Supplementary Material

**Seasonal Variation in Physiology Challenges the Notion of Chimpanzees (*Pan troglodytes verus*) as a Forest-Adapted Species**

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# Model formulations

***1.1. Model Set 1 (Shifted season environmental response)***

**(1.1)** maximum temperature~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.2)** maximum relative humidity ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.3)** minimum temperature ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.4)** minimum relative humidity~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.5)** rainfall~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.6)** FAItotal~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.7)** FAIfruit ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.8)** FAIripe ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.9)** meanheat index ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.10)** meantemperature ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.11)** mean relative humidity ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.12)** relative humidity daily range ~ site\*(sine (Julian date) + cosine (Julian date)) + south

**(1.13)** temperature daily range~ site\*(sine (Julian date) + cosine (Julian date)) + south

***1.2 Model Set 2 (Shifted season endocrine response)***

**(2.1)** square-root (creatinine (mg/ml)) ~ site\*(sine (Julian date) + cosine (Julian date)) +south + rank + drinks day before + sample collection time + sex + random effects

**(2.2)** log (c-peptide (ng/mg creatinine)) ~ site\*(sine (Julian date) + cosine (Julian date)) +south + rank + party size \*method + sample collection time + sex + pregnant + random effects

**(2.3)** log (cortisol (ng/ml SG)) ~ site\*(sine (Julian date) + cosine (Julian date) + log (creatinine) + log (c-peptide)) +south + number in estrus + rank + sample collection time + sex + pregnant + random effects

***1.3 Model Set 3 (non-shifted cortisol model)***

**(3.1)** log (cortisol (ng/ml SG)) ~ site\*(sine (Julian date) + cosine (Julian date) + log (creatinine) + log (c-peptide)) +south + number in estrus + rank + sample collection time + sex + pregnant + random effects

***1.4 Model Set 4 (environmental predictor models)***

**(4.1)** square-root (creatinine (mg/ml)) ~ site\*(F1 + F2 + rainfall + monthly rainfall) + south + rank + drinks day before + sample collection time + sex + random effects

**(4.2)** log (c-peptide (ng/mg creatinine)) ~ site\*(total food + total fruit + ripe fruit + rainfall + monthly rainfall) +south + rank + party size\*method + sample collection time + sex + pregnant + random effects

**(4.3)** log (cortisol (ng/ml SG)) ~ site\*(F1 + F2 + rainfall + monthly rainfall + log (creatinine) + log (c-peptide)) +south + number in estrus + rank + sample collection time + sex + pregnant + random effects

***1.5 Model Set 5 (site-specific models)***

**(5.1: Fongoli)** log (c-peptide (ng/mg creatinine)) ~ total food + total fruit + ripe fruit + rainfall + monthly rainfall + rank + party size\*method + sample collection time + sex + random effects

**(5.2: Taï)** log (c-peptide (ng/mg creatinine)) ~ total food + total fruit + ripe fruit + rainfall + monthly rainfall +south + rank + party size + sample collection time + sex + pregnant + random effects

**(5.3: Fongoli)** log (cortisol (ng/ml SG)) ~ F1 + F2 + rainfall + monthly rainfall + log (creatinine) + log (c-peptide) + number in estrus + rank + sample collection time + sex + random effects

**(5.4: Taï)** log (cortisol (ng/ml SG)) ~ F1 + F2 + rainfall + monthly rainfall + log (creatinine) + log (c-peptide) +south + number in estrus + rank + sample collection time + sex + pregnant + random effects

# Supplementary Figures and Tables

## Supplementary Figures

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**Figure S1.** Inter-site differences in adjusted seasonal variation of environmental variables at Fongoli (red) and Taï (blue).

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**Figure S2.** Histograms of collection times for all samples collected for the study (n=589) from Fongoli (A) and Taï communities (B).

