Growth rate and thermoregulation in reared
king quails (*Coturnix chinensis*)

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**Abstract**

Growth rate was investigated in king quails between 1st and 60th day of life. Gompertz growth constants were 0.075 in males and 0.056 in females. Colonic temperature (*Tb*) was measured in quails divided into four age groups (1–3, 7–10, 16–19, and 44–59 days old) in ambient temperatures set separately for each group. Metabolic rate was measured only in 44–59-day-old birds. The mean value of the thermoneutral body temperature (*Tb* at TNZ) in the active phase in the youngest quails was 39.0 ± 0.8°C. In 44–59-day-old quails, the resting metabolic rate in the thermoneutral zone (RMR at TNZ) was on average 9.44 mW g⁻¹ (1.66 cm³ O₂ g⁻¹ h⁻¹), without sex-specific differences. No such differences were found in this age group neither in *Tb* at TNZ, nor in minimal thermal conductance (*Cmin*). However, differences were found in the rate of metabolic heat production below the thermoneutral zone, even when mass-independent units were used. The maximum metabolic rate (*Mmax*) in 2-month-old males was 34.08 mW g⁻¹ (5.98 cm³ O₂ g⁻¹ h⁻¹), while in females 29.73 mW g⁻¹ (5.21 cm³ O₂ g⁻¹ h⁻¹). Heat-stressed 44–59-day-old quails elevated their *Tb* to as much as an average 44.1 ± 0.8°C. The obtained growth model and a gradual development of the body temperature regulation mechanism in king quails followed the known strategy of development, typical for precocial birds. The sexual size dimorphism in the studied quails did not result in differences in thermoregulation parameters between the sexes, except for the rate of metabolic rate below thermoneutral zone.

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**Keywords:** King quail; *Coturnix chinensis*; Gompertz growth constant; Size dimorphism; Body temperature; Metabolic rate; Heat production; Thermal conductance

1. **Introduction**

Among the many known differences between precocial and altricial birds, the most important are those pertaining to the development of autonomic and behavioural mechanisms for body temperature and heat production regulation. In general, the onset of endothermy in the post-hatching period occurs earlier in precocial birds than that in the altricial species and the rate of growth is slower in the former (Ricklefs et al., 1994; Dietz and Ricklefs, 1997). In newly hatched gallinaceous chicks, behavioural thermoregulation is always well developed (Modrey and Nichelmann, 1992; Tzschentke and Nichelmann, 1999). Nichelmann and Tzschentke (2002) suggest that the ontogeny of thermoregulation in precocial birds is characterised by three phases: the prenatal phase, the early postnatal phase and the phase of full-blown homeothermy. This last phase begins at about 10th day of life of the chicks and it is marked by an activation order of thermoregulatory control elements (Nichelmann and Tzschentke, 2002). Most of the newly hatched precocial chicks have a much lower body temperature, measured in the thermoneutral zone than adults, as shown, e.g. in the chicks of the grey partridge *Perdix perdix* (Marjoniemi et al., 1995; Pis, 2001), chukar *Alectoris chukar* (Pis, 2003), capercaillie *Tetrao urogallus* (Hissa et al., 1983; Pis, 2002), and turkey *Meleagris gallopavo* (Modrey and Nichelmann, 1992).

King quail, also called Chinese painted quail (*Coturnix chinensis*), is a species occurring naturally in southeast Asia and the Indian subcontinent. In Australia, its range is limited.
to the mesic coastal zone of the eastern part of the continent and to the coast of the Northern Territories (Pearson, 1994). Apart from Japanese quail (*Coturnix coturnix japonica*), it is the most commonly reared quail species and in Europe is relatively easily obtainable from commercial suppliers. Till present, the species has not been subject to selective breeding (Pearson et al., 1998). Even though the species is present, the species has not been subject to selective breeding (Pearson et al., 1998). Apart from Japanese quail (*Coturnix coturnix japonica*), body temperature and energy turnover (Bernstein, 1973; Pearson, 1994), metabolic rates in adult birds during brooding (Pearson, 1994), heart rate development (Pearson et al., 1998), body temperature and energy turnover (Prinzinger et al., 1993), and the water economy and water turnover (Bernstein, 1971a,b; Roberts and Baudinette, 1986). The king quail is one of the smallest precocial birds, at 3 g among the smallest precocial hatchlings (Bernstein, 1973). Despite this fact, only one paper (Bernstein, 1973) dealing with the growth rate of this species has been published. Moreover, the amount of information about the effects of its well-pronounced sexual size dimorphism on its bioenergetic parameters is practically next to nothing. For other Galliformes, such reports are available, e.g. for capercaillie (Rintamäki et al., 1984), Japanese quail, turkey and guinea fowl *Numida meleagris* (Dietz and Drent, 1997).

