ROBERT KOCH INSTITUT

Originally published as:

1   **RUNNING HEADING: SHORT COMMUNICATIONS**

2

3   **FULL TITLE:**

4   **NON-INVASIVE BODY TEMPERATURE MEASUREMENT OF WILD**

5   **CHIMPANZEES USING FAECAL TEMPERATURE DECLINE**

6

7   Siv Aina Jensen[1-3], Roger Mundry[1], Charles L. Nunn[1,4], Christophe Boesch[1] and Fabian H.

8   Leendertz[1,2]

9

10   *[1] Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany*

11   *[2] Robert Koch-Institut, Berlin, Germany*

12   *[3] Norwegian School of Veterinary Science, Oslo, Norway*

13   *[4] University of California, Berkeley, USA*

14

15   **CORRESPONDING AUTHOR:**

16   Siv Aina Jensen

17   Robert Koch-Institut, NG2; Emerging Zoonoses

18   Nordufer 20

19   13353 Berlin

20   Germany

21   Phone: +49 1888 754 2592

22   Fax: +49 1888 754 2605

23   E-mail: JensenS@rki.de

24

25

26   **ABSTRACT**

27   New methods are required to increase our understanding of pathological processes in wild

28   mammals. We developed a non-invasive field method to estimate the body temperature of

29   wild living chimpanzees habituated to humans, based on statistically fitting temperature

30   decline of faeces after defecation. The method was established using control measures of

31   human rectal temperature and subsequent changes in faeces temperature over time. The

32   method was then applied to temperature data collected from wild chimpanzee faeces. In

33   humans we found good correspondence between the temperature estimated by the method

34   and the actual rectal temperature that was measured (maximum deviation 0.22°C). The

35   method was successfully applied and the average estimated temperature of the chimpanzees

36   was 37.2°C. This simple-to-use field method reliably estimates the body temperature of

37   wild chimpanzees and probably also other large mammals.

38

39   Key-words: health monitoring; wild great apes; wild chimpanzees; body

40   temperature estimation; non-invasive method

41

42   Disease plays an important role in the demography of great apes, and health

43   monitoring is a vital part of the conservation of these endangered species (Leendertz et al.,

44   2006). In most cases, diagnosis of disease is restricted to observations of clinical signs and

45   laboratory analysis of samples collected non-invasively. The development of non-invasive

46   methods is therefore essential to improve health monitoring of wild great apes. Body

47   temperature can be measured non-invasively with infrared equipment, but such equipment

48   is expensive. Here we present a simple, inexpensive and reliable field method to estimate

49   the body temperature of wild chimpanzees non-invasively.

50   The study was conducted in the tropical rain forest of Taï National Park (5°15'-

51   6°07'N, 7°25'-7°54'W) in Côte d'Ivoire, where wild chimpanzees (*Pan troglodytes verus*)

52   have been habituated to human presence. First, the method was established by 29 control

53   measures performed on humans (one male and one female). Thereafter the method was

54   applied to 31 faecal samples collected from visually healthy chimpanzees (17 samples from

55   nine females; 14 samples from seven males).

56   For the human control measures, the rectal temperature was measured prior to

57   defecation using a commercially available digital thermometer. Thereafter the data were

58   obtained from both humans and chimpanzees in the same way and as follows. The exact

59   time of defecation was recorded and approximately 100 grams of the faeces was collected

60   from the ground as soon as practically possible and held in a gloved hand. Only well

61   formed faeces deposited on the ground were included in the study. The sensor of the

62   thermometer (a digital rectal thermometer or a digital thermometer [Data-Logger

63   thermometer 306]) was placed in the middle of the faeces and held as still as possible

64   during the measurements. The temperature was recorded approximately every 20 seconds

65   or two seconds, with shorter intervals possible using the data-logging thermometer, over a

66   period of at least six minutes. After the measurements were taken the glove was reversed,

67   closed, and weighed with a digital scale. The net weight of the faeces and the

68   environmental temperature were recorded.

69   Measured temperatures occasionally comprised outliers or unrealistic values, e.g.

70   temperatures rapidly decreasing and later increasing again. Such curves might arise when

71   the sensor opens a hole in the faecal sample, or when the sensor moves outside the sample.

72   To exclude such outliers and unrealistic values from analyses, we used the following

73   operational rule: A measure was excluded if a larger value occurred later in the sequence of

74   measurements (Figure 1).