## Supplementary Tables

**Supplementary Table S1.** Summary statistics of environmental variables and physiological biomarkers from Fongoli and two Taï communities.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Fongoli** | **Taï East** | **Taï South** |
| **mean ± SD** | **range** | **mean ± SD** | **range** | **mean ± SD** | **range** |
| **Temperature (daily max)** | 37.7 ± 4.5 | 27.2 - 47.7 | 29.2 ± 2.3 | 23.6 - 36.0 | 27.6 ± 1.8 | 22.5 - 32.9 |
| **Temperature (daily min)** | 22.4 ± 4.4 | 11.2 - 30.3 | 25.8 ± 1.5 | 21.5 - 29.2 | 25.3 ± 1.3 | 21.8 - 30.2 |
| **Temperature (daily mean)** | 29.0 ± 3.5 | 21.7 - 35.9 | 22.4 ± 1.3 | 16.4 - 27.1 | 22.9 ± 1.1 | 18.6 - 28.2 |
| **Temperature (daily range)** | 15.3 ± 5.9 | 2.8 - 27.6 | 6.8 ± 2.0 | 1.2 - 14.3 | 4.8 ± 1.6 | 0.1 - 9.9 |
| **Relative humidity (daily max)** | 75.0 ± 18.4 | 34.0 - 97.6 | 90.5 ± 9.1 | 61 - 99 | 68.7 ± 4.3 | 42 - 79 |
| **Relative humidity (daily min)** | 34.0 ± 21.4 | 5.3 - 83.1 | 66.7 ± 15.2 | 28 - 95 | 53.2 ± 8.2 | 33 - 70 |
| **Relative humidity ( daily range)** | 41.0 ± 12.9 | 11 - 69.1 | 23.8 ± 10.5 | 1 - 54 | 15.4 ± 7.2 | 0 - 33 |
| **Relative humidity (daily mean)** | 55.9 ± 21.3 | 19.4 - 92.8 | 78.5 ± 11.4 | 50 - 97 | 61.0 ± 5.5 | 42 - 73.5 |
| **Factor 1 (F1)** | -0.30 ± 1.28 | -2.485 - 1.731 | 0.704 ± 0.727 | -1.577 - 1.979 | -0.400 ± 0.363 | -1.616 - 0.581 |
| **Factor 2 (F2)** | 1.09 ± 0.85 | -1.002 - 2.705 | -0.302 ± 0.523 | -2.410 - 1.230 | -0.707 ± 0.405 | -1.924 - 0.917 |
| **Heat Index (daily mean)** | 32.0 ± 4.0 | 22.5 - 39.4 | 27.1 ± 2.207 | 21.6 - 35.7 | 25.6 ± 1.8 | 21.3 - 35.1 |
| **Monthly rainfall** | 84.7 ± 125.1 | 0 - 304.0 | 141.0 ± 68.2 | 25.0 - 220.5 | 140.0 ± 73.7 | 22.0 - 249.0 |
| **FAItotal** | 15349 ± 2053 | 10501 - 21248 | 43813 ± 5710 | 33001 - 53190 | 31633 ± 3883 | 25236 - 38185 |
| **FAItotal fruit** | 5054 ± 853 | 3467 - 6733 | 4602 ± 1378 | 2693 - 7305 | 4161 ± 1227 | 2298 - 6626 |
| **FAIripe fruit** | 1894 ± 503 | 299 - 2966 | 399 ± 321 | 43 - 1077 | 319 ± 422 | 22 - 1510 |
| **specific gravity (SG)\*** | 1.022 ± 0.014 | 1.001 - 1.128 | 1.018 ± 0.013 | 1.001 - 1.054 | 1.018 ± 0.014  | 1.001 - 1.061 |
| **cortisol (ng/ml SG)\*** | 135.08 ± 202.38 | 0.001 - 2105.67 | 134.09 ± 211.96 | 0.28 - 1105.34 | 147.27 ± 201.013 | 0.01 - 1066.13 |
| **c-peptide (ng/ml SG)\*** | 7.31 ± 5.31 | 1 - 37.46 | 5.14 ± 10.39 | 0.33 - 83.37 | 3.86 ± 4.86 | 0.39 - 21.33 |
| **c-peptide (ng/mg creatinine)\*** | 6.298 ± 5.118 | 0.678 - 51.875 | 6.608 ± 8.434 | 0.135 - 69.429 | 5.115 ± 3.603 | 0.192 - 15.618 |
| **creatinine (mg/ml)\*** | 1.198 ± 0.766 | 0.012 - 4.628 | 1.309 ± 0.986 | 0.032 - 3.944 | 1.276 ± 0.961 | 0.016 - 3.988 |
| \*Physiological variables are controlled for season, sex, ID, and date.  |  |  |  |

