Thermoregulatory Responses of Chicks (Gallus domesticus) to Low Ambient Temperatures at an Early Age\textsuperscript{1}

D. Shinder,\textsuperscript{*2} M. Rusal,\textsuperscript{*} J. Tanny,\textsuperscript{†} S. Druyan,\textsuperscript{‡} and S. Yahav\textsuperscript{*}

\textsuperscript{*}Institute of Animal Science, the Volcani Center, Bet Dagan 50250, Israel; \textsuperscript{†}Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, the Volcani Center, Bet Dagan 50250, Israel; and \textsuperscript{‡}The Hebrew University of Jerusalem, Faculty of Agricultural, Food and Environmental Quality Sciences, Rehovot 76100, Israel

ABSTRACT The potential to induce improved thermotolerance in broiler chickens is of great importance. Thermal conditioning is one of the management tools used to improve thermotolerance, enabling broilers to cope with extreme environmental conditions. This study investigated the effects of exposing chicks to low ambient temperature (Ta) on-chick body (Tb), surface (Ts) temperatures and total sensible heat loss (SHL) by convection and radiation from the body and from 2 main radiative organs, the face and the legs. At 3, 4, or at both 3 and 4 d of age, chicks were exposed to 5°C for 1.5 h a day (to avoid mortality) or to 10 or 15°C for 3 h a day. In general, in all treatments, the results during exposure to cold differed significantly from the control. A second cold exposure (on d 4 after a first exposure on d 3) clearly enhanced the chicks’ ability to maintain on-chick body surface temperatures during exposure to 15°C and to recover much faster from cold exposure. A dramatic decline in average surface temperature was observed during the first 15 min of chicks’ exposure to the various low ambient temperatures in all ages, reaching the lowest values in the 5°C treated chicks. The face responded immediately to cold exposure by significantly increasing its SHL to a level that then remained relatively steady (15°C) or declined moderately with time (10 and 5°C). In the legs, however, a significant and continuous decline in SHL was exhibited in all ages. The dynamics of SHL from the legs differed from that from the face, suggesting that the legs are a major organ for vasomotor responses, whereas the face is a more conservative vasoregulatory organ. It is concluded that repetitive exposure to cold may enhance thermotolerance, and that this is partially related to the vasomotor responses. This is the first report quantifying the differentiation between the legs as a responsive vasomotor organ and the face as a conservative vasomotor one.

Key words: body temperature, chick, cold exposure, sensible heat loss, thermotolerance

INTRODUCTION

The potential to induce improved thermotolerance in broiler chickens is of great importance, particularly in view of the effectiveness in the development of genetic selection for improved meat production in broilers (Havenstein et al., 2003). That has made it more difficult for broilers to cope with extreme environmental conditions (Yahav, 2000). Thermal conditioning is one of the management tools that partially enable broilers to cope with extreme environmental conditions. This technique takes advantage of the immaturity of the temperature-regulation mechanism in chicks during their first week of life (Dunnington and Siegel, 1984; Modrey and Nichelmann, 1992), a mechanism that involves sympathetic neural activity, integration of thermal information in the hypothalamus (Rothwell, 1992), and buildup of the body-brain temperature difference (Arad and Itsaki-Gluklish, 1991). Thus, induction of thermotolerance can potentially be incorporated into developing thermoregulation mechanisms. For example, heat conditioning in the first week of life has been shown to considerably improve the chick’s ability to subsequently cope with exposure to acute heat stress by causing a significant decline in heat production (Yahav and Hurwitz, 1996), coupled with increased sensible heat loss (SHL) via radiation and convection (Yahav et al., 2005).

Cold conditioning applied to bantam chicks has also been shown to improve thermoregulatory capacity in faster growth chicks (Aulie, 1977). Shinder et al. (2002) demonstrated that repeated short periods of cold conditioning during the first week of life improves the ability of chicks to cope with low ambient temperature (Ta). However, in the first week of life, when the body surface-to-volume ratio is relatively high, how broiler chicks respond thermally to cold conditioning is unknown, especially considering the effects of SHL.
The main driving force for SHL is the temperature difference between body surface temperature ($T_s$) and $T_a$. One of the main impediments to quantifying SHL has been the inability to accurately measure the animal’s $T_s$ distribution and to differentiate between the contributions of different surface regions to heat loss. However, recently, infrared thermometry has been used successfully to measure $T_s$ in mammals (Mohler and Heath, 1988; Klir et al., 1990; Klir and Heath, 1992; Phillips and Heath, 1992) and in birds (Phillips and Sanborn, 1994; Yahav et al., 1998, 2004, 2005).

