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Unraveling the relationship between the topographic distribution patterns of skin temperature and perspiration response in dromedary camels

Emad M. Samara

Department of Animal Production, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh, 11451, Saudi Arabia

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ABSTRACT

The question of how skin temperature (T_{sk}), measured at different regions of the skin, can affect sudomotor activity and thus show a pattern in topographic distribution for the perspiration response (*PR*) rate in dromedary camels was approached and examined in this experiment. Under natural summer conditions, four healthy dromedary bulls, with a mean body mass of 420 kg and age of three years, were measured for T_{sk} and *PR* in seven skin regions (i.e. head, neck, shoulder, axillary, hump, flank, and hip) twice daily [between 04:00–05:00 h with a mean ambient temperature (T_a) of 26·78 °C and relative humidity (*RH*) of 18·25% as well as between 13:00–14:00 h with T_a of 44·78 °C and *RH* of 5·90%] for two successive days. The experiment has clearly demonstrated some novel findings. In fact, results pointed out that T_{sk} ($P < 0·05$) exhibited a distinct topographic pattern that faded almost completely at a higher T_a. Meanwhile, *PR* unexpectedly manifested a uniform ($P \geq 0·05$) distribution throughout the experiment, which appears to serve an eco-teleological purpose in dromedaries. Moreover, the obtained findings indicated that the hump and hip regions in particular can work as thermal windows, yet all seven skin regions can predict whole-skin *PR* fairly accurately ($R^2 \geq 0·90$; $P < 0·000$). Above all, analysis indicated that T_{sk} in many regions can affect perspiration in camels ($R^2 < 0·82$; $P < 0·000$), but it failed to demonstrate a topographic pattern in perspiration response at higher or lower T_a; therefore, the data attests that no specific relationship may exist between the topography of a perspiration pattern and the level of regional T_{sk}. Some shortcomings were noted herein, but research dealing with this subject may very well improve our understanding of the basic functional mechanisms of the thermoregulatory system in this species.

1. Introduction

The evaporative heat dissipation mechanism of most farm animals engages under hot environmental conditions for the purpose of maintaining a constant body temperature. Considering the two basic requirements for evaporation (i.e. water and air movement), we know that perspiring species control the amount of water, while panting species control the amount of air movement (da Silva and Maia, 2013). The dromedary camel is mainly a perspiring animal, and as such most heat dissipation is handled through perspiration; thus, studies have documented that heat dissipation through the camel's respiratory tract only constitutes 3% of the total evaporative heat dissipation (Schroter et al., 1987). Moreover, data from my laboratory demonstrated that perspiration rates (*PR*) increased close to ten-fold when the effective ambient temperature (T_a) increased from 10 to 44 °C, with no noticeable changes observed in the animals' respiratory rates (unpublished observations).

The presence of sudoriferous (i.e. sweat) glands ordinarily suggests a thermoregulatory function. Although the structure of these glands in dromedaries roughly resembles that of other animal species, the epitrichial-apoeccrine type is the primary sweat glands responsible for the thermoregulatory perspiration in this species (Lee and Schmidt-Nielsen, 1962; Taha and Abdalla, 1980; Gbolagunte, 1983, 2016). By relying primarily on the epitrichial-apoeccrine type of gland, dromedaries retain a more or less definite quantity of secretory fluid; thus, the structural orientation of the terminal portion of the glandular excretory ducts can play an important role in creating highly functional skin, which consequently, may increase this animal's ability to adapt to desert conditions (Hafez, 1968; Fath El-Bab et al., 2017).

Since these glands are part of hair-follicle units, the density of their population is essentially the same as the density of a camel's hair-follicle population. In fact, the distribution of these glands in various species can vary greatly between different regions of the skin, but in dromedaries, they are distributed over nearly the entire body except the lips, extremal nares, and perianal regions (Lee and Schmidt-Nielsen, 1962; Taha and Abdalla, 1980). In a previous experiment, my colleagues and I found that the shoulder and flank regions expressed higher *PR* in this species (Abdoun et al., 2012). Our findings agree with

E-mail address: Dremas@ksu.edu.sa.