The main objectives of this study were to investigate:

- growth rate in king quails from hatching till they reach the body mass of adults;
- body temperature development in chicks from hatching till the third week of life in active phase (α) [according to Bernstein (1973), during first 2 weeks of life, the king quail chicks are not fully homeothermic];
- body temperature, metabolic rate and thermal conductance in 2-month-old quails, exposed to a wide range of ambient temperatures; and
- intersexual differences in the thermoregulation, if any, in this species.

2. Materials and methods

Investigations were carried out on king quail chicks (*Coturnix chinensis* Linnaeus, 1766; formerly *Excalfactoria*) from May to August 2001, in the breeding facility of the Institute of Environmental Sciences, Jagiellonian University, Kraków, Poland. In total, measurements involved 12 chicks, the offspring of three adult pairs. The adult birds were of a coloured variety, similar to a wild pattern and to two other colour varieties: white and cinnamon. The chicks hatched after 18 days of incubation. Measurements involved only chicks in good health and active. The chicks were kept in an open plastic cage under heating lamps. The temperature immediately below the heating lamps was approximately 42 °C while in places not immediately affected by heat radiation, temperature was approximately 35 °C. In the breeding room, the ambient temperature was between 25 and 27 °C, and the relative humidity was between 65% and 70%. When the birds started to avoid direct presence under the lamps (approximately in the second week of life), the heating lamps were gradually withdrawn. From the second week of life, the young birds were placed in two separate cages with mesh roof-shields. The photoperiod in the breeding room was maintained by fluorescent lamps set at 16 h of light (04.00–20.00 GMT). The chicks were initially fed only animal food (chopped tubeworms and meal worms larvae) and a standard IB I chicken feed (protein content 26.5%). After less than 1 week, a commercial MEGAN mix for pet budgerigars (composition: Laplata millet, white millet, Japanese millet, sorghum, canary seed, hemp, oat), poppy seed, apple, chopped clover and yarrow, cottage cheese and hard boil whites of hen eggs chopped with shells were added to the diet. The birds were given permanent access to fresh water.

Colonic body temperature ($T_c$) was measured in four post-hatching age groups of quails: 1–3, 7–10, 16–19, and 44–59 days old (also referred to as 2-month-old quails) in various ranges of ambient temperatures ($T_a$). In the group of 44–59-day-old birds, the metabolic rate (oxygen consumption rate) was also measured. The ranges of temperatures were set separately for each age group of chicks: from 23.4 to 42.1 °C for 1–3–day-old chicks (in three series: 23.8, 31.5 and 40.4 °C, on average), from 14.8 to 42.5 °C for 7–10–day-old chicks (in three series: 19.8, 24.8 and 39.6 °C, on average), from 12.0 to 33.4 °C for 16–19–day-old chicks (in four series: 13.4, 19.3, 24.4 and 33.0 °C, on average), and from −3.4 to 45.1 °C for 44–59–day-old birds (in 13 series: in most cases the measurements were taken in ca. 5 °C intervals). Prior to each measurement of the colonic temperatures and metabolic rate, the birds were weighed with accuracy to the nearest 0.01 g (electronic balance Precisa 1600C, Switzerland). The body masses were also determined in the intervals between the metabolic rate measurements and the body temperature measurements.