The present study was designed to elucidate the effects of exposing chicks at an early stage of life to low $T_a$ on their body temperature ($T_b$) and on total SHL via convection and radiation, to quantify SHL from the body and from 2 main radiative organs, the face and the legs.

**MATERIALS AND METHODS**

Male broiler chicks (Cobb) were obtained from a commercial hatchery. At 1 d of age, 140 male chicks were assigned according to BW into 6 cold-exposed groups and 1 control (20 chicks per group). A control group was kept at 33°C and 60% RH. At 3, 4, or at 3 and 4 d of age (the latter is the group of 3 d that was exposed again at 4 d of age), chicks were exposed to 5°C for 1.5 h a day (to avoid mortality) or to 10 or 15°C for 3 h a day. All groups were kept under 60% RH and exposed to air velocities of less than 0.3 m s$^{-1}$, necessitating the development of a theoretical free-convection and radiation model.

The chicks were raised and thermally treated in 4 computer-controlled environmental chambers with temperatures maintained to within ±1.0°C, RH within ±2.5%, air velocity within ±0.25 m s$^{-1}$, and continuous fluorescent illumination. At the ages designated for cold thermal conditions (3 and 4 d), the chicks were transferred to the appropriate chambers for treatment with exposure to their designated temperatures. Immediately after treatment, the chicks were returned to the chamber with control environmental conditions. Feed in crumble form and water were supplied ad libitum. The local Animal Care Committee approved the use of animals and all experimental procedures in the present study (IL 16-02).

**Body Temperature**

During the various cold exposure, chicks’ $T_b$ was measured every 30 min with a digital thermometer (Newtron TM-5007, K-type thermocouple sensor, Extech Instruments, Waltham, MA). This equipment was accurate to ±0.1°C, coupled to an external K-type thermocouple sensor inserted 3 cm into the colon.
Body Surface Temperature

During the chicks’ cold exposure, their overall average $T_s$ was measured every 15 min. Thermal images were acquired with a radiometric infrared camera (model PM545 FLIR Systems Inc., Danderyd, Sweden). The PM545 is an uncooled thermal-imaging camera equipped with a 320 × 240-pixel focal plane array microbolometer that yields high-resolution imagery; it is sensitive to long-wave radiation in the 7.5- to 13-μm range and has a thermal sensitivity of ±0.1°C. Full-resolution digital thermal images were stored on a removable PC card for subsequent downloading to a PC, where they were then analyzed (via mapping and point measurements of temperatures) with the ThermaCam (FLIR Systems Inc) and Adobe Photoshop 7.0 ME (Adobe, San Jose, CA) software packages.

SHL Calculations

The very low air velocity (less than 0.3 m·s$^{-1}$) to which the chicks were exposed necessitated the use of a theoretical free-convection and radiative heat-transfer model. In calculating the heat transfer, each organ was represented by a geometrical shape, from which heat transfer via radiation and free convection was estimated by means of available or specially derived heat-transfer correlations. Below, a brief introductory account for free-convection and radiative heat transfer. It is followed by a detailed discussion of the correlations used.

Free-Convection Heat Transfer

Heat is transferred to the surrounding air by free (or natural) convection when a body at a given temperature is in contact with otherwise quiescent air at another temperature. The free-convection heat flux, $q_c$, depends on the temperature difference, $\Delta T$, between the body and the air, the contact area, $A$, and the heat-transfer coefficient, $h$, according to the formula

$$q_c = hA\Delta T.$$  \[1\]