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previous research on the guanaco showed that regional differences in sweat gland density exist, with higher densities found in the anterior at the shoulder and axillary regions as well as posterior at the flank region (Morrison, 1966; de Lamo et al., 2001). Because these regional sites are distinctly covered with very short and sparse pelage, they are potentially more effective in facilitating evaporative heat dissipation. In fact, skin temperature (T_{sk}) in thinly insulated and shaded regions called "body thermal windows" (Morrison, 1966) has especially been shown to be higher than other skin regions under hot environmental conditions. Several studies consequently demonstrated that T_{sk} is one of the major thermal sudomotor functions in Camelidae (de Lamo et al., 2001; Samara, 2015), as is common to other farm animals (Whittow, 1962; Sumbera et al., 2007; Scharf et al., 2008). The literature to date, however, was still unclear about how T_{sk} in different skin regions could affect sudomotor activity and demonstrate a pattern in topographic perspiration response distribution in dromedary camels. Furthermore, previous research left uncertainties about which regional sites could accurately predict the whole-skin *PR* as it is influenced by changes in environmental conditions.

Accordingly, the present investigation was designed to first determine the topographic patterns of T_{sk} and *PR* under two different levels of T_a, to secondly assess the relationships between both topographical patterns, and to thirdly examine whether the obtained data from the perspiration topography could be used to predict whole-skin *PR* in dromedaries reared under natural conditions.

2. Materials and methods

Four healthy dromedary bulls of a local breed, with a mean body mass of 420 kg and mean age of 3 years, were used to conduct this experiment. Data was collected at the experimental station affiliated with the Department of Animal Production, College of Food and Agriculture Sciences (located at +24°48′ N, +46°31′E), in accordance with the Research Ethics Committee guidelines for King Saud University. Throughout the experiment, bulls were individually housed in shaded pens (4 × 5 m in size), and fed un-chopped grass hay, Rhodes (*Chloris gayana* spp.), which was offered twice daily (at 06:00 & 17:00 h) and contained 75 Kcal per $kg^{0.75}$ of metabolizable energy per day consistent with feeding recommendations outlined by Zine Filali and Guerouali (1994). All bulls had free access to a clean tap water and mineral salt throughout the experiment.

Both of T_{sk} and *PR* were measured during two successive experimental days between the hours of 04:00–05:00 and later between 13:00–14:00. On those days, the mean T_a was 26·78 °C (SD = 1·86) and relative humidity (*RH*) was 18·25% (SD = 4·94) during the early time period, while during the 13:00–14:00 time period the mean T_a was 44·78 °C (SD = 1·45) and *RH* was 5·90% (SD = 0·44). As depicted in Fig. 1, a 2 × 10 cm area was shaved one-day prior to the experimental day in seven skin-regions (i.e. head, neck, shoulder, axillary, hump, flank, and hip) of the animals' right sides for measuring T_{sk} and *PR*. An infrared thermometer (Traceable Mini IR™ Thermometer, Friendswood, TX, USA) was used to measure T_{sk}, while *PR* was determined using the cobalt chloride method proposed by Schleger and Turner (1965) and modified by Pereira et al. (2010). In brief, several filter papers were saturated with a 10% cobalt chloride solution and then prepared as described by Schleger and Turner (1965), while a device was built as specified by Pereira et al. (2010). Two (2 × 2 cm) strips of Velcro were accordingly glued onto the shaved surface as well as to the free ends of Pereira's device. Thereafter, three cobalt chloride discs were mounted on a double-adhesive strip and fixed onto the device immediately prior to be placed on the skin. The mean time taken by all the three discs to change their color from blue to pink was recorded with a stopwatch. Subsequently, *PR* ($g{\cdot}m^{-2}{\cdot}h^{-1}$) was calculated using a formula established by Schleger and Turner (1965). It is worth mentioning, however, that a technical problem occurred once during the 04:00–05:00 time frame, which prevented the collection of *PR* from one bull.

