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1 **ABSTRACT**

2

3 **Purpose:**

4 The application of infrared thermography (IRT) to assess the effects of athletic training is
5 increasing. It is not known if changes in skin temperature (Tsk) as assessed by IRT are affected
6 by the training load or muscle soreness experienced by the athlete. The aim of the present case
7 study was to describe the variations in Tsk in body areas affected by running training and
8 examine any relationships with subjective ratings of muscle soreness. A secondary aim was to
9 assess the feasibility of using IRT for assessing training load in 2 junior middle-distance
10 athletes.

11 **Methods:**

12 Data were collected over a 42-d period with Tsk of the quadriceps, knees, shins, lateral
13 hamstrings, biceps femoris' and Achilles tendons and subjective ratings of muscle soreness
14 taken each morning prior to any training. All training load was quantified via heart rate, running
15 speed and distance. Changes in Tsk outside the typical error (TE) were identified. Relationships
16 between Tsk and subjective ratings of muscle soreness were also examined.

17 **Results**

18 Over the 42-d observational period mean Tsk of the regions of interest were reported outside
19 the TE on 31-d and 22-d for athletes 1 and 2 respectively. These changes in Tsk did not follow
20 similar trends to training loadings. No significant relationships were observed between Tsk of
21 any regions of interest and muscle soreness

22 **Conclusions:**

23 Whilst Tsk changed outside the TE throughout the 42-d observational period these changes
24 were not reflective of training load quantified via cardiovascular strain nor subjective ratings
25 of muscle soreness.

26

27 **KEY WORDS**

28

29 Thermography, training monitoring, thermal, screening, injury, infrared

30 INTRODUCTION

31

32 Infrared thermography (IRT) detects infrared light emitted by the body to visualize changes in
33 body heat due to abnormalities in the surface blood flow. Human skin, with an emissivity of
34 0.98, is almost equal to a black body radiator ¹ and therefore, thermal images can be used to
35 assess thermal properties of the body. IRT is a tool that visualizes physiological changes in
36 the underlining tissues. Historically, IRT has been utilized in the field of veterinary medicine
37 to detect locomotion injuries in racehorses and to monitor their health status ².

38

39 Due to the development of portable cameras IRT could be used to assess the effects of training
40 and identify soft tissue and tendon injuries in athletes ³. IRT has been shown to be valid for
41 assessing skin temperature (Tsk) ⁴, and has been recommended for clinical use ³. Previous work
42 has suggested that IRT can be used to assess acute responses to exercise paradigms ⁵⁻⁷. IRT
43 can be used to describe the temporal characteristics of delayed onset of muscle soreness
44 (DOMS) ⁸. Recent work has investigated the acute responses and short term recovery time
45 course of Tsk to exercise ⁸ and abnormal thermal patterns have been used to identify
46 inflammatory responses in muscles and ligaments ⁹. It is logical that Tsk may be reflective of
47 physical responses which contribute to training induced muscle soreness. It is may be suggested
48 that IRT could be applied to monitoring training stress in athletes. However, it is presently
49 unknown if the Tsk of the regions of interest (ROIs) involved during exercise relates to the
50 imposed training load.

51

52 The aim of the present case study was to describe the variations in Tsk in target body areas
53 affected by running training and examine any relationships with subjective ratings of muscle
54 soreness.

55

56 METHODS

57

58 Data collection was conducted over 42-d in 2 junior male middle distance athletes (Athlete 1.
59 18 years, stature 178.4 cm, body mass 71.8 kg, $\sum 7$ skinfolds 43.7 mm, $\dot{V}O_{2max}$ 67.3 ml·kg·min⁻¹,
60 800 m personal best (PB) 01:53.01 mm:ss.0, 1500 m PB 04:00.03; Athlete 2. 16 years, stature
61 176.4 cm, body mass 63.2 kg, $\sum 7$ skinfolds 36.8 mm, $\dot{V}O_{2max}$ 63.7 ml·kg·min⁻¹, 800 m PB
62 01:56.21 mm:ss.0, 1500 m PB 04:02.18). All data were collected as a part of routine sport
63 science support provided to the athlete group, which all athletes/parents had consented to. The
64 study was part of a larger study on the effects of training on young athletes approved by the
65 local ethics committee.