**Supplementary** **Table S2.** Seasonal variation at Taï for 13 environmental variables and inter-site differences in adjusted seasonal variation.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   | **Taï South** |   | **Taï East** |  |  |   |  **Fongoli-Taï comparison** |
| **Term** | **F** | **DF** | **r2** | **p** | **F** | **DF** | **r2** | **p** | **F** | **DF** | **p** |
| Temperature (max) | 163.793 | (2, 375) | 0.463 | <0.001 |  56.785  | (2, 352) | 0.24 | <0.001 | 182.014 | (2, 1063) | <0.001 |
| Relative humidity (max) |  29.393 | (2, 373) | 0.132 | <0.001 | 244.095 | (2, 357) | 0.575 | <0.001 | 482.881 | (2, 1066) | <0.001 |
| Temperature (min) |  13.418 | (2, 368) | 0.063 | <0.001 |  19.162  | (2, 355) | 0.092 | <0.001 | 241.752 | (2, 1055) | <0.001 |
| Relative humidity (min) |  18.337 | (2, 375) | 0.084 | <0.001 | 179.866 | (2, 352) | 0.503 | <0.001 | 224.098 | (2, 1063) | <0.001 |
| Rainfall |  4.748 | (2, 391) | 0.019 | 0.009 | 4.694 | (2, 390) | 0.018 | 0.010 | 4.025 | (2, 1117) | 0.018 |
| FAItotal | 426.957 | (2, 391) | 0.684 | <0.001 | 584.261 | (2, 360) | 0.763 | <0.001 | 148.818 | (2, 1087) | <0.001 |
| FAItotal fruit | 232.370 | (2, 391) | 0.541 | <0.001 | 311.248 | (2, 360) | 0.632 | <0.001 | 14.061 | (2, 1087) | <0.001 |
| FAIripe fruit | 119.546 | (2, 391) | 0.376 | <0.001 | 228.246 | (2, 360) | 0.557 | <0.001 | 13.366 | (2, 1087) | <0.001 |
| Heat index (mean) |  61.220 | (2, 375) | 0.242 | <0.001 | 12.960 | (2, 356) | 0.063 | <0.001 | 75.764 | (2, 1067) | <0.001 |
| Temperature (mean) |  66.829 | (2, 368) | 0.262 | <0.001 | 28.364  | (2, 351) | 0.134 | <0.001 | 205.083 | (2, 1059) | <0.001 |
| Relative humidity (mean) |  19.056 | (2, 373) | 0.088 | <0.001 | 236.073 | (2, 352) | 0.57 | <0.001 | 552.682 | (2, 1061) | <0.001 |
| Relative humidity (daily range) | 23.156 | (2, 373) | 0.106 | <0.001 | 67.542  | (2, 352) | 0.273 | <0.001 | 18.255 | (2, 1061) | <0.001 |
| Temperature (daily range) | 166.447 | (2, 368) | 0.472 | <0.001 | 95.204  | (2, 351) | 0.348 | <0.001 | 459.892 | (2, 1055) | <0.001 |

**Supplementary** **Table S3.** Results of the Factor Analysis of the climatic variables. Loadings of the original environmental variables on the two resulting factors (largest absolute loading per covariate indicated in bold), the Eigenvalues of each factor and the percentage of the total variance explained by each factor.