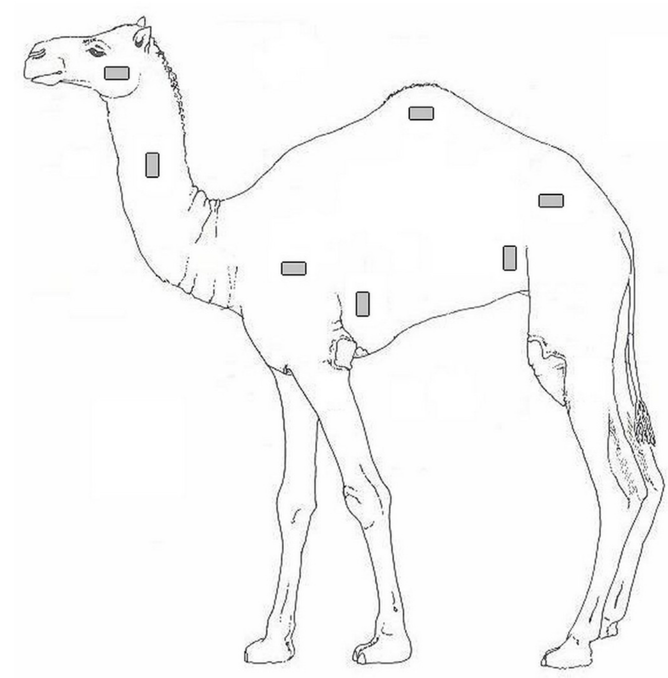

Fig. 1. Selected skin-regions used for measuring skin temperature and perspiration rate.

Experimental data was analyzed using statistical analysis software (SAS Inst., Inc., Cary NC, USA). Based on the collection times and skin regions, differences in T_{sk} and *PR* measurements were determined using the PROC GLM procedure in SAS, while mean differences were presented using the PDIFF option. Interrelationships among these parameters were obtained using SigmaPlot software (SigmaPlot v12·0, Systat Software Inc., San Jose CA, USA). The probability value that denotes statistical significance was determined as $P < 0{\cdot}05$ throughout the experiment.

3. Results

Regional variations for the collected T_{sk} and *PR* data are shown in Fig. 2. The obtained findings revealed that overall means of both measurements in all seven regions were clearly influenced ($P < 0{\cdot}05$) by the time of day, with minimum values exhibited between the hours of 04:00–05:00 and maximum values attained during the 13:00–14:00 time period. Actually, this was my goal in the first place, where bulls ought to efficiently undergo a different level of surrounding T_a to consequently induce such tangible changes.

Between the seven skin regions, large variations ($P < 0{\cdot}05$) were evident for T_{sk} but not for *PR* (Fig. 2). As a matter of fact, the T_{sk} collected between the hours of 04:00–05:00 were greatest ($P < 0{\cdot}05$) in the head and flank regions, followed by the neck and hip regions, and lastly the other three regions. Meanwhile, hump and hip regions showed the highest T_{sk} values between the hours of 13:00–14:00 (Fig. 2). Ratios of regional T_{sk} and *PR* to their total values confirmed these outcomes, where T_{sk} manifested ($P < 0{\cdot}05$) a topographic distribution in contrast to a uniform ($P \geq 0{\cdot}05$) distribution of perspiration response (Fig. 3).

Data was evaluated, thereafter, to compare the level of regional T_{sk} to the obtained perspiration topography (Table 1). Results demonstrated positive correlation coefficients (*r*) in all regions. The results are as follows: positive correlation was strong ($r > 0{\cdot}90$) in the hump ($P < 0{\cdot}000$) and hip ($P < 0{\cdot}000$) regions, high ($r > 0{\cdot}80$) in the axillary ($P < 0{\cdot}000$), shoulder ($P < 0{\cdot}000$), and flank ($P = 0{\cdot}002$) regions, moderate ($r \geq 0{\cdot}70$) in the neck region ($P < 0{\cdot}001$), and weak