The average heat-transfer coefficient, $h$, depends on the geometry of the body, the physical properties of the air, and the flow regimen. The major difficulty in calculating $q_c$ stems from the strong dependence of $h$ on the flow regimen. The heat-transfer coefficient, $h$, is expressed through the nondimensional group of variables, known as the Nusselt number (Nu),
where \( D \) is a characteristic length scale (e.g., diameter in the case of a sphere or a cylinder) and \( k \) is the thermal conductivity of the air. Heat-transfer correlations given in the literature relate the Nusselt number to 2 other nondimensional groups. The first is the Grashof number (Gr),

\[
Gr_D = \frac{g\beta \Delta T D^3}{\nu^2}
\]

where \( g \) is the acceleration due to gravity, \( \beta \) is the coefficient of thermal expansion, \( \Delta T \) is the temperature difference between the body and the air, and \( \nu \) is the air kinematic viscosity. The second nondimensional group is the Prandtl number (Pr),

\[
Pr = \frac{\nu}{\kappa}
\]

where \( \kappa \) is the air thermal diffusivity. The relation among the above 3 groups are given as

\[
Nu_D = f(Pr,Gr_D),
\]

where the function \( f \) is specified for each geometry and flow regimen. It is sometimes useful to present the correlations in terms of the Rayleigh number, defined as \( Ra = Gr \times Pr \). In equations [2], [3], and [5], the subscript \( D \) is replaced with subscript \( L \), which usually represents the length of an organ.

The corresponding correlation in the form of equation 5 is presented below for each of the fowl’s organs. This enables the calculation of \( h \) and the heat transfer for each organ by means of equations 1 and 2, and hence the total convective heat transfer from the bird is calculated.

**Radiative Heat Transfer**

Radiative heat transfer occurs through electromagnetic radiation from one surface to another because of a temperature difference between the 2 surfaces. The rate of radiative heat transfer between 2 surfaces depends on their temperatures, the areas being viewed and the surfaces’ emissivities.

Radiative heat transfer can take place between the fowl and its environment and among the fowl’s own organs that differ in temperature (e.g., a leg and the body). Also, the area being viewed changes frequently because of the bird’s movement. In the simple model used in the present study, it was assumed that radiative heat transfer takes place only between the fowl and its environment; the radiation among the bird’s organs was neglected. It was also assumed that the environment is equivalent to a large surface of uniform temperature surrounding the relatively small bird.

Consequently, the radiative heat flux from (or to) the bird is given by

\[
q_r = \varepsilon_1 \sigma A(T_1^4 - T_2^4),
\]

where the subscript \( r \) stands for radiation, indices 1 and 2, respectively, represent the body surface and the environment, \( \varepsilon_1 (= 0.96) \) is the emissivity of a biological tissue, \( \sigma \) is the Stefan-Boltzmann constant (\( = 5.669 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4} \)), \( A \) is the surface area, and \( T \) is the absolute temperature in K.

**Free-Convection Heat Transfer from the Bird’s Organs**

The present simple model is based on the assumption that the bird is at rest in otherwise quiescent air in which any movement is due only to the buoyancy force generated by temperature differences between the bird and the air. Thus, heat transfer is only by free convection. In practice, the bird was frequently in motion, but this was not taken into account in the present model.

The infrared thermal-imaging system measured the \( T_s \) of each organ as well as the \( T_a \). The estimation of the surface area of the organ was also based on the thermal images. As already mentioned, to estimate the total free-convective heat transfer, the coefficient \( h \) was estimated for each organ by means of the following correlations.

**Face.** The face was modeled as a vertical circular flat plate immersed in quiescent air. Following an extensive but unsuccessful literature search for an appropriate correlation, the required correlation was specially derived from the correlation for a vertical rectangular flat plate. For the present range of Grashof numbers, the induced airflow near the bird’s face was laminar.

The local Nusselt number for laminar free convection from a flat rectangular plate at any \( x \) (Ozisik, 1989) is

\[
Nu_x = 0.508Pr^{1/4}(0.952 + Pr)^{-1/4}Gr^{1/4},
\]

where \( x \) represents the vertical distance along the plate. The surface of the circular plate is composed of an infinite number of narrow rectangular vertical plates, each of a different length. For each narrow plate, the correlation in equation 7 was applied and the average heat-transfer coefficient over the circular plate of diameter \( D \) was obtained by integration.

\[
\begin{array}{cccc}
\text{Age} & T_a = 15^\circ & T_a = 10^\circ & T_a = 5^\circ \\
3 \text{ d} & -0.002^c & -0.025^b^{**} & -0.072^{***} \\
4 \text{ d} & -0.002^c & -0.020^b^{**} & -0.0055^{***} \\
3 \text{ and } 4 \text{ d} & -0.003^c & -0.012^b^{**} & -0.059^{***} \\
\end{array}
\]

\(^{a-c}\)In rows, values designated by different letters differ significantly (\( P < 0.05 \)).