The quails allocated to experiments were placed in plastic chambers matching the size of the birds (i.e. of capacities ranging from 0.6 to 1.2 l), which were then placed in a climatic chamber with the temperature stabilised. The temperature in a chamber with an experimental bird inside was measured with accuracy to the nearest 0.1 °C (digital thermometer Elmetron PT-217, Poland) and the readings were taken at the end of each measurement. Air flow was forced through the chamber with birds at a constant flow rate (from 20.0 to 60.0 l/h) depending on ambient temperature and the size of the bird. At the outlet of the chamber, the flow rate was determined using a mass flowmeter β-ERG (Poland). The colonic temperature was taken at depths from 5 mm (in the youngest chicks) to 10 mm in the oldest birds, with accuracy to the nearest 0.1 °C (thermistor
thermometer THERM 2244-1 with probe of 2 mm in diameter, AHLBORN Mess- und Regelungstechnik, Germany), after at least a 40-min exposure in a given ambient temperature. For each ambient temperature, the chicks were subject to measurements only once a day. The measurements were conducted between 09.00 and 15.00 GMT. The oxygen consumption rate in 44–59-day-old quails was measured with a flow respirometer MAGNOS 6G (HARTMANN & BRAUN, Germany) equipped with a paramagnetic oxygen analyser and plugged into a laptop computer. Incurrent air coursed through column of calcium chloride (CaCl₂) to absorb water before passing through the analyser. Carbon dioxide (CO₂) was not absorbed prior to a gas analysis to minimize error in the conversion of oxygen consumption to energy expenditure (Koteja, 1996). The rate of oxygen consumption was calculated using the equation of Koteja (1996) and then expressed in mW g⁻¹ of oxygen consumption was calculated using the equation of King (1974):

\[
\text{O}_2 \text{ consumption rate (cm}^3 \text{ O}_2 \text{ g}^{-1} \text{ min}^{-1}) = \frac{C_0}{C_0} \times \text{mW g}^{-1} \text{ h}^{-1}
\]

44–59-day-old birds was calculated according to Calder and King (1974):

\[
\text{The maximum metabolic rate (Mmax)} = \frac{\text{RMR at TNZ}}{\text{W}} \text{ h}^{-1} \text{ or mW g}^{-1}
\]

and wet (Cₜ₈: uncorrected for evaporative heat loss) thermal conductance (Schleucher and Withers, 2001). The lower critical temperature (Tₜ₈) (Tₜ₈=Tₚ−RMR/C, is the ambient temperature below which the maintenance of constant body temperature requires thermoregulatory heat production) was calculated according to Calder and King (1974).

Results were expressed as means±S.D. The number of measurements are denoted as n and a number of individuals in which measurements were taken as N. The values of Tₚ at TNZ in various groups of quails were compared with a non-parametric Kruskall–Wallis test. The t-test for independent groups was used for comparisons between the body masses and growth parameters as well as the values of Tₚ, RMR and Cₘᵢₙ between sexes. The relationships between the body temperature and metabolic rate for quails from various age groups, and ambient temperature were described by equations of linear or polynomial regression, depending on computed values of R² and significance of regression parameters. Differences between linear regression were tested by analysis of covariance (ANCOVA). Gompertz growth curves were fitted through the individual body masses with the non-linear model, according to the formula:

\[
W(t)=A \exp[-\exp\{-k(t-t_i)\}]
\]

where W(t) is body mass (g) at age t (days), A is asymptotic body mass (g), k is Gompertz growth constant (days⁻¹), and tᵢ is the age at the inflection point (days).

3. Results

3.1. Body mass

The average mass of eggs laid by quails was 5.33±0.458 g (N=30). Newly hatched chicks weighed an average of 3.48 g, doubling the weight in the second week to reach more than 20 g after another week of life (Table 1; Fig. 1). From the 22nd day of life, sexing birds was possible. At this age, young male chicks attained an average body mass of 27.58 g and a young female 30.34 g (Fig. 1), and these two values did not differ significantly (tₛ=1.812; P=0.108). The 59-day-old birds reached the body mass of adult quails but at that age, the males (weighing 46.99 g on average) were significantly lighter than females whose average weight was

<p>| Table 1 |
| Thermoneutral body temperatures (Tₚ at TNZ) and body masses in king quail chicks from the 1st to 19th day of life |</p>
<table>
<thead>
<tr>
<th>Age group (days)</th>
<th>N</th>
<th>Body mass (g)</th>
<th>Tₚ at TNZ (°C)</th>
<th>Tₚ (°C)</th>
<th>Predicted values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–3</td>
<td>12</td>
<td>3.48±0.343</td>
<td>39.0±0.71</td>
<td>40.4</td>
<td>41.5</td>
</tr>
<tr>
<td>7–10</td>
<td>10</td>
<td>8.51±1.011</td>
<td>41.1±0.40</td>
<td>39.6</td>
<td>41.4</td>
</tr>
<tr>
<td>16–19</td>
<td>8</td>
<td>21.14±1.438</td>
<td>41.2±0.27</td>
<td>33.0</td>
<td>41.2</td>
</tr>
</tbody>
</table>

Results are expressed as means±S.D. Ambient temperatures (Tₚ) in which Tₚ at TNZ measurements were measured and predicted values of Tₚ calculated for non-passerine birds are given.