66

67 Each morning between 0630 h and 0830 h prior to any physical activity participants were
68 acclimated for 5 min in a temperature-controlled environment in order to achieve thermal
69 balance with their surroundings wearing only shorts. Mean temperature of the controlled
70 environment across the 42-d experimental period was 24.3 ± 1.2 °C and 43.4 ± 2.7 % relative
71 humidity, environmental conditions were measured and quantified using a Kestrel 4400 Heat
72 Stress Monitor (Kestrel Meters, MN, USA). During this time participants also gave a subjective
73 rating of general muscle soreness as part of a holistic well-being questionnaire administered
74 via a tablet. Muscle soreness was rated on a visual analogue scale of 1 – 10, 10 being the worst
75 muscle soreness they had ever experienced and 1 being no soreness whatsoever.

76

77 Following the acclimation period an image or “thermogram” was taken of participant’s front
78 and rear legs (Figure 1) using a FLIR T600 infrared camera (FLIR Systems, Oregon, USA).
79 Mean Tsk of the right and left quadriceps, knees, shins, lateral hamstrings, biceps femoris’,

80 calves and Achilles tendons were subsequent quantified. On all occasions the camera was
81 positioned 1.5 m from the participant at the same height each day. When temperature readings
82 were stable 1 image was taken and used for analysis, pilot testing indicated 1 stable reading
83 displayed levels good reliability (ICC = 0.94, $r = 0.91$).

84
85 *Figure 1 about here.*

86
87 The training content was prescribed by the group's Head Coach. Throughout training sessions
88 participant's heart rate (HR) was recorded using Polar RS800CX monitors (Polar Electro,
89 Kempele, Finland) for the purposes of quantifying training load using the Edwards approach
90 ¹⁰. Briefly, the TRIMP score was calculated by multiplying the accumulated training duration
91 spent in each intensity domain by an intensity-weighted multiplier. One-minute in the first
92 intensity domain (50 – 59% max heart rate (HRmax)) is given a score of 1, 1-minute in the
93 second intensity domain (60 – 69% HRmax) is given a score of 2, 1 minute in the third intensity
94 domain (70 – 79% HRmax) is given a score of 3, 1 minute in the fourth intensity domain (80
95 – 89% HRmax) is given a score of 4 and 1 minute in the fifth intensity domain (≥ 90 HRmax)
96 is given a score of 5. Distances and velocities were also quantified via Polar RS800CX global
97 positioning satellite (GPS) systems (Polar Electro, Kempele, Finland), all training took place
98 outdoors and time of training differed depending on the coach's plan or environmental
99 conditions. Mean environmental conditions at the times of day the athletes trained over the 42-
100 d period were 28.2 ± 2.8 °C and 43.0 ± 11.4 %.

101 102 **Statistical analysis**

103
104 The alpha level of 0.05 was set prior to data analysis. Statistical analyses were conducted using
105 SPSS Statistics version 20 (IBM, Chicago, IL). Pearson's correlation (r) analysis evaluated
106 relationships between the Tsk and ratings of muscle soreness. Typical error (TE) for the
107 measurement of the Tsk of all ROIs were calculated using pilot data collected over 7 d prior to
108 the observational period (mean TE of all regions for both athletes = 0.5°C). Student's t -tests
109 for paired samples assessed any asymmetries between the right and left legs.

110 111 **RESULTS**

112
113 Details of training performed over the 42-d observational period are presented in Table 1. No
114 asymmetries between right and left limbs were observed for any ROIs. It was deemed
115 appropriate to use mean data (right and left limb) for further analysis.

116
117 *Table 1 about here*

118
119 Tsk of all ROIs changed outside the TE over the 42-d observational period. Mean Tsk of all
120 ROIs were reported outside the TE on 31-d and 22-d for athletes 1 and 2 respectively. These
121 changes in Tsk did not follow similar trends to training loadings nor correlate with subjective
122 rating of muscle soreness (Figure 2).