\(* P < 0.05; ** P < 0.001.\)
The effects of exposing chicks to different low ambient temperatures ($T_a$): 15°C (A) and 10°C (B) for 3 h a day, and 5°C (C) for 1.5 h a day, at 3 d (circle), 4 d (white square) or at 3 and 4 d (triangle) of age on total sensible heat loss (SHL—free convection + radiation). Control treatment (33°C, black square) represents average total SHL on d 3 and 4. **At any given time point, values designated by different letters differ significantly ($n = 6$; $P < 0.05$). Hatched bar on x-axis indicates cold exposure.

\[
\text{Nu}_D = \frac{4.477}{\pi} \Pr^{1/2} (0.952 + \Pr)^{-1/4} \text{Gr}^{1/4}.
\]  

The characteristic length scale is the face diameter, $D$, and the area is composed of the 2 sides of the face.

**Legs.** The leg was modeled as a vertical circular cylinder. Ozisik (1989) suggested that if curvature effects were negligible, the average Nusselt number for a flat plate could be applied directly to a vertical cylinder. However, in the present case, the curvature of the birds’ legs could not be neglected; therefore, a correction factor, $K$, was included (Ozisik, 1989), which is the ratio of the average Nusselt number for a vertical cylinder (denoted as $cyl$) to that for a vertical plate (denoted as $f.p.$): $K = (\text{Nu})_cyl / (\text{Nu})_{f.p.}$.

Thus, the correlation used was

\[
(\text{Nu})_cyl = K \text{Gr}^{1/4} \Pr^{n},
\]  

where the values of the constants $c$ and $n$ depend on whether the flow is laminar or turbulent. The length scale in the expressions for Nu and Gr is the length of the leg, and the area is its surface area.

**Toes and Beak.** The toes and beak were modeled as horizontal circular cylinders. For a wide range of values of the Rayleigh number, $Ra = \text{Gr} \times \Pr$, $10^4 < Ra < 10^{12}$, Ozisik (1989) suggests the following correlation for the average Nusselt number:

\[
\text{Nu}_{1/2} = 0.6 + \frac{0.387 \text{Ra}_{1/6}^{1/6}}{[1 + (0.559/\Pr)^{9/16}]^{8/27}},
\]  

where $\text{Nu}_D$ and $\text{Ra}_D$ are based on the toe or beak diameter.

**Body.** The body of the fowl was modeled as a sphere in contact with the surrounding air, on the assumption that the wings were always folded against the body. The correlation for air at close to room temperature (i.e., $\Pr$ close to unity; Ozisik, 1989) is

\[
\text{Nu}_D = 2 + c \text{Ra}_D^{1/4},
\]  

where the constant $c = 0.43$ when $1 < \text{Ra}_D < 10^5$, or $c = 0.5$ when $3 \times 10^5 < \text{Ra}_D < 8 \times 10^8$. $\text{Nu}_D$ and $\text{Ra}_D$ are based on the body diameter.

**Radiative Heat Transfer from the Body Organs.**

The above assumptions were applied, and each organ was regarded as a small body surrounded by an infinitely large environment at a uniform temperature. The radia-
The effects of exposing chicks to different low ambient temperatures ($T_a$): 15°C (A) and 10°C (B) for 3 h a day, and 5°C (C) for 1.5 h a day, at 3 d (circle), 4 d (white square) or at 3 and 4 d (triangle) of age on facial sensible heat loss (SHL). Control treatment (33°C, black square) represents average facial SHL on d 3 and 4. *a–dAt any given time point, values designated by different letters differ significantly (n = 6; $P < 0.05$). Hatched bar on x-axis indicates cold exposure.