* Prinzing et al. (1991): Tₚ=(41.7±1.03)W⁻⁰.₀₀₃₆; W in g.
61.51 g ($t_s=-4.943; P<0.001$) $(\text{Fig. 1})$. Also different were the growth rates of the sexes. The Gompertz growth curve attained a higher value in males than in females ($t=3.266, P<0.05$), whereas the asymptotic body mass was greater in females than in males ($t_s=-3.789, P<0.01$) $(\text{Fig. 1})$.

3.2. Body temperature

The values of $T_b$ at TNZ in chicks changed with age (Kruskall–Wallis test, $H=36.829; P<0.001$). The lowest value of $T_b$ at TNZ occurred in 1–3-day-old chicks (39.0 °C) whereas the highest was noted in 2-month-old birds (42.2 °C) $(\text{Tables 1 and 2}; \text{Figs. 2 and 3})$. The 7–10- and 16–19-day-old birds had their $T_b$ at TNZ fairly close to each other (41.1 and 41.2 °C, respectively) and to predicted values $(\text{Table 1}; \text{Fig. 2})$. Lowering the ambient temperature caused a drop in body temperatures in 1–3-, 7–10- and 16–19-day-old chicks, and these relationships were linear and showed a difference in their slopes ($F_{2,83}=33.807; P<0.001$) $(\text{Fig. 2})$. In 2-month-old birds, this relationship (in a much broader range of $T_a$ compared with younger age classes) is described well by a polynomial function $(\text{Fig. 3})$. In this age group, no intersexual differences were found in the values of $T_b$ at TNZ ($t=1.094; P=0.306$). Again, no intersexual differences were found either in the lowest ($T_a=0.7 \pm 0.110; P=0.916$) and the highest ($T_a=44.8 \pm 0.326$) $T_a$.

| References               | Body mass (g) | RMR at TNZ (cm$^3$ O$_2$ h$^{-1}$ g$^{-1}$) | $M_{\text{max}}$ (cm$^3$ O$_2$ h$^{-1}$ g$^{-1}$) | $M_{\text{max}}$/RMR | $T_b$ at TNZ °C | $T_{lc}$ °C | $C_{\text{min}}$ (cm$^3$ O$_2$ h$^{-1}$ g$^{-1}$ °C$^{-1}$)
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>51.7±6.91</td>
<td>1.66±0.195</td>
<td>5.98±0.326</td>
<td>3.6</td>
<td>42.2±0.32</td>
<td>29.6</td>
<td>0.131±0.0096</td>
</tr>
<tr>
<td></td>
<td>46.8±2.88</td>
<td>(N=6; males)</td>
<td>(N=6; males only)</td>
<td>(N=9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>59.2±2.50</td>
<td>(N=4; females)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted value</td>
<td>–</td>
<td>1.73*</td>
<td>11.53*</td>
<td>6.7*</td>
<td>41.1±1.03*</td>
<td>27.4*</td>
<td>0.140*</td>
</tr>
<tr>
<td>Roberts and Baudinette,</td>
<td>44.9</td>
<td>1.47</td>
<td>5.20*</td>
<td>3.5</td>
<td>41.7</td>
<td>28.0</td>
<td>0.119</td>
</tr>
<tr>
<td>1986</td>
<td>47.2 males, 62.7 females</td>
<td>2.50*</td>
<td>7.00*</td>
<td>2.8</td>
<td>39.0</td>
<td>29.0</td>
<td>0.131</td>
</tr>
<tr>
<td>Hinds et al., 1993</td>
<td>42.7</td>
<td>1.71</td>
<td>9.13</td>
<td>5.3</td>
<td>40.5</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Pearson, 1994</td>
<td>44.5 males, 50.2 females</td>
<td>1.62</td>
<td>–</td>
<td>–</td>
<td>41.6</td>
<td>28.0</td>
<td>0.163</td>
</tr>
</tbody>
</table>

The predicted values for these parameters are also supplied along with data derived from the literature for this species. Source of prediction equations:

- Aschoff and Pohl (1970): $M=91.0W^{0.729}$ (kcal 24 h$^{-1}$ bird$^{-1}$); $W$ in kg.
- Rezende et al. (2002): $\text{MMR}=44.36W^{-0.146}$ (cm$^3$ O$_2$ h$^{-1}$ g$^{-1}$); $W$ in g.
- Prinzinger et al. (1991): see Table 1.
- Swanson and Weinacht (1997): $T_{lc}=T_a-4.24W^{0.317}$ °C; $W$ in g.
- Schleucher and Withers (2001): $C=0.994W^{-0.509}$ (cm$^3$ O$_2$ h$^{-1}$ °C$^{-1}$); $W$ in g.
- Approximated values.
of RMR at TNZ ($t_S=0.617; P=0.554$). The maximum metabolic rate ($M_{\text{max}}$) in 2-month-old birds, amounting to an average of 34.08 mW g$^{-1}$ (5.98 cm$^3$ O$_2$ g$^{-1}$ h$^{-1}$), was 3.6 times higher than the resting metabolic rate, and lower almost by half than the predicted value (Table 2; Fig. 4). The $C_{\text{min}}$, which amounted to an average 0.748 mW g$^{-1}$ °C$^{-1}$ (0.131 cm$^3$ O$_2$ g$^{-1}$ h$^{-1}$ °C$^{-1}$) was found for the ambient temperatures ranging from 4.7 to 6.0 °C (Table 2). There was no intersexual difference in the $C_{\text{min}}$ values in the experimental king quails ($t_S=1.999; P=0.081$).

4. Discussion

4.1. Growth rate

Thermoregulatory capacity in birds depends on muscle mass, the level of functional maturity of the skeletal muscles which are primary source of heat production, as well as on the muscle fibre type (Ricklefs et al., 1994; Visser and Ricklefs, 1995; Dietz and Ricklefs, 1997; Marjoniemi and Hohota, 1999; Krijgsveld et al., 2001). Throughout the entire period of postnatal development, the organisms have to achieve the compromise between the growth rate of the muscle mass and the indices of their functional maturity, such as: dry matter content of muscles, catalytic enzyme activity indicating the capacity to generate ATP, which is necessary for shivering thermogenesis and locomotion (pyruvate kinase, citrate synthase, hydroxyacyl-CoA-dehydrogenase) (Ricklefs et al., 1994; Krijgsveld et al., 2001). At hatching, altricial and precocial birds differ in their levels of functional maturity, which is more advanced in precocial species (Choi et al., 1993; Ricklefs et al., 1994; Krijgsveld et al., 2001). A consequence of faster achievement of homeothermy by precocial birds is their slower rate of growth, even three to four times slower than in altricial ones (Olson, 1992; Ricklefs et al., 1994; Krijgsveld et al., 2001). In birds, large species grow for a longer time than small ones. It is obvious that this phenomenon is partly implied by the fact that the chicks of large species hatch as a smaller percentage of the adult mass. However, they also show a lower growth rate at any particular relative size (actual body mass/asymptotic body mass) (Ricklefs, 1979; Dietz and Ricklefs, 1997). Thus in the equations fitted to the data on growth, the constant growth rates for larger species are lower than those for smaller species, and lower for a precocial than for altricial birds (Ricklefs, 1968, 1979).

Detailed discussion of the reasons for slower growth in large gallinaceous species can be found in Dietz and Ricklefs (1997). The chicks and adult king quails are among the smallest gallinaceous birds. Bernstein (1973) reported that during the 4th through 9th day after hatching, growth rate of king quails was slow and between the 9th and 35th day, growth proceeded in a linear fashion. The values of the Gompertz growth constant obtained in this study for chicks of king quail were as follows: 0.066 for both sexes