123
124 *Figure 2 about here*

125 126 **DISCUSSION**

127
128 This case study presented changes in Tsk of the lower limbs in response to longitudinal training
129 in 2 junior middle-distance athletes. Mean Tsk of the regions of interest were reported outside

130 the TE on numerous occasions, this indicates that Tsk of the trained musculature appears to be
131 affected by the training stimulus, although these changes did not follow a similar trend to
132 training load quantified by the Edwards approach. Furthermore, no significant relationships
133 were observed between subjective ratings of muscle soreness and Tsk of any ROIs.

134
135 It is possible that the lack of relationships between muscle soreness and Tsk are attributable to
136 the manner in which soreness data were collected. Soreness data were collected as part of
137 holistic well-being questionnaire with the single soreness metric incorporating all muscle
138 groups. The soreness measure employed provided a measure of general muscle soreness rather
139 than a specific descriptor of which muscle groups were experiencing soreness. It is likely that
140 this measure was not sensitive enough to detect subtle changes in soreness of the individual
141 trained musculature. Previous work has reported relationships between Tsk and DOMS ⁸.
142 Unlike the present study participants were asked about muscle soreness in the muscle group
143 trained (this being the biceps brachii), this was also the muscle from which Tsk was recorded.
144 It is advisable to assess perceived soreness in the same ROIs as the IRT measurements to assess
145 how specific body parts are affected by training. Additionally, here training load was quantified
146 via cardiovascular rather than mechanical strain. It is reasonable to suggest that if training load
147 was reflective of muscular or mechanical strain relationships between Tsk and load may have
148 been observed.

149
150 Athletes trained in the AM, PM or both. As recordings were conducted each morning prior to
151 any training (0630 h - 0830 h) if on the previous day only an AM session was performed there
152 was a ~21.5 h period between the cessation of training and the thermogram being taken. If a
153 PM session was performed there was a ~15.5 h between the cessation of training and the
154 thermogram being recorded. Much of the previous work pertaining to IRT in exercise
155 paradigms has investigated the acute effects of various exercise modalities on the Tsk response.
156 Furthermore, this is the only study to track changes in Tsk in response to training over a
157 longitudinal period.

158

159 PRACTICAL APPLICATIONS

160

161 Data presented here do not support the application of IRT as a monitoring tool in junior middle
162 distance athletes.

163

164 CONCLUSIONS

165

166 This case study analysed Tsk assessed via IRT in response to longitudinal and real world
167 training that is conducted in athletic populations. It is possible that in laboratories IRT can
168 provide a useable measure to quantify the effects of training loads on Tsk and muscle loading.
169 Further, and larger scale work is needed to analyse the application of IRT in athletic paradigms.

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200

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202

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209

210 **CONFLICT OF INTEREST**

211

212 Authors have no conflict of interest to declare.

FIGURE LEGENDS

Figure 1. Thermogram and regions of interest.

Figure 2. Edwards training load (Athlete 1 Panel A; Athlete 2 Panel B), muscle soreness (Athlete 1 Panel C; Athlete 2 Panel D) and mean skin temperature of all regions of interest. Shaded grey area represents the mean typical error of the skin temperature measurements.

TABLES

Table 1. Summary of middle-distance training performed over the 42-d observational period. Data are reported as athlete total and mean \pm SD per athlete.

	Sum		Average per session	
	Athlete 1	Athlete 2	Athlete 1	Athlete 2
Training time (h:mm:ss)	36:33:48	32:42:49	0:52:14 \pm 0:24:14	0:45:18 \pm 0:35:08
Distance covered (km)	382.2	351.5	10.2 \pm 2.3	8.3 \pm 2.5
Edwards TRIMP (AU)	6532	5901	165 \pm 41	139 \pm 48

AU = arbitrary units, Edwards TRIMP = Edwards training impulse, Training time = time in session spent above 50% max heart rate