|  |  |  |
| --- | --- | --- |
| **Environmental Variable** | **Factor 1** | **Factor 2** |
| Temperature (max) | -0.430 | **0.821** |
| Temperature (mean) | -0.290 | **0.902** |
| Heat Index (mean) | \* | **0.966** |
| Relative humidity (min) | **0.853** | -0.397 |
| Relative humidity (max) | **0.921** | \* |
| Relative humidity (mean) | **0.968** | -0.242 |
| **Eigenvalues** | 2.783 | 2.639 |
| **Cumulative Variance** | 0.464 | 0.904 |
| \*Value unreported if loading is < |0.100|. |  |

**Supplementary** **Table S4.** Model results of environmental predictors on urinary cortisol levels at (a) Fongoli and (b) Taï. Statistically significant results (p ≤ 0.05) appear in bold; sample sizes are 307 and 191, respectively.

|  |  |  |  |
| --- | --- | --- | --- |
| **(a) Fongoli** |  |  |  |
|  |  | **Estimate ± SE** | **LRT\*** | **Pr (Chi)** |
|  | (Intercept) | 4.081 ± 0.131 |  |  |
| *Test predictors* |  |  |  |
|  | **F1** | **-0.499 ± 0.08** | **32.845** | **<0.001** |
|  | F2 | 0.042 ± 0.054 | 0.603 | 0.438 |
|  | rainfall | 0.036 ± 0.058 | 0.392 | 0.531 |
|  | **monthly rainfall** | **0.179 ± 0.080** | **4.965** | **0.026** |
| *Control predictors* |  |  |  |
|  | creatinine‡‡ | 1.145 ± 0.092 | 42.010 | <0.001 |
|  | c-peptide‡‡ | -0.036 ± 0.086 | 0.169 | 0.681 |
|  | estrus‡‡ | 0.073 ± 0.058 | 1.388 | 0.239 |
|  | rank | -0.509 ± 0.295 | 2.620 | 0.105 |
|  | sample collection time‡‡ | 0.070 ± 0.051 | 1.917 | 0.166 |
|   | sex# | 0.332 ± 0.200 | 2.543 | 0.111 |
| **(b) Taï** |  |  |  |
|  | **Term** | **Estimate ± SE** | **LRT\*** | **Pr (Chi)** |
|  | (Intercept) | 3.453 ± 0.165 |  |  |
| *Test predictors* |  |  |  |
|  | F1 | 0.658 ± 0.417 | 0.658 | 0.417 |
|  | F2 | 3.823 ± 0.051 | 3.823 | 0.051 |
|  | rainfall | 0.109 ± 0.741 | 0.109 | 0.741 |
|  | **monthly rainfall** | **5.911 ± 0.015** | **5.911** | **0.015** |
| *Control predictors* |  |  |  |
|  | south community§ | 0.000 ± 0.162 | 0.000 | 0.999 |
|  | creatinine§§ | 1.716 ± 0.056 | 82.391 | < 0.001 |
|  | c-peptide§§ | -0.115 ± 0.063 | 3.146 | 0.076 |
|  | estrus§§ | 0.055 ± 0.054 | 0.970 | 0.325 |
|  | rank | 0.476 ± 0.333 | 1.808 | 0.179 |
|  | sample collection time§§ | -0.224 ± 0.056 | 11.851 | 0.001 |
|  | sex# | -0.453 ± 0.201 | 4.518 | 0.034 |
|   | pregnant¶ | 0.635 ± 0.213 | 7.539 | 0.006 |
| \*Degrees of Freedom is one for all three models.  |  |  |
| §,#,¶ Estimate refers to the comparison with the reference categories:  |
|  | § Not south community |  |  |  |
|  | # Female |  |  |  |
|  | ¶ Not pregnant |  |  |  |
| ‡‡z-transformed to a mean of 0 and a standard deviation of 1. Original means +- SD of the original variables: |
|  | estrus: 0.788 ± 0.906, creatinine: 1.213 ± 0.758, c-peptide: 7.406 ± 5.131, collection time: 7.9 ± 1.4. |
| §§z-transformed to a mean of 0 and a standard deviation of 1. Original means +- SD of the original variables: |
|  | estrus: 0.958 ± 1.600, creatinine: 1.219 ± 0.943, c-peptide: 6.508 ± 8.946, collection time: 10.2 ± 3.0. |