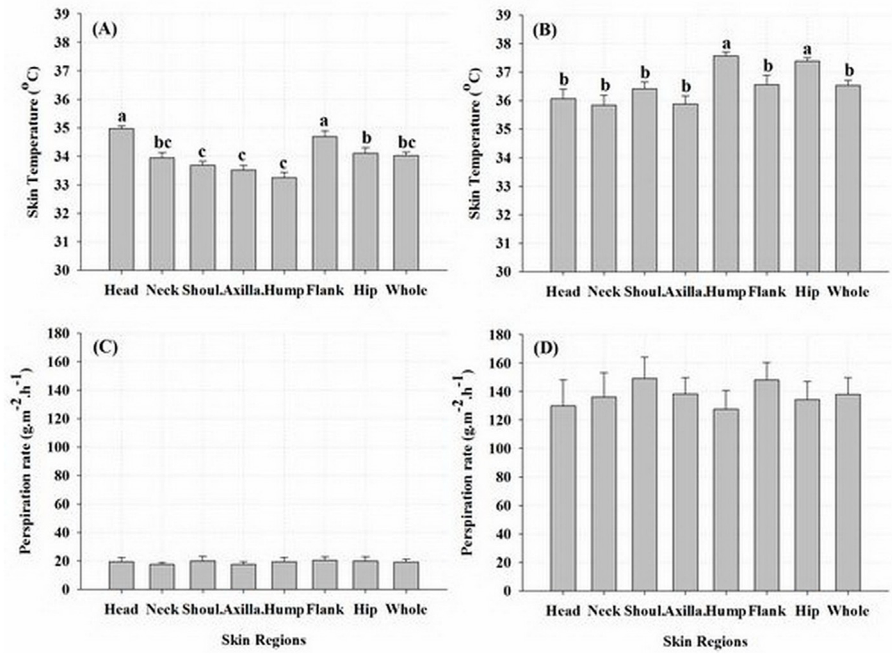

Fig. 2. Topographic patterns of both of skin temperature and perspiration rate measured twice [4:00–5:00 h (A, C) and 13:00–14:00 h (B, D), respectively] for two successive days in four dromedaries reared under natural/shaded condition.

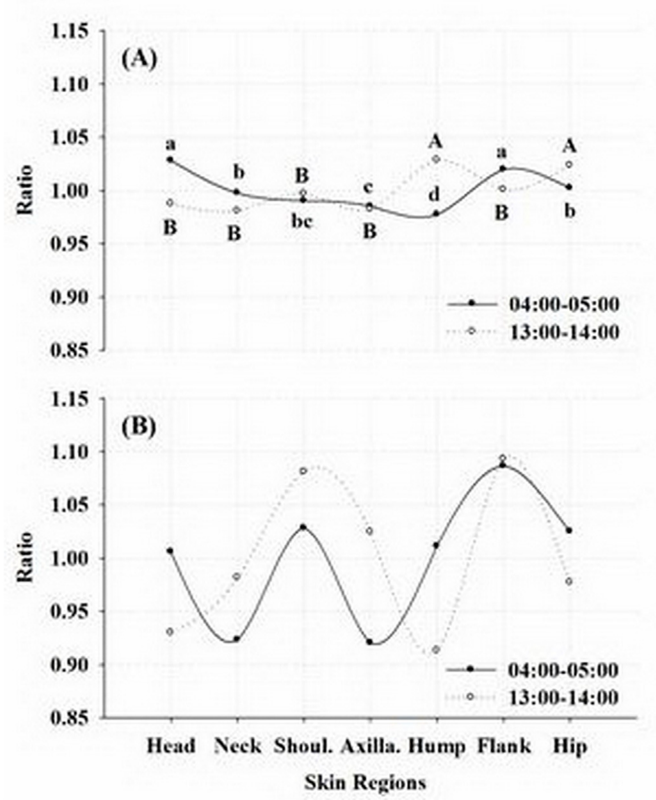

Fig. 3. Ratios of regional skin temperature (A, SE = 0·00, $P < 0·05$) and perspiration rate (B, SE = 0·04, $P \geq 0·05$) to their total whole-skin values.

($r < 0·70$) in the head region ($P = 0·143$). Moreover, results pointed out that the best fit ($R^2 \geq 0·90$; $P < 0·000$) linear relationships of *PR* were merely obtained versus the hump and hip regions (Table 1). On the other hand, it should be noted that strong correlations ($r \geq 0·95$) were evident between regional and whole-skin *PR*, which actually reflected on exhibiting strong relationships ($R^2 \geq 0·90$; $P < 0·000$; Table 2). In fact, regression equation coefficients implied that the absolute perspiration observed at the hump and shoulder regions were the closest to whole-skin values, 0·99 and 0·97 respectively (Table 2).

