Methods and Results

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Figure 1. The comprehensive workflow of the experimental design aimed at identifying trade-offs in thermoregulation and their implications for survival. Laboratory thermal gradient experiments (A) were used to (1) measure the preferred body temperature (Tset) and (2) assess the correlation between surface temperatures (Tsurf) recorded with accelerometers and internal body temperatures, enabling the prediction of body temperatures in the field (Tb,predict). Seasonal thermoregulation and field performance metrics were evaluated using accelerometers (B). Copper pipes were placed in various microhabitats to characterise the thermal environment (Te) available to lizards in the field (C). Metrics (D) derived from experiments were then used as covariates to understand their impact on survival during the spring season, a period of high predation pressure for this species (E). ![](data:application/pdf;base64,) Figure 2. Mean environmental temperature (Te), thermal preference (Tset), and predicted body temperature (Tb,predict) for male (A) and female (B) Pogona vitticeps during each season. Accuracy of thermoregulation (db) between sex, where low values indicate body temperature was closer to thermal preference (C). The thermal quality of habitat (de), measured with copper models, accounted for sex differences in thermal preference (D). Low de values indicate more environmental temperatures fell within Tset (i.e. favourable thermal environment). Error bars for all panels are ±1 standard error of the mean. In all panels, males are denoted with open circles and dashed lines, and females are denoted with closed grey circles and solid lines. The asterisk symbol indicates a significant difference (P<0.01) when comparing mean differences between sexes for that season using a Tukey-Kramer post-hoc test ![](data:application/pdf;base64,) Figure 3. Effectiveness of thermoregulation (E index) by sex and season in Pogona vitticeps. Values represent the means accounting for all individuals for each season. Error bars indicate ±1 standard error of the mean. The asterisk symbol denotes a significant difference (P<0.01) between sexes when comparing mean differences for that season using a Tukey-Kramer post-hoc test.  
 ![](data:application/pdf;base64,) Figure 4. Predicted body temperatures (lines with circles) and activity levels (lines with triangles) for male (A) and female (B) Pogona vitticeps by time of day. The dashed line represents their preferred body temperature ranges. Coloured circles indicate mean environmental temperatures for different habitat types, measured using copper models.  
 ![](data:application/pdf;base64,) Figure 5. Thermal performance curves of free-ranging Pogona vitticeps across different seasons and sex. The data were obtained from the top-performing Generalized Additive Mixed Models (GAMM) presented in Table S5. Each data point represents the average performance (95th percentile of acceleration) at a given temperature for all individuals in each season and sex. Females are represented by triangles and grey fitted lines, while males are represented by open circles and black fitted lines. Light grey bands around lines indicate the 95% confidence interval of the model fit ![](data:application/pdf;base64,) Figure 6. Survivorship as a function of the maximum performance (Pmax) for free-ranging Pogona vitticeps. Data are extracted from the top candidate model in program Mark (Table S8).

# Supplement Tables & Figures

Table S1. Microhabitat categories of sun exposure. At each micro-habitat category, copper pipes were placed at each cardinal direction. Sun% was calculated using a spherical densiometer. Table S2. ANOVA table for predicted body temperature (Tb Predict), accuracy of thermoregulation (db), thermal quality of habitat (de), and effectiveness of thermoregulation (E) for Pogona vitticeps. Each estimate is compared across the season, sex, and interaction. Individual lizard (or copper model ID) was treated as a repeated (random) variable. Bold values indicate significant differences.

| Model Name | Effects | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Tb Predict | Sex | 9.80 | 9.80 | 1 | 37 | 0.70 | 0.41 |
| **Season** | **743,844.79** | **247,948.26** | **3** | **24,044** | **17,810.07** | **<0.01** |
| **Season x Sex** | **1,814.79** | **604.93** | **3** | **24,044** | **43.45** | **<0.01** |
| db | Sex | 5.66 | 5.66 | 1 | 33 | 0.73 | 0.4 |
| **Season** | **201,042.09** | **67,014.03** | **3** | **8,233** | **8,670.41** | **<0.01** |
| **Season x Sex** | **816.86** | **272.29** | **3** | **8,233** | **35.23** | **<0.01** |
| de | **Sex** | **14.05** | **14.05** | **1** | **304** | **12.65** | **<0.01** |
| **Season** | **1,983.80** | **661.27** | **3** | **307** | **595.59** | **<0.01** |
| **Season x Sex** | **12.36** | **4.12** | **3** | **304** | **3.71** | **0.01** |
| E | Sex | 0.46 | 0.46 | 1 | 83 | 4.10 | 0.05 |
| **Season** | **2.14** | **0.71** | **3** | **83** | **6.34** | **<0.01** |
| **Season x Sex** | **1.69** | **0.56** | **3** | **83** | **4.99** | **<0.01** |

Table S3. Tukey-Kramer multiple comparisons from Tb predict model (Table 2). Contrasts were extracted from overall seasonal effect.