**THERMOTOLERANCE OF CHICKS EXPOSED TO COLD**

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**Statistical Analyses**

All results were subjected to 1-way ANOVA (ANOVA) and to Student’s t-test, by means of JMP software (SAS Institute, 2002). Means were considered significantly different at $P \leq 0.05$.

**RESULTS**

**Body Temperature**

Exposing chicks to 15°C on d 3 or 4 of age caused significant reductions in $T_b$ in comparison to control, which lasted up to 150 min, fluctuated thereafter, and were followed by recovery (Figure 1A). Chicks from the 3 and 4 d of age group exhibited a moderate decline in $T_b$ in comparison with the control, reduction that was less pronounced than that of the other cold-treated groups (particularly between 60 and 150 min of exposure). Chicks’ exposure to 10 or 5°C resulted in significant drops in their $T_b$ in all ages, being moderate or severe at 10 or 5°C, respectively (Figure 1B and 1C, respectively). Recovery from cold exposure was significantly faster in chicks from the 3 and 4 d of age group than in those exposed to cold on d 3 or 4 in all $T_a$ treatments. However, only at 15 and 10°C, chicks from 3 and 4 d of age group completely recovered.

**Body Surface Temperature**

Exposing chicks to 15°C at 3 or 4 d of age, or both, resulted in significant declines in $T_s$ within 15 min, to 73, 67, and 71% of the initial $T_s$ value, respectively (Figure 2A). Thereafter, fluctuations in $T_s$ were recorded, with some (not significant) reductions evident (Table 1) among the group ages up to 90 min of exposure, after which $T_s$ values were similar in chicks exposed to 15°C on 3, 4, or 3 and 4 d of age.

Exposing chicks to 10°C at 3 or 4 d of age, or both, resulted in significant decreases in $T_s$ within 15 min, to 61, 62, or 63%, respectively, of the initial $T_s$ (Figure 2B). Thereafter, a significant regression of $T_s$ was exhibited (Table 1) in the 3- and 4-d-old chicks compared with that of 3 or 4 d of age. During most of the 10°C exposure period, the $T_s$ of the 3-old chicks was significantly lower than those of the ones that were exposed at 4 d or at both 3 and 4 d of age.

A similar pattern was observed for the chicks exposed to 5°C (Figure 2C). The $T_s$ of those exposed at 3, 4, or both 3 and 4 d of age fell to 48, 49, and 49%, respectively,
Figure 5. The effects of exposing chicks to different low ambient temperatures (T_a): 15°C (A) and 10°C (B) for 3 h a day, and 5°C (C) for 1.5 h a day, at 3 d (circle), 4 d (white square), or at 3 and 4 d (triangle) of age on sensible heat loss (SHL) from the legs. Control treatment (33°C, black square) represents average SHL from the legs on d 3 and 4. At any given time point, values designated by different letters differ significantly (n = 6; P < 0.05). Hatched bar on x-axis indicates cold exposure.

of the initial T_s with further significant reduction of T_s until the end of the exposure (Table 1).

From 30 min up to the end of the exposure, a significant difference was found in T_s among chicks exposed to 15°C in comparison with those exposed to 10°C, which significantly differ from the T_s values recorded in those exposed to 5°C.

In both treatments (i.e., 5 and 10°C), the T_s recovery of the chicks exposed to cold on 3 d of age was inferior to that of those exposed at 4 or 3 and 4 d of age.

**SHL by Free Convection and Radiation**

Total SHL was significantly higher during cold exposure in the cold-treated chicks than in the controls in all treatments (Figure 3). Exposing chicks to 10 and 5°C at 3 d of age resulted in lower to significantly lower SHL in comparison to 3- and 4-d-of-age-exposed chicks (Figure 3B, 3C, respectively). The SHL recovery from cold was the fastest in chicks exposed to 15 and 5°C in 3- and 4-d-exposed chicks.