75   We used a sigmoidal equation to express temperature decrease as a function of time

76   since defecation. The model we fitted was:

77

78                          $T_{(t)} = d + a*(1/(1+e^{(t-b)/c}))$

79

80   where T indicates temperature, t the time since defecation, and a, b, c, and d are coefficients

81   needed to describe the sigmoidal curve. More information on the equation, and a program

82   to   implement   this   method   is   freely   available   via   the   internet

83   (https://diseasegroup.eva.mpg.de/mediawiki-1.6.5/index.php/Defecation)   or   via   email

84   contact with the authors. To evaluate the procedure we compared observed values of rectal

85   temperature with those predicted by the method and related the differences to several

86   covariates. We used standard non-parametric procedures chosen according to the rationales

87   described in Siegel & Castellan (1988) for statistical testing. Tests and curve fits were

88   calculated using SPSS 13.0.1 or a computer program written by R.M. for Spearman's rank

89   correlation. When small samples required their use, we applied exact tests (Mundry &

90   Fischer, 1998; Siegel & Castellan, 1988). Approximate P-values were based on 10,000

91   permutations for calculating the significance of Spearman's rank correlation coefficients.

92   Using the sigmoidal model on the human control measures we found a clear

93   relationship between the temperature estimated and the actual rectal temperature that was

94   measured (Spearman's rank correlation: r_S=0.62, N=29, P<0.01; Figure 2). The average

95   (arithmetic mean) absolute deviation between estimates and actual rectal temperatures was

96   0.22°C (N=29). Fifteen of the estimates differed less than 0.12°C from the actual value,

97   whereas only three differed by more than 0.5°C from the rectal temperature. Estimated

98   temperatures did not obviously over- or underestimate rectal temperatures (Wilcoxon test:

99   T^+= 262, N=29, P=0.35). Temperature estimates were not influenced significantly by

100   sample weight (r_S=0.08, N=26, P=0.68) or environmental temperature (r_S=0.08, N=30, P=

101   0.70). Absolute deviations of the estimated temperature from the rectal temperature were

102   neither related to sample weight (r_S=-0.13, N=25, P=0.53) nor to environmental

103   temperature (r_S=0.27, N=29, P= 0.16). However, accuracy of temperature estimation in the

104   human samples decreased with increasing interval between defecation and beginning of

105   measurement (r_S=0.46, N=29, P=0.01; Figure 3). The measurements started on average

106   1.42 minutes (=mean; range 0.17 – 3.17) after defecation. Note that after the thermometer

107   was first placed into the faecal sample, the temperature usually increased for several

108   measurements. We took the point at which the temperature reached its maximum as the

109   beginning of measurement. Accuracy decreased with decreasing number of measures

110   obtained (r_S=-0.37, N=29, P=0.05), whereas total duration of measurement interval did not

111   obviously influence accuracy (r_S=0.06, N=29, P=0.75).

112   The estimated temperature of the chimpanzees ranged from 34.6 to 39.5°C

113   (excluding one value of 44.3°C, which was clearly outside physiological range). The

114   average temperature of 16 chimpanzees was 37.2°C (figure 4). We found no significant

115   difference in estimated body temperature between males and females (U=22, $N_{females}$=9,

116   N_{males}=7, P=0.35). For the females, the temperature generally increased during the day,

117   whereas this difference was not obvious in the males (Figure 5).

118   The weight of faecal samples did not differ significantly between chimpanzees

119   (median 97 grams; range: 40 – 172) and humans (median 99 grams; range: 23 – 156)

120   (Mann-Whitney U-test: U=352.5, $N_{chimpanzee\ samples}$=29, $N_{human\ samples}$=26, P=0.68). The

121   temperature measurements of chimpanzee samples started on average 0.58 minutes after

122   defecation (= median; range: 0.18 – 6.00).

123   In summary, our non-invasive method allows reliable estimation of the body

124   temperature of wild living chimpanzees. The method is easy to perform and requires no

125   expensive equipment, as only a commercially available digital thermometer is needed, in

126   addition to subsequent access to a computer. In the human control measurements half of the

127   body temperatures were estimated with an error of less than 0.12°C. To ensure the most

128   accurate results from this method, it is important to start the measurements as soon as

129   possible after defecation and to continue the measurement until the temperature curve

130   "flattens out." The requirement for fresh faecal samples means, however, that the method

131   is most applicable to human-habituated animals, such as the chimpanzees studied here.

132   The weight of the faeces did not influence the accuracy of the temperature

133   estimation. Only adult chimpanzees were included in this study, however, as their faeces

134   were most comparable in size to human faeces. The method has not yet been evaluated for

135   use in younger chimpanzees with relatively smaller faeces, or in other species.