Table S4. Tukey-Kramer multiple comparisons of overall seasonal activity rate (min/hr). Activity rate was log (x+1) scale for all *P. vitticeps*.

| contrast | estimate | SE | df | t.ratio | p.value |
| --- | --- | --- | --- | --- | --- |
| Spring - Summer | -0.28 | 0.15 | 92 | -1.86 | 0.25 |
| Spring - Autumn | 0.12 | 0.20 | 83 | 0.61 | 0.93 |
| **Spring - Winter** | **0.80** | **0.21** | **83** | **3.89** | **<0.01** |
| Summer - Autumn | 0.40 | 0.20 | 82 | 2.03 | 0.19 |
| **Summer - Winter** | **1.08** | **0.21** | **82** | **5.23** | **<0.01** |
| **Autumn - Winter** | **0.68** | **0.23** | **69** | **3.01** | **0.02** |

Table S5. General additive mixed-models for investigating how performance curves varied across season, sex and their interactions for *Pogona vitticeps*. a) accounted for all individuals in study, b) accounted for smooth per individual, c) accounted for sex as a fixed factor, d) accounted for sex as a fixed factor and allowed for smooth per individual, e) accounted for season as a fixed factor, f) accounted for season as a fixed factor and allowed for smooth per individual, g) accounted for season and sex as a fixed factor, h) accounted for season and sex as a fixed factor and allowed for smooth per individual, i) accounted for season, sex, and their interaction as a fixed factor, and j) accounted for season, sex, and their interaction as a fixed factor and allowed for smooth per individual. Models b:j accounted for random intercept for individual lizard.

| Model.id | Model | Residual.DF | Residual.Deviance | DF | AIC | Delt\_AIC | Dev.Expl... |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **j** | **Season + Sex + Season\*Sex + s(Temprature, by = id) + (1|id)** | **2756.35** | **262.57** | **277.61** | **1688.84** | **0** | **70.57** |
| h | Season + Sex + s(Temprature, by = id) + (1|id) | 2760.13 | 264.88 | 273.83 | 1707.66 | 18.82 | 70.31 |
| f | Season + s(Temprature, by = id) + (1|id) | 2760.12 | 264.93 | 273.84 | 1707.87 | 19.03 | 70.3 |
| e | Season s(Temperature) + (1|id) | 2967.9 | 299.67 | 66.06 | 1724.75 | 35.91 | 66.41 |
| d | Sex + s(Temprature, by = id) + (1|id) | 2766.84 | 270.68 | 267.12 | 1760.11 | 71.27 | 69.66 |
| b | s(Temprature) + (1|id) | 2766.56 | 270.73 | 267.4 | 1760.93 | 72.09 | 69.65 |
| i | Season + Sex + Season\*Sex + s(Temprature) + (1|id) | 2989.09 | 315.19 | 44.87 | 1840.57 | 151.73 | 64.67 |
| g | Season + Sex + s(Temperature) + (1|id) | 2992.13 | 317.28 | 41.84 | 1854.36 | 165.52 | 64.43 |
| c | Sex + s(Temprature) + (1|id) | 2986.68 | 319.93 | 47.28 | 1888.45 | 199.61 | 64.14 |
| a | s(Temprature) | 3033.96 | 358.89 | 8.96 | 2152.09 | 463.25 | 59.77 |

Table S6. Tukey-Kramer multiple comparisons from Pmax model that accounted for season, sex and the interaction. Contrasts were extracted from seasonal effect.

| Contrast | Estimate | SE | df | t Ratio | p value |
| --- | --- | --- | --- | --- | --- |
| Autumn - Spring | -0.01 | 0.01 | 45 | -1.3 | 0.57 |
| Autumn - Summer | 0.07 | 0.01 | 45 | 13.4 | <0.01 |
| Autumn - Winter | 0.10 | 0.01 | 45 | 18.6 | <0.01 |
| Spring - Summer | 0.08 | 0.00 | 45 | 15.1 | <0.01 |
| Spring - Winter | 0.11 | 0.01 | 45 | 18.4 | <0.01 |
| Summer - Winter | 0.03 | 0.01 | 45 | 6.1 | <0.01 |

Table S7. Tukey-Kramer multiple comparisons from Topt model that accounted for season, sex and the interaction.

| Contrast | Season | Estimate | SE | df | t Ratio | p value |
| --- | --- | --- | --- | --- | --- | --- |
| ZWf - ZZm | Autumn | 0.76 | 1.1 | 41 | 0.71 | 0.48 |
| ZWf - ZZm | Spring | 0.10 | 1.1 | 40 | 0.10 | 0.92 |
| ZWf - ZZm | Summer | 0.56 | 1.1 | 39 | 0.53 | 0.60 |
| ZWf - ZZm | Winter | 0.63 | 1.1 | 42 | 0.59 | 0.56 |

Table S8. Model comparisons of spring survival probability (φ) for *Pogona vitticeps*, depending on sex, movement (mins), accuracy of thermoregulation (de), effectiveness of thermoregulation (E), and maximum performance (Pmax). Sex interactions for d\_b and E were accounted for because of the differences between males and females during the spring (Table 1). Values within the brackets are nested variables and variables outside of brackets are covariates. Bold values indicate values were considered to have support (ΔAICc of < 2.0).

| Model | AICc | Delta AICc | AICc Weights | Model Likelihood | Number of Parameters | Deviance |
| --- | --- | --- | --- | --- | --- | --- |
| **φ(Sex) Eindex** | **33.42** | **0** | **0.42** | **1** | **2** | **28.92** |
| **φ(.)** | **34.98** | **1.56** | **0.19** | **0.46** | **1** | **32.82** |
| **φ(Sex)** | **35.51** | **1.9** | **0.16** | **0.39** | **2** | **30.81** |
| φ(Activity - mins) | 35.98 | 2.67 | 0.12 | 0.28 | 1 | 33.82 |
| φ(Pmax) | 36.52 | 3.11 | 0.09 | 0.21 | 1 | 34.36 |
| φ(Sex) db | 39.98 | 6.56 | 0.02 | 0.04 | 2 | 35.48 |

Figure S1.

## [1] 5

## [1] 21

Figure S2. Environmental temperature range and how adult *Pogona vitticeps* thermoregulated during the duration of the study. Black solid lines represent the grand mean environmental temperatures of operative models (Te) for each day and grey bands represent the daily mean minimum and maximum of Te. Coloured lines represent the daily grand mean (green), mean minimum (blue), and mean maximum (red) predicted body temperatures Tb Predict for all lizards during the study.