The calculated values of SHL from the face or legs are summarized in Figures 4 and 5, respectively. The SHL from the face during cold exposure was significantly higher in all T_a and ages for treated chicks compared with control. The ones exposed to cold twice (on 3 and 4 d of age) exhibited higher to significantly higher loss compared with the other cold-treated chicks (3 or 4 d of age). A complete recovery from cold was in 15 and 10°C exposed chicks (in all ages) 1 h postexposure, with some minor but significant fluctuations. In the 5°C treated chicks, only 4 and 3- and 4-d-of-age-treated chicks completely recovered from cold 1 h postexposure. The SHL from the legs exhibited a temporal trends during cold exposure that were completely opposite from those of the face. During the first 60 min of various T_s exposure, a sharp reduction in SHL of the legs was observed. Thereafter, it fluctuated at 15°C (Figure 5A) or demonstrated a general trend toward further decline in 10 and 5°C cold-treated chicks (Figure 5B, 5C, respectively). No complete recovery from the legs was observed in SHL. At 15°C the 3- and 4-d-of-age-treated chicks exhibited significant and better recovery than that of 3- or 4-d-treated chicks, whereas at 5°C the recovery in general was slower than that of 15 and 10°C, and that of 3-d-of-age-treated chicks was significantly slower than that of the 2 other ages treated chicks.

**DISCUSSION**

This study was aimed at elucidating the effects of repeated exposures at an early age to low T_a on their T_b, T_s, and on free-convective and radiative SHL. The goal was to define the thermoregulatory limitation of chicks that results from such exposures and, for the first time,
to quantify SHL from the body and 2 main vasomotor organs, which play an important role in SHL.

**Body Temperature**

The 3 \( T_a \) chosen for this study imposed heavy demands on the chicks to maintain their \( T_{vb} \), resulting in shallow to extreme hypothermia. Hypothermia in chicks caused by early-postnatal cold exposure has been documented previously (Weinstein and Zolman, 1971; Freeman and Manning, 1984; Arad, 1991; Shindler et al., 2002).

In this study, the decline in \( T_a \) of 5°C caused energy demands to increase to a level at which chicks exposed at 3 or 4 d of age, or at both 3 and 4 d of age, could not maintain \( T_b \) level for longer than 90 min without causing mortality. On the other hand, a second cold exposure (i.e., exposure at both 3 and 4 d of age) to 15°C enhanced the chicks’ ability to maintain \( T_{vb} \), in agreement with Shindler et al. (2002). Exposure at both 3 and 4 d of age also improved the chicks’ ability to recover from cold exposure in all \( T_a \). We conclude that repeated cold exposure in postnatal chicks might improve their ability to control \( T_{vb} \) to better recover from cold exposure, or both.

**Sensible Heat Loss.** Two major factors affect SHL: surface area and the vasomotor response, which is related to differences between surface and surrounding temperatures.

**Surface-Area Ratio.** The increase in the chick surface area between 3 and 4 d of age was calculated to be only 2.23%: from 149.48 ± 3.8 to 152.81 ± 6.2 cm². Such a small increase in surface area may preclude this parameter from being crucial for the ability/ inability to control \( T_b \) when comparing age effects on SHL.

**Vasomotor Alterations.** A dramatic decline in chicks’ average \( T_s \) was observed during the first 15 min of exposure to the various low \( T_a \) in all ages. Similar associations between surface and ambient temperatures have been observed thermographically in several species of birds (Veghte and Herreid, 1965; Hill et al., 1980; Phillips and Sanborn, 1994; Ward et al., 1999; Zerba et al., 1999; Yahav et al., 2004; Lin et al., 2005) and were attributed to immediate vasoconstriction of the peripheral blood vessels. The \( T_a \) was significantly lower in chicks exposed to 5°C than in those exposed to 10°C, and \( T_s \) in the latter was significantly lower than in chicks exposed to 15°C (Figure 2). These differences, coupled with the differentiated slope of \( T_s \) with time, which differ significantly between \( T_a \) (Table 1), emphasize the effect of lowering \( T_s \) on lowering \( T_a \) and, consequently, on vasoconstriction.

Monitoring the temporal variation in free SHL revealed a significant elevation of this parameter during the first 30 min after exposure in comparison to the control SHL level. This was followed by maintaining the level of SHL in the 15°C exposed chicks, or by progressive decline of its level in 10 and 5°C exposed chicks. These results suggest that although vasoconstriction is activated by exposing the chicks to cold, the main driving force behind the significant increase in SHL is the temperature gradient between the surface and the environment. It should be remembered that the present study was conducted under free convection because of the very low air velocity; it is likely that a higher ventilation rate would enhance the chicks’ sensitivity to falling \( T_s \) (Tzschentke et al., 1996; Tzschentke and Nichelmann, 2000).