Table 1
Interrelationships between skin temperature (Tsk) and perspiration rate (PR) measured twice (4:00–5:00 and 13:00–14:00) for two successive days in seven regions of four dromedaries reared under natural/shaded environment.

Regions	Interrelationship			
	R	Regression linear equation	R^2	*P value*
Head	0·40	$PR = -1007·21 + (30·52 * T_{sk})$	0·16	0·143
Neck	0·77	$PR = -1471·76 + (44·37 * T_{sk})$	0·60	< 0·001
Shoulder	0·84	$PR = -1329·18 + (40·36 * T_{sk})$	0·71	< 0·000
Axillary	0·88	$PR = -1398·45 + (42·56 * T_{sk})$	0·78	< 0·000
Hump	0·90	$PR = -785·25 + (24·21 * T_{sk})$	0·80	< 0·000
Flank	0·80	$PR = -1789·56 + (52·58 * T_{sk})$	0·64	0·002
Hip	0·91	$PR = -1104·57 + (33·07 * T_{sk})$	0·82	< 0·000
Whole-skin 1	0·75	$PR = -1068·41 + (32·55 * T_{sk})$	0·60	< 0·000

[1]Complete dataset -not data means-were considered herein for calculation.

Table 2
Interrelationship analysis between regional and whole-skin perspiration rate (PR).

Skin-regions	Interrelationship		
	r	R^2	Regression linear equation[a]
Head	0·95	0·90	$PR_{Whole} = 10·562 + (0·918 * PR_{Head})$
Neck	0·95	0·91	$PR_{Whole} = 10·355 + (0·893 * PR_{Neck})$
Shoulder	0·98	0·97	$PR_{Whole} = 4·100 + (0·883 * PR_{Shoulder})$
Axillary	0·96	0·92	$PR_{Whole} = 4·768 + (0·949 * PR_{Axillary})$
Hump	0·99	0·99	$PR_{Whole} = 0·125 + (1·052 * PR_{Hump})$
Flank	0·97	0·95	$PR_{Whole} = 2·155 + (0·905 * PR_{Flank})$
Hip	0·97	0·94	$PR_{Whole} = 2·411 + (0·991 * PR_{Hip})$

[a] All relationships demonstrated a probability value of $P < 0·000$.

4. Discussion

Our previous experiment had described regional differences of T_{sk} and *PR* in dromedaries exposed to various T_a (Abdoun et al., 2012). However, after that experiment, several questions, such as the ones mentioned in the introduction section, were left unanswered. Hence, further information was desired. In fact, I designed the present experiment to try answering these questions. As a result, the topographic patterns of T_{sk} and *PR* during various levels of T_a were identified, the relationships between both topographical patterns were analyzed, and the regional and whole-skin *PR* were compared.

Based on the current findings, T_{sk} exhibited a distinct topographic pattern that faded almost completely at a higher T_a (Figs. 2 and 3). Indeed, due to the "ON-OFF" mechanism of the subcutaneous vascular system, T_{sk} changed suddenly as the surrounding T_a fluctuated (Samara, 2015), especially in thinly insulated and shaded regions, also known as "body thermal windows" (Morrison, 1966), which were best defined by Tattersall et al. (2009) as "*regions of the body under vascular control that are capable of being 'opened' within and above the thermal neutral zone and 'closed' to conserve metabolic heat at lower temperatures*" (p. 468). Such regions are identified in several studies on guanaco, which demonstrated that the axillary and flank regions are potentially more effective at heat dissipation (Morrison, 1966; de Lamo et al., 2001). Furthermore, our previous research on dromedaries, using an infrared thermography, consistently illustrated that the axillary and flank regions might be working as thermal windows by dissipating heat during the night. Nevertheless, different outcomes were obtained in this current experiment where both the hump and hip regions expressed lower ratios of regional to whole-skin T_{sk} values [and consequently lower thermal (T_a–T_{sk}) gradients] at higher T_a and higher ratios [higher thermal (T_a–T_{sk}) gradients] at lower T_a. These results collectively signify that these particular regions of the skin could work as thermal windows in dromedary camels.