136   Environmental temperature also did not obviously influence the accuracy of body

137   temperature estimates. Conditions could be somewhat different in other field sites with

138   different climatic conditions and habitats. If so, it would be useful to verify the correct

139   measurement technique by performing human control measurement in local conditions.

140   Normal human rectal temperature ranges from 34.4 to 37.8°C (Sund-Levander et al.,

141   2002), which shows that even for humans it is impossible to assign a single value as

142   "normal" body temperature. We should therefore expect a similar variation in normal body

143   temperature in wild great apes. Indeed, most of the body temperature estimates of the

144   chimpanzees in this study were within the range of normal human temperature, with an

145   average of 37.2°C. The very low end of the temperature estimate range could be explained

146   by poor measurement techniques, although they are within normal range in humans. Any

147   results could be retested if doubts emerge concerning the measurements. The estimated

148   temperature should be evaluated together with behavioural data, since stress or activities

149   such as hunting or fighting potentially produce a temporary increase in body temperature. It

150   might be useful to know the usual range for an individual when he or she is healthy, so that

151   a comparison can be made when illness occurs. We did not find any difference between the

152   temperature of males and females in this study, but the numbers of samples might have

153   been too low to detect a difference. Our study also showed that, at least for females, body

154   temperature tends to be lower in the morning than later during the day. More data are

155   required to confirm this pattern in wild primates.

156   When assessing the health status of individuals, veterinarians and field workers in

157   many areas of great ape research could use temperature data to complement behavioural

158   and reproductive data. Body temperature measurements can also be linked to the study of

159   self-medication (Huffman, 2003) – e.g. to help identify the fever-reducing effects of certain

160   plants – and more generally to increase our knowledge about sickness behaviour in

161   primates, as few detailed reports are available (Nunn & Altizer, 2006). Lastly, data on

162   body temperature can help to investigate disease outbreaks and, more generally, will

163   increase our understanding of the effects of disease and fever on wild chimpanzees and

164   other animals.

165   We thank the Ivorian authorities for long-term support, especially the Ministry of

166   Environment and Forests as well as the Ministry of Research, the directorship of the Taï

167   National Park, L'Office Ivoirienne des Parcs et Réserves, the Max Planck Society, and the

168   Swiss Research Centre in Abidjan. We also thank the field assistants of the Taï

169   Chimpanzee Project.

170

171   **LITERATURE CITED**

172   HUFFMAN, M. A. 2003. Animal self-medication and ethno-medicine: exploration and

173   exploitation of the medicinal properties of plants. Proceedings of Nutrition Society

174   62(2):371-81.

175

176   LEENDERTZ, F. H., PAULI, G., ELLERBROK, H., MAETZ-RENSING, K.,

177   BOARDMAN, W., JENSEN, S. A., JUNGLEN, S., AND C. BOESCH. 2006. Pathogens as

178   drivers of population declines: The importance of systematic monitoring in great apes and

179   other threatened mammals. Biological Conservation 131:325-337.

180

181   MUNDRY, R., AND J. FISCHER. 1998. Use of statistical programs for nonparametric

182   tests of small samples often leads to incorrect P-values: Examples from Animal Behaviour.

183   Animal Behaviour 56: 256 - 259.

184

185   NUNN, C. L., AND S. ALTIZER. 2006. Infectious Diseases in Primates. Oxford

186   University Press, Oxford, England, 384 pp.

187

188   SIEGEL, S., AND N. J. CASTELLAN. 1988. Nonparametric Statistics for the Behavioral

189   Sciences (2nd ed.). McGraw-Hill. New York.

190

191   SUND-LEVANDER, M., FORSBERG, C., AND L. K. WAHREN. 2002. Normal oral,

192   rectal, tympanic and axillary body temperature in adult men and women: a systematic

193   literature review. Scandinavian Journal of Caring Science 16: 122-128.

194

195

196

197

198

199

200

201

202

203

204

205

206

207

208 Fig.1. Temperature decrease of human feces samples over time. Indicated are measures

209 (diamonds) of two samples (left and right), rectal temperature (crosses at time zero) and the

210 temperature estimated using sigmoidal curve fitting (unfilled squares on the y-axis).