To demonstrate the dynamics of SHL, 2 major radiative organs in chicks were chosen: the face and the legs. The face responded immediately to all cold exposure treatments by significantly increasing its SHL, to a level that then remained relatively (15°C) or declined moderately with time (10 and 5°C). In the legs, however, a significant and continuous decline in SHL was exhibited. These re-

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**Table 2.** Percentage of total sensible heat loss from the body (excluding face and legs), from the legs and from the face of chicks exposed to 15, 10, and 5°C at 3, 4, and 3 and 4 d of age.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>d 3</th>
<th>d 4</th>
<th>d 3 and 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td>Legs</td>
<td>Face</td>
<td>Body</td>
</tr>
<tr>
<td>33°C 15 min</td>
<td>71.37</td>
<td>21.65</td>
<td>6.98</td>
</tr>
<tr>
<td>15°C 30 min</td>
<td>83.21</td>
<td>7.03</td>
<td>9.75</td>
</tr>
<tr>
<td>10°C 60 min</td>
<td>83.79</td>
<td>5.15</td>
<td>11.07</td>
</tr>
<tr>
<td>5°C 90 min</td>
<td>83.73</td>
<td>4.35</td>
<td>11.92</td>
</tr>
<tr>
<td>15°C 180 min</td>
<td>86.76</td>
<td>2.28</td>
<td>10.96</td>
</tr>
<tr>
<td>10°C</td>
<td>84.87</td>
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<td>5°C</td>
<td>87.79</td>
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</tr>
<tr>
<td>15°C</td>
<td>84.84</td>
<td>1.76</td>
<td>13.40</td>
</tr>
<tr>
<td>10°C</td>
<td>85.09</td>
<td>4.05</td>
<td>10.86</td>
</tr>
</tbody>
</table>

1Values represent measurements at 15, 30, 60, 90, and 180 min of exposure (n = 6).
ults suggest that the legs are major vasoconstricting organs in chicks.

In general the recovery of total SHL and SHL from the face and legs was more efficient in chicks exposed to 15 and 10°C than in those exposed to 5°C. The ability to recover in 15 and 10°C than in 5°C exposed chicks may be related to the higher level of thermal stress that the latter group of chicks had experienced. The recovery of the legs when cold exposure was terminated was not completed in all treatments within 1 h of recovery.

The percentage of SHL from the face was relatively constant with respect to time and age (Table 2). In general, the SHL from the legs exhibited a continuous decline with time, in all treatments and on both days. The percentage of SHL contributed by the face was relatively constant with respect to time and age (Table 2). In general, the recovery of total SHL and SHL from the face was more efficient in chicks exposed to 15°C than in those exposed to 5°C. The ability to recover faster in 15°C than in 5°C exposed chicks may be related to the higher level of thermal stress that the latter group of chicks had experienced. The recovery of the legs when cold exposure was terminated was not completed in all treatments within 1 h of recovery.

The percentage of SHL from the face was relatively constant with respect to time and age (Table 2). In general, the SHL from the legs exhibited a continuous decline with time, in all treatments and on both days. The percentage of SHL contributed by the legs declined from a maximum of 21.6 to 0.81% (Table 2, d 3). These results coupled with the dynamics of SHL and its distribution among organs, suggest that the legs are a major organ in controlling the vasomotor response, which changes with repeated exposures, whereas the face is a conservative organ for SHL. Although Zerba et al. (1999) and Ostnes and Bech (1997, 1998) also showed that the face is a major site for heat loss in contrast to the legs, the present study quantifies this difference and demonstrates, for the first time, the dynamics of SHL and its distribution among organs, as affected by Tₐ and repeated exposures to cold.

It can be concluded that repeated cold exposures of chicks to 15°C increases their ability to maintain Tₑ. However, in all 3 Tₑ recovery from cold exposure was the fastest in the chicks that were repeatedly exposed to it. This suggests that repetitive exposure to cold may enhance thermotolerance and that this is partially related to the vasomotor response. This is the first time that the differentiation between the legs as a responsive vasomotor organ and the face as a conservative vasomotor organ has been quantified.

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