On the other hand, and contrary to our hypothesis, perspiration did not show any regional variation despite the marked change under various levels of T_a (Figs. 2 and 3). It is well known in farm animals that a rise in T_a raises *PR* to a new and steady rate (Murray, 1966; Allen and Bligh, 1969; Yoshida et al., 1995), and their *PR* is not uniform across the skin's surface (Pan et al., 1969; de Lamo et al., 2001; Scharf et al., 2008). Despite the fact that no previous research has documented the number and volume of sweat glands per unit area in dromedary camels, the uniformity in the topographic *PR* distribution obtained herein may imply that these glands are evenly distributed across the surface of the skin in these camels. Moreover, I think that expressing such uniform topographic distribution of *PR* appears to serve one influential eco-teleological purpose, where this type of distribution would be essential at higher thermal demand if perspiration is to be maximally effective as an evaporative heat dissipation mechanism. Now, whether a camel that shows a relatively uniform topographic perspiration distribution is better equipped or less adapted, in a thermoregulatory sense, to endure heat loads than one that exhibits a relatively heavy perspiration in one or two regions could not be answered here in this experiment. Further research is definitely imperative to assert such possibilities. Nevertheless, considering the uniform topographic perspiration pattern, current results bear substantial evidence that any skin region can be considered and used to estimate whole-skin *PR* in dromedary camels (Table 2).

Furthermore, by regressing *PR* against T_{sk}, results clearly indicated that T_{sk} affects perspiration in dromedary camels (Table 1). Notably, this finding agrees with previous reports (de Lamo et al., 2001; Samara, 2015). However, the data is not clear about whether a particular skin region affects the relationship between T_{sk} and *PR*. Results of the present experiment initially suggest that sudomotor activity in selected regions of the skin is associated with a higher level of regional T_{sk}, since both the hump and hip regions expressed the strongest relationships and the head region was the weakest (Table 1). Despite the fact that regional T_{sk} explains more than 80% of the variations in *PR* (as shown in the hump and hip regions), it generally fails to generate a pattern in the topographic perspiration response distribution at higher and lower T_a; therefore, there may be no specific relationship between the topography of the perspiration pattern and the level of regional T_{sk} in dromedary camels.

5. Conclusion

The current experiment clearly demonstrated that T_{sk} exhibited a distinct topographic pattern that faded almost completely at higher T_a, while *PR* unexpectedly showed a uniform distribution throughout the experiment. It was evident that T_{sk} affects perspiration, but it failed to show a distinct topographic perspiration response pattern at higher or lower T_a. Moreover, the data obtained indicated that hump and hip regions in particular can work as thermal windows, even though any of the seven skin region that we tested can accurately predict whole-skin *PR*. Nevertheless, this experiment is not without limitations. In fact, some shortcomings deserve to be noted. For example, the appendages (i.e. fore- and hind-limb) were not considered in this experiment; thus, these areas should be included in future experimentation to fully cover the whole skin surface and to subsequently confirm the obtained results. Additionally, further studies are warranted to adequately examine the reproducibility of these perspiration patterns when a camel is under the effects of exercise, dehydration and/or sympathectomy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2019.07.020.

Compliance with ethical standards

The protocol of this experiment was carried out in accordance with the guidelines of the Research Ethics Committee at King Saud University.

Conflicts of interest

The author declare that no competing interests exist that are of influence on this work.

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Emad Samara (ORCID ID: 0000-0002-3231-9193) is a veterinarian and faculty animal biometeorologists at the King Saud University. His current research is centered on providing an up-to-date knowledge regarding the basic controlling strategies, tactics and mechanisms of body thermoregulatory system as well as bioenergetics in animals particularly dromedary camels. His research interests include the spatiotemporal modelling of heat transfer, biotelemetry, electrophysiology, molecular thermotolerance, epigenetic adaptation, phenology, neuroethology, paleoclimatology, ergonomics, development of non-living models, as well as innovative non-invasive methodologies. He published more than 50 research articles in several peer-reviewed international scientific research journals and conferences.