211 Unfilled diamonds depict measures that were excluded prior to curve fitting since they were
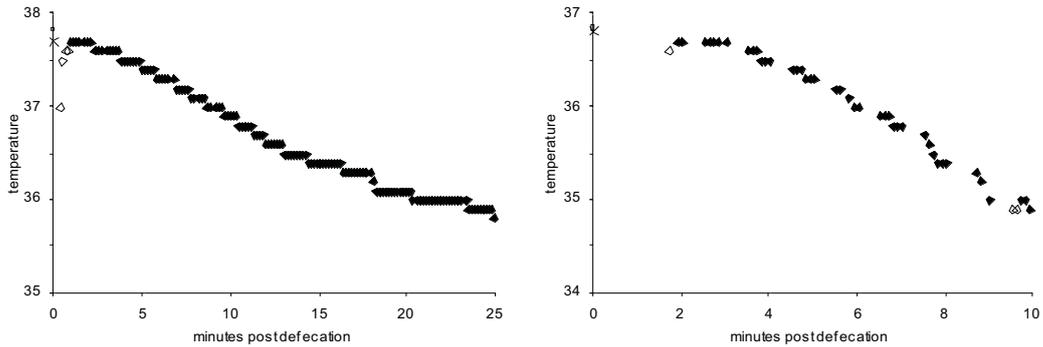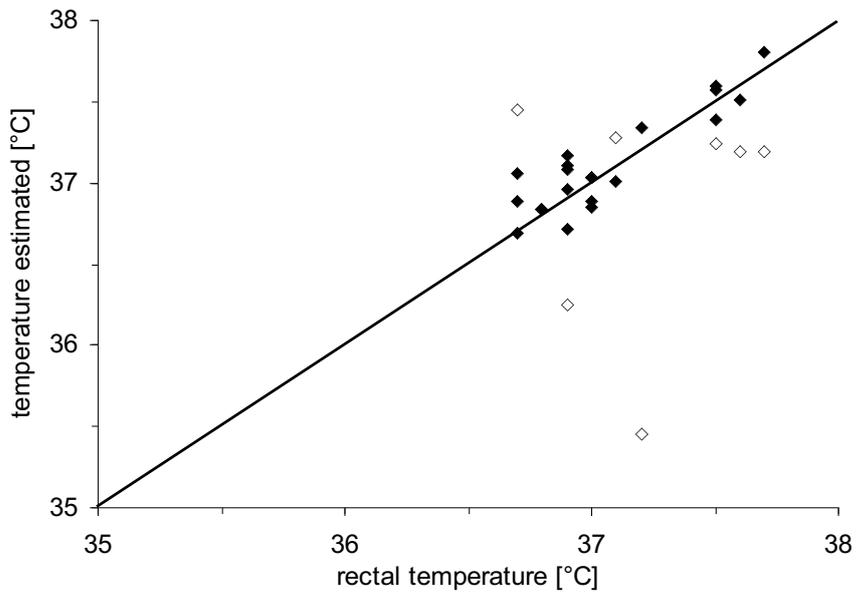
212 later followed by a larger measure (see text).

213

214

215

216

217

218

219

220

221

222

223

224   Fig.2. Relation between human rectal temperature and its estimation based on sigmoidal

225   curve fitting. White diamonds denote samples for which measurement began more than two

226   minutes after defecation. The diagonal line indicates the desired result (perfect fit).
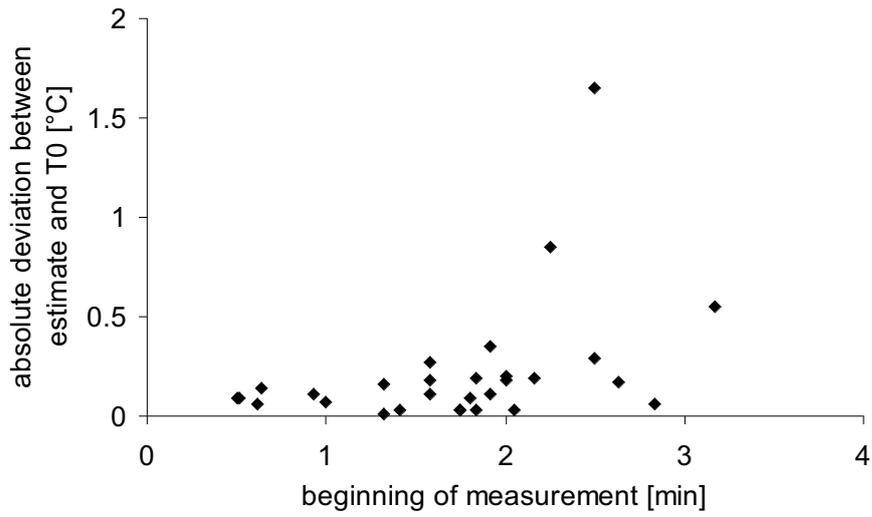
227

228

229

230

231

232

233

234

235

236

237

238

239 Fig.3. Relation between the absolute deviation of estimated human temperature from

240 measured rectal temperature and the beginning of measurement.