![Fig. 2. Body temperatures in three age groups of king quail chicks: 1–3, 7–10 and 16–19 days old (α-phase), exposed to various ambient temperatures.](image-url)
combined, 0.075 for males and 0.056 for females (Fig. 1). These values are similar to those reported for Japanese quails: 0.060 (Ricklefs et al., 1994); 0.073 for males and 0.064 for females (Akbaş and Oğuz, 1998). Dietz and Drent (1997) reported, however, higher values for Japanese quails: 0.093 for males and 0.073 for females. The values of the Gompertz growth constant known for larger Galliformes are much lower, e.g. 0.039 for grey partridge and 0.042 for chukar (Pis, 2003), 0.031 for guinea fowl, and 0.018–0.025 for turkey (Dietz and Drent, 1997) and much higher for altricial birds, for example: 0.123 for dunlin Calidris alpina (Krijgsfeld et al., 2001), 0.131–0.156 for cockatiel Nymphicus hollandicus (Pearson, 1998), 0.246 for European starling Sturnus vulgaris (Ricklefs et al., 1994) and 0.448 for blue-naped mousebird Urocolius macrourus (Finke et al., 1995). The compilation of data on growth rates for 22 altricial species (although logistic fitted for most of them) can also be found in Dunn (1975). In king quails, the difference in body mass between males and females were noted by Prinzinger et al. (1993) and Pearson (1994) (Table 2). The sexual dimorphism in growth rate may partly result from differences in precocity between sexes at the same chronological age and from the scale effect, with the difference between sexes being proportional to the mean of the trait (Ricklefs, 1985; Mignon-Grasteau et al., 1999, 2000). The parameters of the Gompertz curve describing the relationship between body mass and age can be inherited and, as demonstrated by Mignon-Grasteau et al. (1999,
2000), the genes controlling these parameters seem to be partly different in two sexes, at least in chickens.

4.2. Body temperature in developing chicks

The 1–3-day-old king quail chicks had lower $T_b$ at TNZ than both other age groups of experimental birds and lower than the calculated predicted value (Table 1; Fig. 2). This indicates a typical and widely reported thermoregulation mechanism, saving energy expenditure for thermoregulation through a thermal gradient between the surroundings and the bodies of chicks, in insufficient plumage and having an unfavourable body surface/body volume ratio (Hissa et al., 1983; Tzschentke and Michelmann, 1999; Michelmann and Tzschentke, 2002; Pis, 2002, 2003).

Lowering the ambient temperature below TNZ brought about a linear decrease in body temperature in 1–3-, 7–10- and 16–19-day-old chicks, but the slopes of the regression lines lessened with age in these groups of quails (Fig. 2), which clearly point to a gradual development of thermoregulatory capacities of the chick, described earlier by Bernstein (1973). The difference in the values of the $T_b$ at TNZ between 16–19-day-old and 2-month-old chicks was 1.0 °C (Tables 1 and 2; Figs. 2 and 3). The fact that 16–19-day-old quails maintained the $T_b$ at TNZ at a level of predicted $T_b$ value calculated for birds of the same mass and being at the same activity phase (Table 1) may testify to their homeothermy. Bernstein (1973) reported that a group of 24–28-day-old king quails held $T_b$ well above $T_a$ at all experimental temperatures (10–40 °C). At this age, the quails’ plumage was fully developed, and their body mass amounted to some 65% of the body mass of adult birds.

4.3. Thermoregulation in 2-month-old quails

The values of RMR at TNZ obtained in this study for 2-month-old king quails (9.44 mW g$^{-1}$) were quite close to the values of the basal metabolic rate (BMR) in adult birds of this species reported by other authors (Table 2).

The broad range of ambient temperatures in which 2-month-old quails were studied permitted the description of the relationship between $T_b$ and $T_a$ by a polynomial function (Fig. 3). Below $T_a$ of ca. 10 °C, the body temperature in experimental quails dropped but not below the level of 40 °C (Fig. 3), i.e. it was maintained throughout at the normal physiological level. Below the thermoneutral zone, the metabolic heat production expressed in mass-specific units (mW g$^{-1}$) in quails, increased linearly and showed an evident difference in the slope between males and females (Fig. 4). As mentioned in Results, this difference was retained also when the metabolic rate was expressed in mass-independent units, partly erasing the differences in body masses of the birds (mW g$^{-0.67}$). The value of metabolic scope ($M_{max}$/RMR at TNZ) of 3.6 regards only males, when their $M_{max}$ was measured at the lowest ambient temperature employed, i.e. ca. –2 °C (Table 2; Fig. 4). The females had been already excluded from the measurements because of sporadic cases of egg laying among them. As regards the next lowest ambient temperature (average 0.7 °C), where the metabolic rate was measured in both sexes and with the same level of RMR at TNZ found for males and females, it can easily be inferred that the values of metabolic scope also differ between the sexes. The obtained value of cold-induced $M_{max}$ was lower than the predicted maximum metabolic capacity by almost half, which meant that the lowest $T_a$ applied was still too low a temperature stress for the quails involved in the experiment (Table 2).