**Supplementary** **Table S5.** Model results of environmental predictors on urinary c-peptide levels at (a) Fongoli and (b) Taï. Statistically significant results (p ≤ 0.05) appear in bold; sample sizes are 259 and 172, respectively.

|  |  |  |  |
| --- | --- | --- | --- |
| **(a) Fongoli** |  |  |  |
|   | **Term** | **Estimate ± SE** | **LRT\*** | **Pr(Chi)** |
|  | (Intercept) |  1.32 ± 0.221 |  |  |
| *Test predictors* |  |  |  |
|  | **FAItotal\*\*** |  **0.237 ± 0.08** | **8.536** | **0.003** |
|  | FAItotal fruit\*\* |  0.111 ± 0.077 | 2.043 | 0.153 |
|  | FAIripe fruit\*\* | -0.121 ± 0.078 | 2.258 | 0.133 |
|  | rainfall |  0.063 ± 0.045 | 1.914 | 0.167 |
|  | monthly rainfall | -0.007 ± 0.056 | 0.016 | 0.900 |
| *Control predictors* |  |  |  |
|  | rank |  0.296 ± 0.244 | 1.390 | 0.238 |
|  | party size‡‡ |  0.284 ± 0.123 |  |  |
|  | Party size method|| |  0.443 ± 0.223 |  |  |
|  | sample collection time‡‡ |  0.025 ± 0.047 | 0.280 | 0.597 |
|  | sex# | -0.303 ± 0.164 | 3.075 | 0.079 |
|   | party size‡‡ : Method|| | -0.158 ± 0.190 | 0.690 | 0.406 |
| **(b) Taï** |  |  |  |
|  | **Term** | **Estimate ± SE** | **LRT\*** | **Pr(Chi)** |
|  | (Intercept) |  1.464 ± 0.245 |  |  |
| *Test predictors* |  |  |  |
|  | **FAItotal\*\*** | **-0.378 ± 0.175** | **4.577** | **0.032** |
|  | FAItotal fruit\*\* | -0.214 ± 0.128 | 2.722 | 0.099 |
|  | **FAIripe fruit\*\*** |  **0.271 ± 0.106** | **6.079** | **0.014** |
|  | rainfall |  0.003 ± 0.073 | 0.002 | 0.968 |
|  | monthly rainfall | -0.115 ± 0.098 | 1.357 | 0.244 |
| *Control predictors* |  |  |  |
|  | south community§ | -0.406 ± 0.304 | 1.775 | 0.183 |
|  | rank | -0.157 ± 0.424 | 0.134 | 0.715 |
|  | pregnant¶ |  1.150 ± 0.264 | 17.579 | 0.000 |
|  | party size§§ |  0.202 ± 0.067 | 8.667 | 0.003 |
|  | sample collection time§§ |  0.125 ± 0.070 | 2.714 | 0.100 |
|   | sex# | -0.400 ± 0.257 | 2.284 | 0.131 |
| \*Degrees of Freedom is one for all three models.  |  |  |
| §,#,¶,||Estimate refers to the comparison with the reference categories:  |
|  | § Not south community |  |  |  |
|  | # Female |  |  |  |
|  | ¶ Not pregnant |  |  |  |
|  | || Method: total individuals observed |  |  |
| \*\* Variable is centered per community. Original means per site can be found in table S1. |
| ‡‡z-transformed to a mean of 0 and a standard deviation of 1. Original means +- SD of the original variables: |
|  | party size: 12.925 ± 9.045, collection time: 7.9 ± 1.3. |
| §§z-transformed to a mean of 0 and a standard deviation of 1. Original means +- SD of the original variables: |
|  | party size: 7.320 ± 3.330, collection time: 10.2 ± 2.9. |