241

241
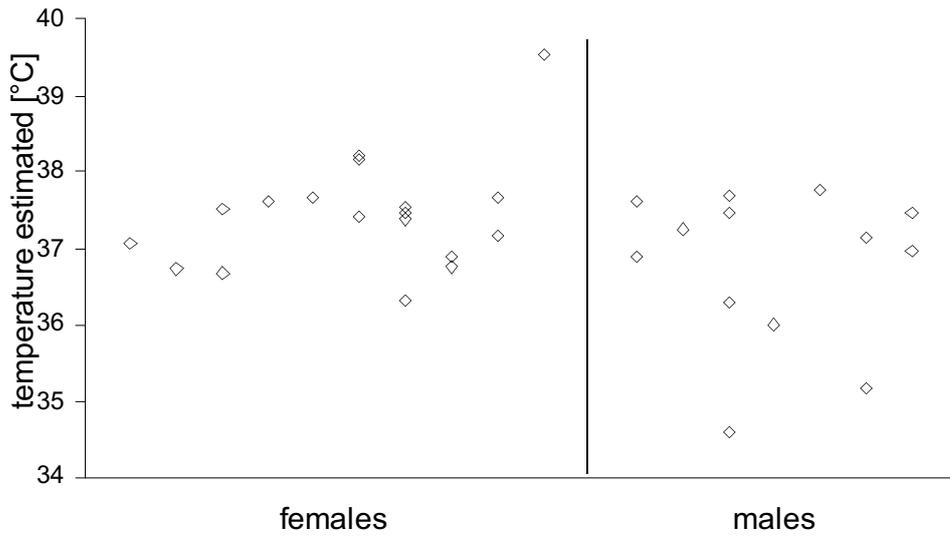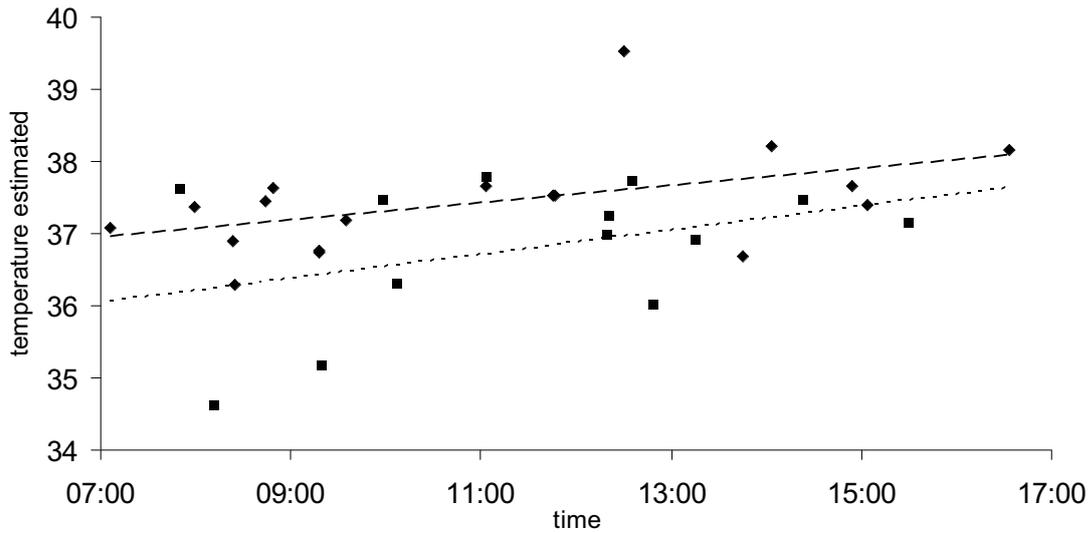
242

243

244

245

246

247

248

249

250

251

252 Fig.4. Temperature estimated for 17 chimpanzees. Values above one another are from the

253 same subject.

254

255

256

257

258

259

260

261

262

263 Fig. 5. Temperature of chimpanzees as estimated using the sigmoidal curve fitting approach

264 and their variation with defecation time. Indicated are temperatures for females (diamonds,

265 dashed line) and males (squares, dotted line). Lines were calculated using linear regression.

266 Subjects were pooled. Rank correlation coefficients (with data pooled across subjects):

267 Females: $r_S=0.53$, N=18, P=0.022; Males: $r_S=0.14$, N=13, P=0.64.