natalia Mazzella, Giovanni Zamboni, Giulio Marchesini, and Pietro Cortelli. 2015. Evidence of a diurnal thermogenic handicap in obesity. *Chronobiology International* 32, 2 (2015), 299–302. DOI: http://dx.doi.org/10.3109/07420528.2014.983603 arXiv:http://dx.doi.org/10.3109/07420528.2014.983603 PMID: 25414044.

[8] Marc J Heikens, Alexander M Gorbach, Henry S Eden, David M Savastano, Kong Y Chen, Monica C Skarulis, and Jack A Yanovski. 2011. Core body temperature in obesity. *The American Journal of Clinical Nutrition* 93, 5 (2011), 963–967. DOI: http://dx.doi.org/10.3945/ajcn.110.006270 arXiv:http://ajcn.nutrition.org/content/93/5/963.full.pdf+html

[9] Mindy E. Hoffmann, Sarah M. Rodriguez, Dinah M. Zeiss, Kelley N. Wachsberg, Robert F. Kushner, Lewis Landsberg, and Robert A. Linsenmeier. 2012. 24-h Core Temperature in Obese and Lean Men and Women. *Obesity* 20, 8 (2012), 1585–1590. DOI: http://dx.doi.org/10.1038/oby.2011.380

[10] John H. Holland. 2014. *Complexity: A Very Short Introduction.* Oxford University Press, Oxford, UK.

[11] L. Landsberg. 2012. Core temperature: a forgotten variable in energy expenditure and obesity? *Obesity Reviews* 13 (2012), 97–104. DOI: http://dx.doi.org/10.1111/j.1467-789X.2012.01040.x

[12] D.M. Savastano, A.M. Gorbach, Eden H.S., S.M. Brady, J.C. Reynolds, and J.A. Yanovski. 2009. Adiposity and human regional body temperature. *The American Journal of Clinical Nutrition* 90, 5 (2009), 1124–1131.

[13] J.C. Seidell. 1999. Obesity: a growing problem. *Acta Paediatr. Suppl.* 88, 428 (1999), 46–50.

[14] M. Torii, M. Yamasaki, T. Sasaki, and H. Nakayama. 1992. Fall in skin temperature of exercising man. *British Journal of Sports Medicine* 26, 1 (1992), 29–32.