Thermal conductance ($C$) is an important biophysical factor in animals, reversely proportional to body insulation (Aschoff, 1981; Schleucher and Withers, 2001). At low $T_a$ values, the evaporative water loss is relatively low and it can be assumed that $C_{win}=C_{day}$ (Schleucher and Withers, 2001). The minimum value of thermal conductance obtained for 2-month-old quails was identical with the value obtained by Prinzinger et al. (1993) and lower than the predicted value (Table 2), which is indicative of good insulation of the body and effective thermoregulatory mechanisms present in birds of this age.

The sexual size dimorphism did not affect the intersexual differences of the RMR values at TNZ, $T_b$ at TNZ, $T_a$ in the lowest temperature applied in the experiment, and in $C_{min}$. The differences in body mass cannot directly explain the stronger metabolic response in males than in females during cooling. Such intersexual differences in the thermoregulation have been also described in capercaillies, known for their extreme sexual dimorphism in terms of body mass (males weigh 4.00–4.11 kg, whereas females 1.80–1.85 kg) (Rintamäki et al., 1984). In this case, the authors are also of the opinion that this great difference in body mass cannot be the sole factor responsible for the difference in the metabolic rate below the thermoneutral zone, as well as for the intersexual difference in body temperature they found (Rintamäki et al., 1984).

In line with allometric equations based on phylogenetically independent contrast analysis, the value of RMR for non-desert birds of the same size as king quail is 10.02 mW g$^{-1}$, while for desert birds it is 7.18 mW g$^{-1}$ [respectively: $3.94W^{0.616}$ and $2.01W^{0.702}$ kJ day$^{-1}$, where $W$ is expressed in g (Tieleman and Williams (2000))]. As the king quail is a species which lives in mesic habitats (Bernstein, 1971b; Pearson, 1994), the value of RMR at TNZ 9.44 mW g$^{-1}$ obtained in this experiment is not surprising. For known desert quail species, the values of $T_a$c are: 30 °C for Gambel’s quail (Weathers, 1981) and stubble quail Coturnix pectoralis (Roberts and Baudinette, 1986) or even as high as 34 °C for barred button-quail Turnix suscitator of the Gruiformes order (Prinzinger et al., 1993). For king quails investigated under this study, the calculated value of $T_a$ (28.8 °C) slightly exceeded the predicted value and the values suggested by the majority of other authors (Table 2).

It should be noted however that the manner of calculating...
the $T_{kc}$ values in this paper (see Material and methods) was somewhat different than those in the paper referred to in Table 2.

5. Conclusions

The king quails, being the smallest of the gallinaceous birds, manifested a high growth rate. The growth parameters determined in this study differed between sexes, confirming the reversed sexual dimorphism in body mass, being otherwise fairly rare in the order of Galliformes. This dimorphism did not affect intersexual differences in values of the $T_b$ at TNZ, RMR at TNZ and $C_{min}$ and could not be the sole explanation of the different levels of heat production by males and females below the thermoneutral zone. The gradual improvement of the body temperature control and regulatory mechanisms indicate a typical precocial model of thermoregulation development in these birds. In such a model, it is difficult to point to one particular moment when the fully expressed homeothermy occurs. The results of our study indicate that a crucial period in the development of homeothermy in king quails seems to come in the time interval between the 10th and 16th day of life, which corroborate well with earlier findings by Bernstein (1973). The 10th of life, however, which marks an approximate beginning of full-blown homeothermy in turkeys, domestic fowls Gallus gallus f. domestica and Muscovy ducks Cairina moschata f. domestica (Nichelmann and Tschenkite, 2002), for the much smaller king quail represents, in the terminology introduced by these authors, an early postnatal phase in the ontogeny of thermoregulation.

Finally, we have to point to two circumstances that might affect the interpretation of the results of this study. First, the experimental 2-month-old quails were kept in a breeding facility in a temperature lower by ca. 2–3 °C than predicted or calculated value $T_{kc}$, that is, they were de facto acclimatised to the ambient temperature slightly below the thermoneutral zone. And secondly, the king quails employed in the experiment were reared birds with the potential effects of earlier inbred and maintained mutations, thus the impact of these factors on the variability of bioenergetic parameters cannot be excluded.

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References


